# Deliverable D3.2 – Power grid power request and grid management strategies technical report

## WP3

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### UNPLUGGED: Wireless charging for Electric Vehicles

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

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

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

### Project Consortium

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| **PP** | Restricted to other programme participants (including the Commission Services) | |
| **RE** | Restricted to a group specified by the consortium (including the Commission Services) | |
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## Abbreviations

| | |
|---|---|
| AAA | Authentication, Authorization, and Accounting |
| ATAF | Azienda Trasporti Area Fiorentina |
| BMS | Battery Management System |
| CDM | Construction Design and Management |
| CRF | Centro Ricerche Fiat |
| CT | Transformation Center |
| DD | Double Decker |
| DNO | Distribution Network Operator |
| DSO | Distribution System Operator |
| EV | Electric Vehicle |
| GIS | Geographic Information System |
| GPS | Global Positioning System |
| ICE | Internal Combustion Engine |
| IMU | Inertia Measurement Unit |
| LV | Low Voltage |
| MLTB | Millbrook London Transport Bus |
| MV | Medium Voltage |
| NEDC | New European Driving Cycle |
| PEV | Plug in Electric Vehicle |
| PSS | Power System Simulator |
| PVR | Peak Vehicle Requirement |
| RBCI | Remote Battery Charging Interface |
| SLA | Service Level Agreement |
| SMMT | Society of Motor Manufacturers and Traders |
| SOC | State Of Charge |
| SORT | Standardised On-Road Test |
| TFL | Transport For London |
| TIC | Testo Integrato Connessione |
| TVR | Total Vehicle Requirement |

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# 1 Executive Summary

The spread of the electric vehicles requires a detailed study and analysis of the power network and social environment to assure a full successful deployment. In this scenario the inductive charging plays a relevant and critical role, with its flexibility and facility of utilization for the customer.

In details, this document focuses on the

1. Preliminary study to provide an overview for the power consumptions for different class of vehicles, Volvo Bus, Gulliver Micro Bus and CRF's EV, for different driving cycles, as Firenze city typical driving cycle, standard SORT and NEDC driving cycles and MLTB (typical of London city) driving cycle.
2. Preliminary study of the mobility in Firenze city, to indicate the power consumption of the typical bus used in Firenze city for the mobility service.
3. Cost evaluation for power network in order to sustain and guarantee a full public transport service in Firenze (Italy) with buses equipped with inductive circuits. This analysis is based on real data and existing network of the city. The study has been overcome using a load flow software, evaluating the effect and impact after introducing the charging stations in the power network, assuring that this introduction does not comport any critical situations. Moreover a rough analysis of the cost necessary for sustaining the electric taxi service is performed.
4. Effects of the positioning of charging stations simulating a typical urban area in Spain, with 7 distribution substations, 7 loads at MV level and 2 transformers of 630 kVA, and taking into account the installation of three charging stations. This analysis has been also accomplished with a load flow software, able to calculate the voltage drops on each lines after inserting the charging stations in the network.
5. Social – economical impact of the inductive charging, from the design to installation and how the inductive can change the behaviour of the people. A document with guidelines on how to install inductive charging infrastructure at bus stations and depots has been created. Moreover a survey to collect point of view surrounding the viability of inductive charging technology has been diffused to different industry sectors that undertake business in, or provide service to, the automotive industry. A first preliminary cost analysis have been carried out for difference levels of penetration for conductive and inductive vehicles.

As results just the last analysis is tailored on the inductive/wireless charging, so the other aspects are valid for electric vehicle charging in general.

The document has been upgraded to fulfill one question from UNPLUGGED Project Officer, regarding the utilization of the Volvo 7700 bus instead of the Volvo 7900 bus. The last Annex reports the whole analysis and results for Volvo 7900 bus and a comparison with Volvo 7700 bus.

# 2 Vehicle Recharge Rate

The main objective of this chapter is to calculate and analyze the power consumption of different commercial vehicles using different driving cycles. This study gives a clear overview for the power consumption during a specific driving cycle, and also calculates the required energy from the battery system in the vehicle powertrain.

## 2.1 Commercial Vehicles

In this study, the following three commercial vehicles have been used and analyzed:

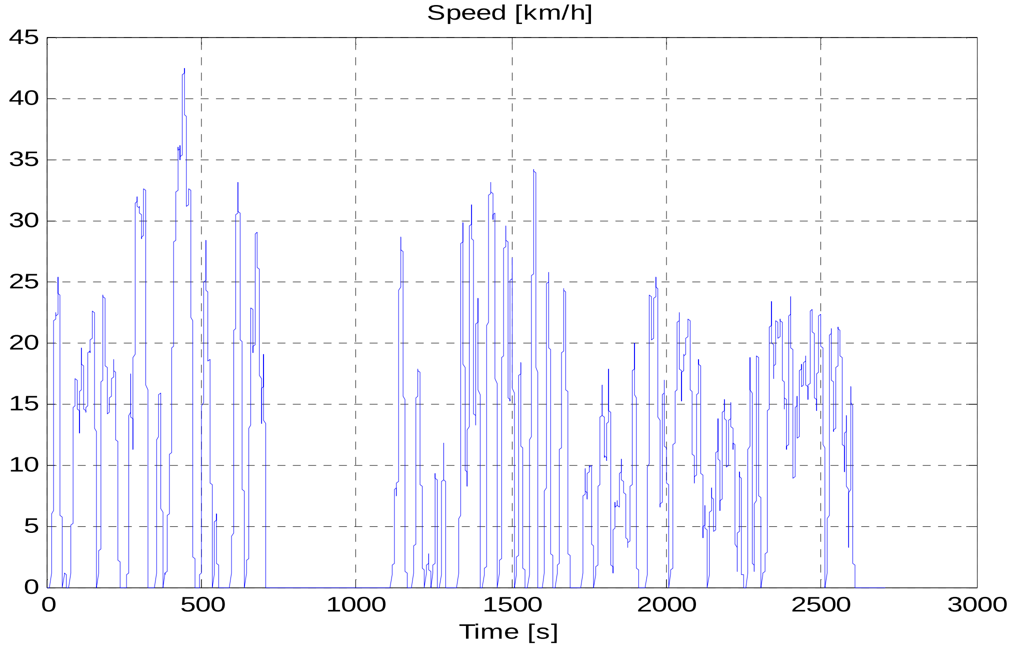
- Tecnobus Gulliver (Microbus)
- 7700 Bus (Volvo Bus)
- Small Passenger Car (CRF's EV)

## 2.2 Typical Driving Cycles

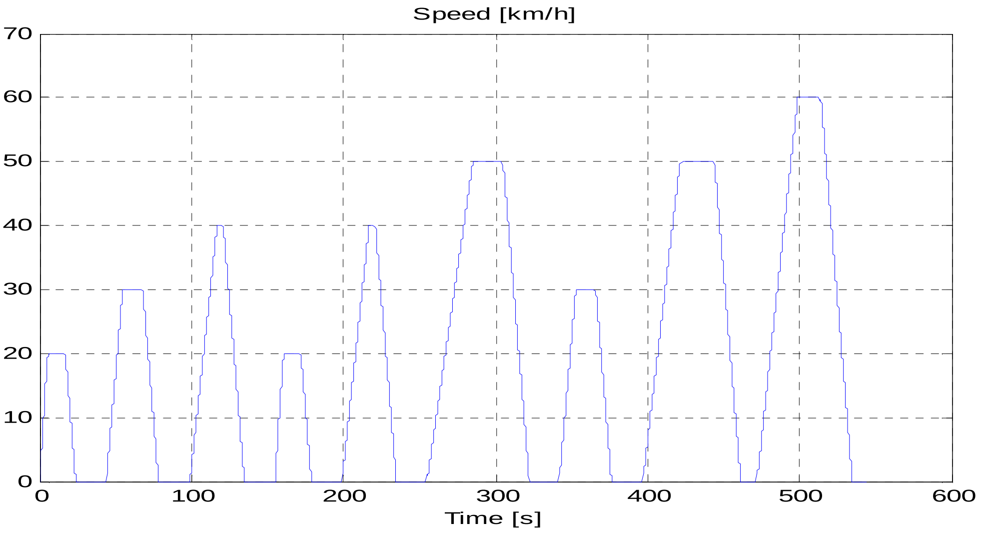
In order to calculate the power consumption of those different vehicles, four standard driving cycles are considered according to the vehicle type. These driving cycles are the following:

1) Firenze Driving Cycle for Microbus – measured with a data collection campaign
2) SORT Standard Driving Cycle for Buses;
3) NEDC Standard Driving Cycle for Passenger Car;
4) MLTB Driving Cycle for Buses

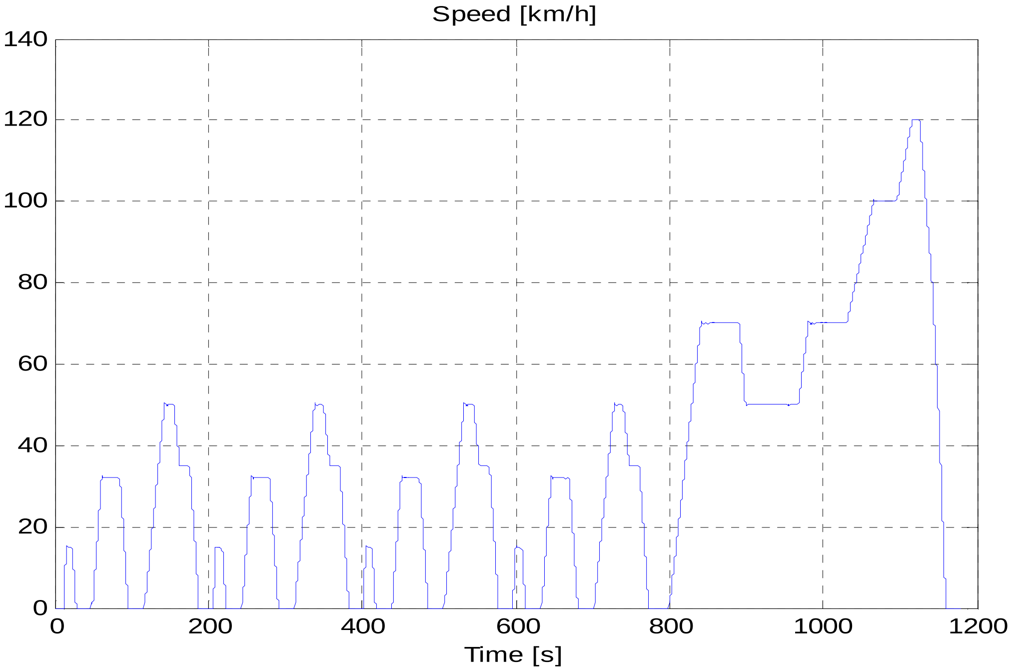
These driving cycles are represented by vehicles speed versus operating time in the Figure 1, which shows the different driving cycles used in this study.



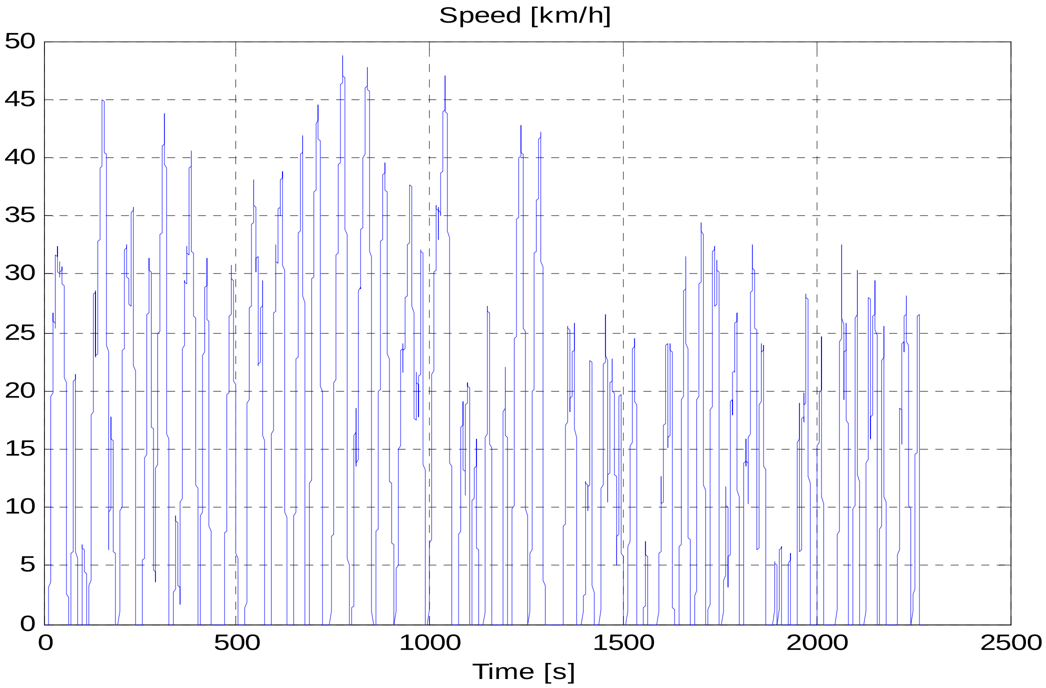
(a) Firenze Driving cycle



(b) SORT Driving cycle



(c) NEDC Driving cycle



(d) MLTB Driving cycle

Figure 1 Different Driving Cycles

## 2.3 Power consumption analysis

The evaluation of power consumption has been carried out for the three commercial vehicles reported in para 2.1 for the following typical driving cycles:

1. Tecnobus Gulliver (Microbus) for Firenze driving cycle and standard SORT driving cycle
2. 7700 Bus (Volvo) for standard SORT driving cycle and MLTB driving cycle
3. Small Passenger Car (CRF's EV) for standard European NEDC driving cycle

### 2.3.1 Tecnobus Gulliver (Microbus)

The Microbus parameters are detailed in Table 1.

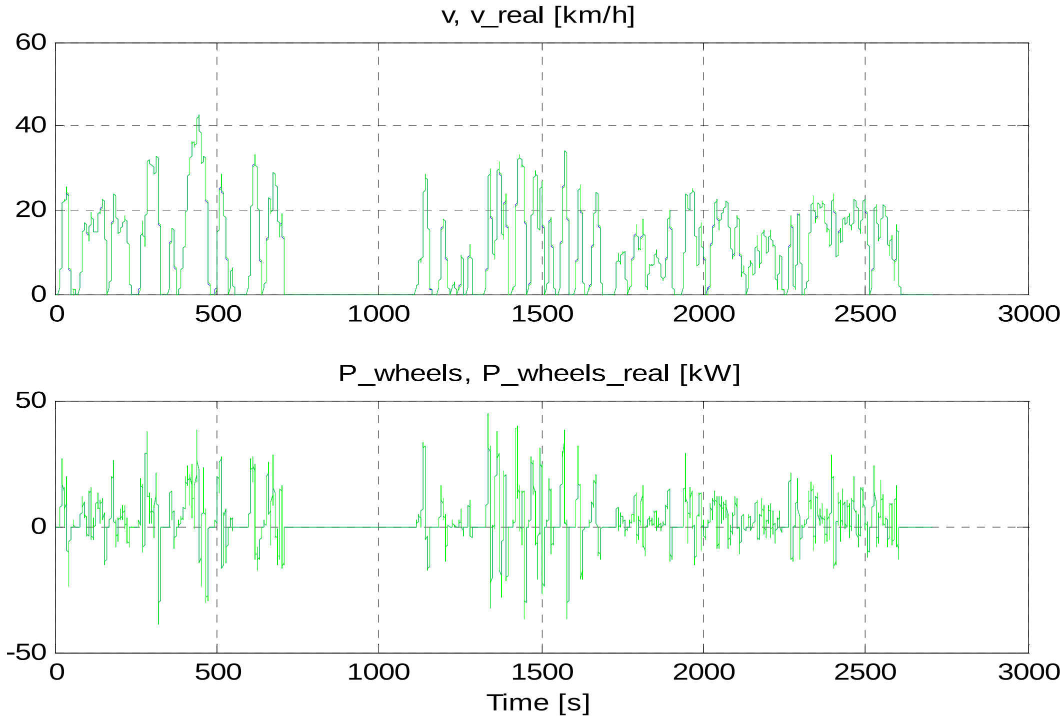
Table 1 Microbus Parameters

| | | |
|---|---|---|
| $M$ | Vehicle mass ($kg$) | 5636 |
| $f_r$ | Rolling Resistance Coefficient | 0.013 |
| $C_D$ | Aerodynamic Drag Coefficient ($C_D$) | 0.5 |
| $A_f$ | Front Area ($m^2$) | 5.340 |
| $r_w$ | Radius of the wheel (m) | 0.28 |

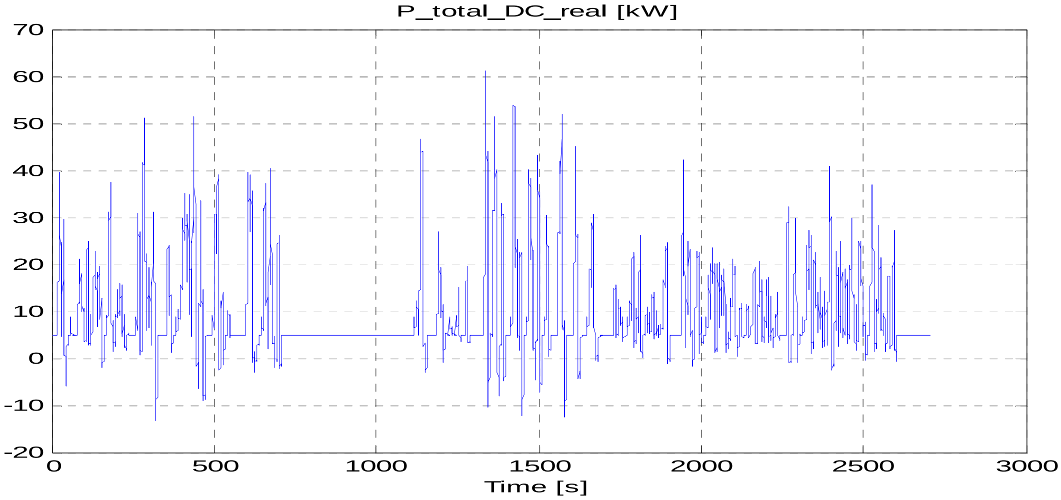
The analysis of the power consumption of this microbus is performed on two driving cycles, which are Firenze and SORT cycles.

#### 2.3.1.1 Power consumption during Firenze Driving Cycle

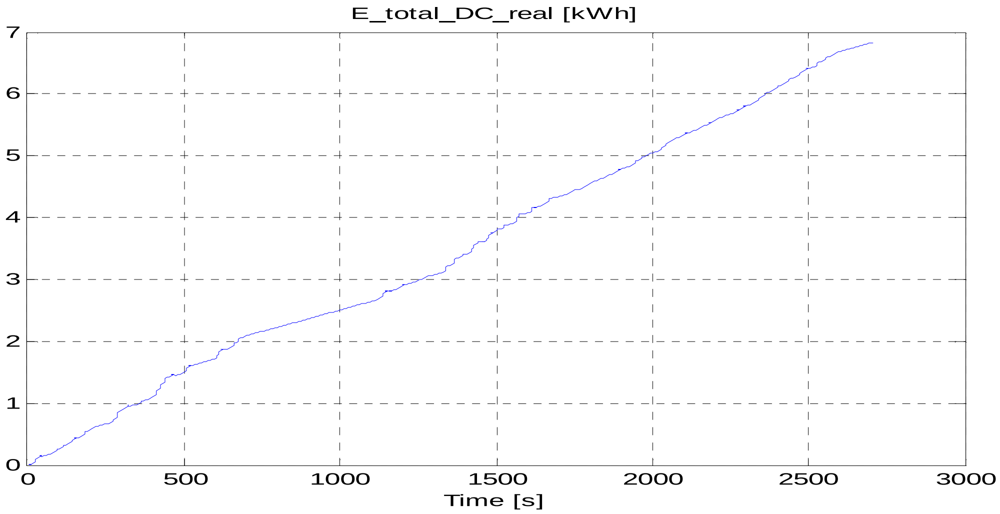
Figure 2 presents the wheels power consumption, the total DC power, total distance and energy consumption of the vehicle during Firenze driving cycle.



(a) The wheels power consumption (kW)



(b) The total DC power (kW)



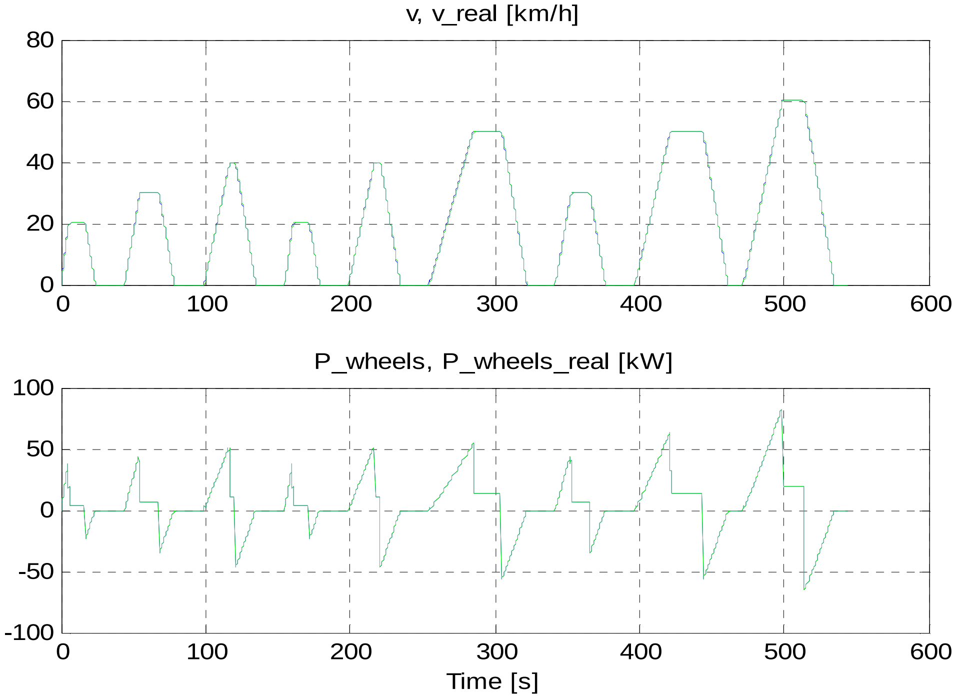
(c) The total DC energy (kWh)

(a) The total distance (km)

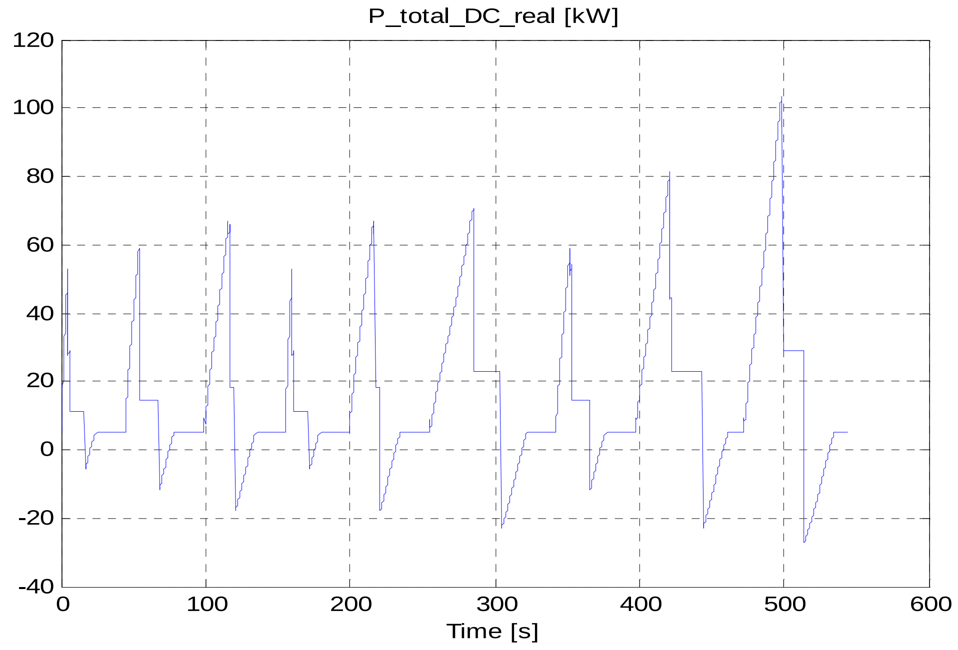
Figure 2 The performance of Tecnobus during Firenze driving cycle

### 2.3.1.2 Power consumption during Sort Driving Cycle

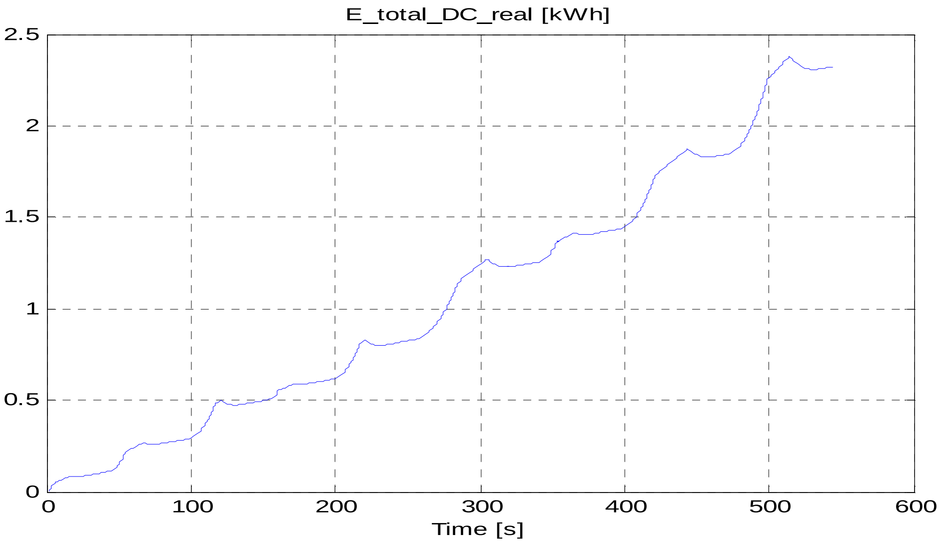
Figure 3 shows the performance of the Tecnobus during SORT driving cycle.



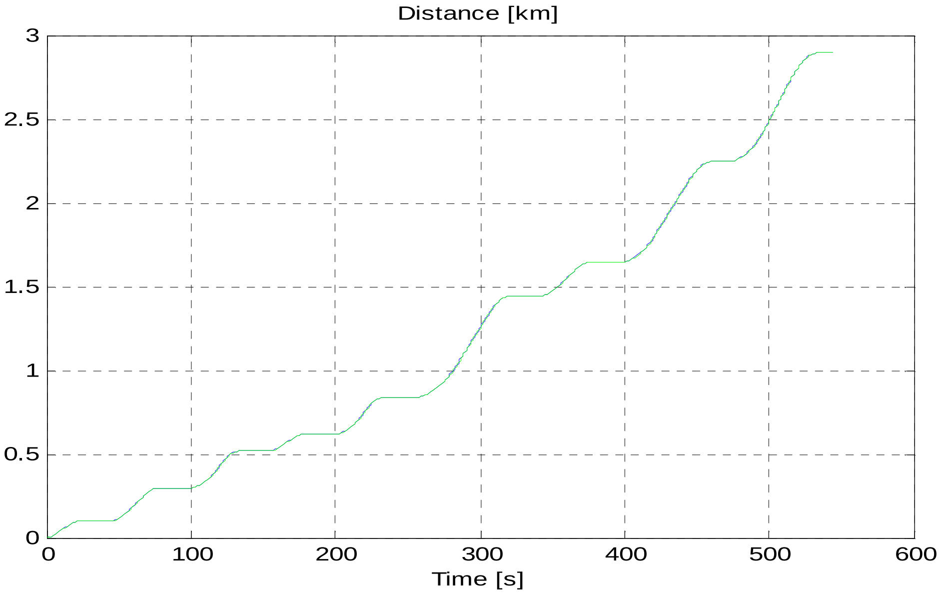
(a) The wheels power consumption (Kw)



(b) The total DC power (kW)



(c) The total DC energy (kWh)



(d) The total distance (km)

Figure 3 The performance of Tecnobus during SORT driving cycle

### 2.3.2 7700 Bus (Volvo Bus)

The parameters of this bus are reported in Table 2.

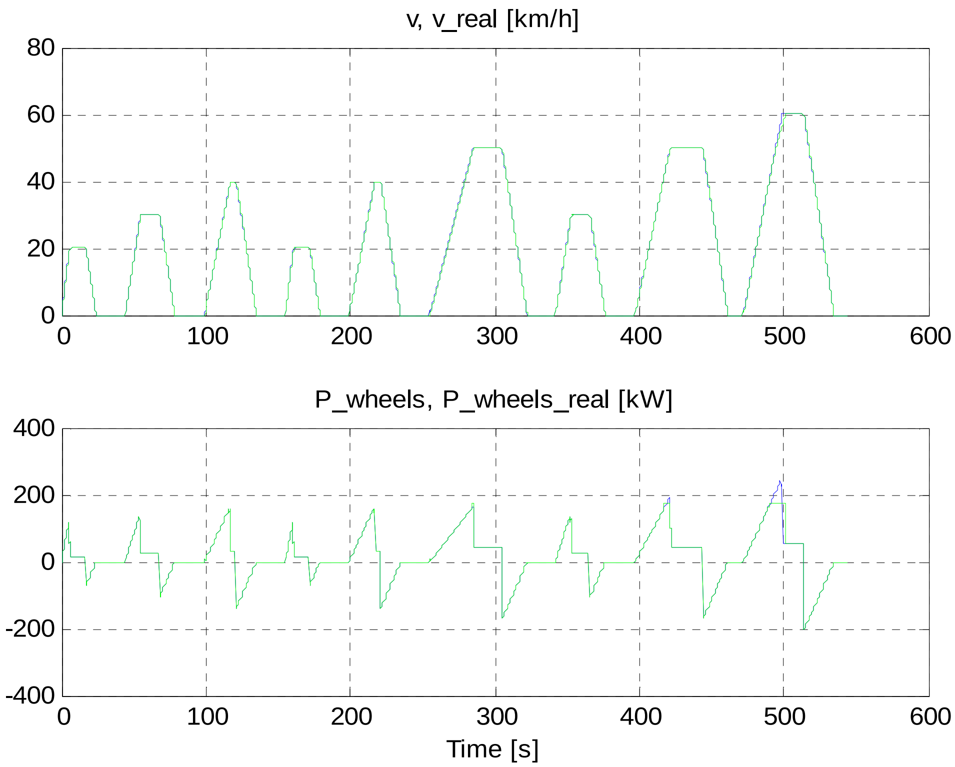
Table 2 7700 Bus Parameters

| | | |
|---|---|---|
| $M$ | Vehicle mass (*kg*) | 18900 |
| $f_r$ | Rolling Resistance Coefficient | 0.0056 |
| $C_D$ | Aerodynamic Drag Coefficient ($C_D$) | 0.65 |
| $A_f$ | Front Area ($m^2$) | 4.288 |
| $r_w$ | Radius of the wheel (m) | 0.452 |

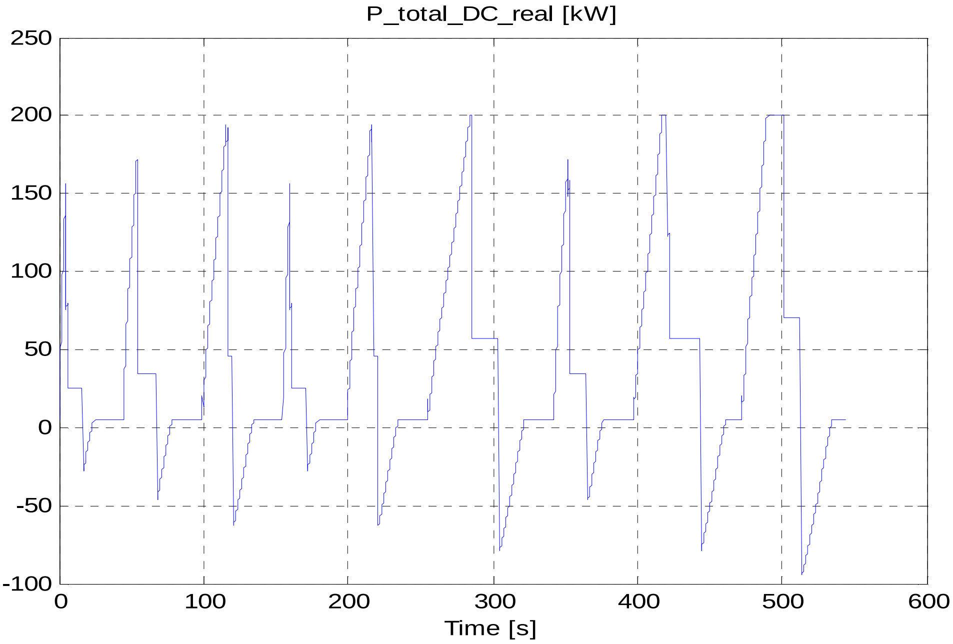
The analysis of the power consumption of this 7700 Bus is performed on a standard SORT driving cycle.

#### 2.3.2.1 Power consumption during Sort Driving Cycle

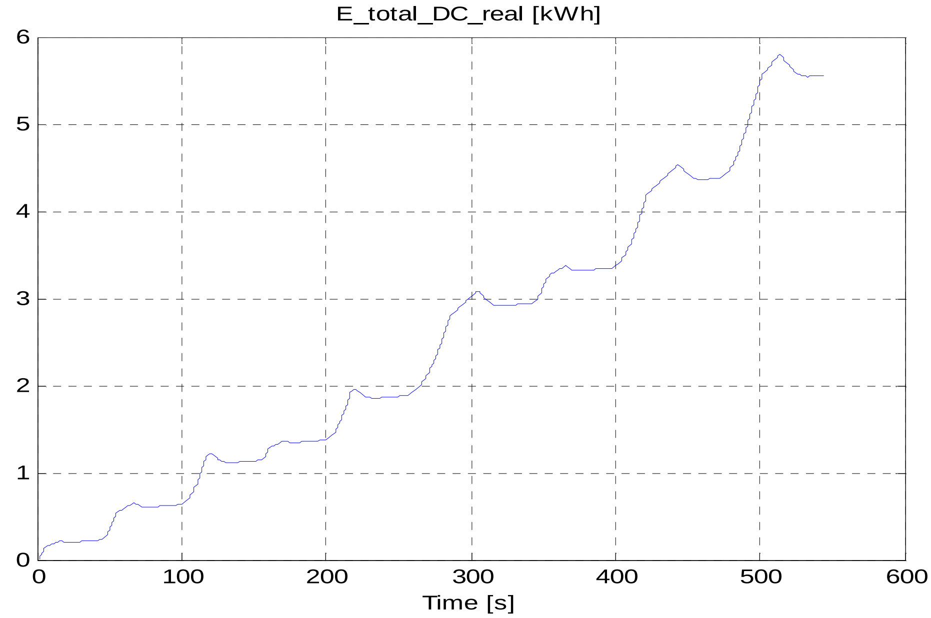
Figure 4 illustrates 7700 Volvo bus power and energy consumptions during SORT driving cycle.



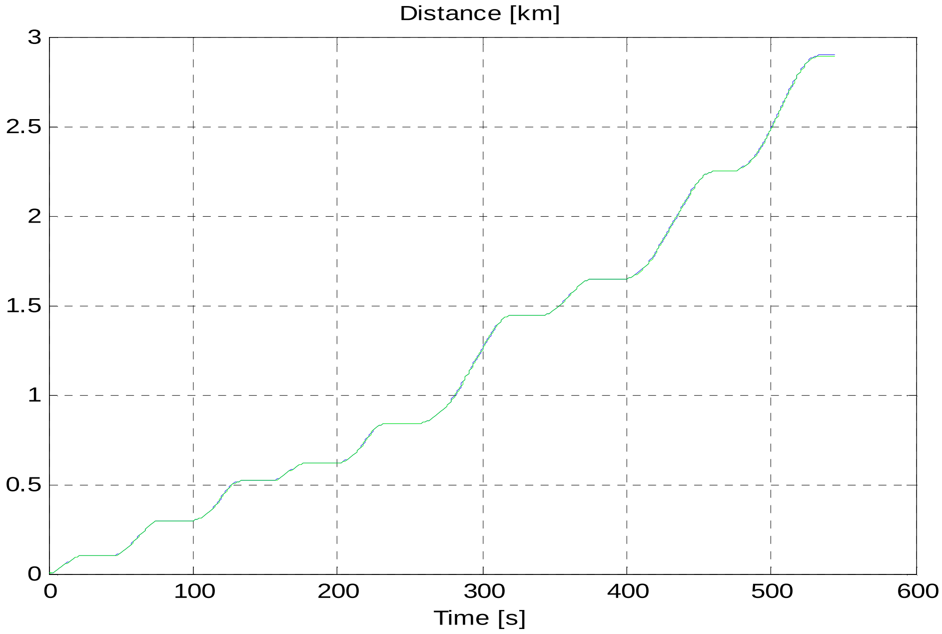
(a) The wheels power consumption (kW)



(b) The total DC power (kW)



(c) The total DC energy (kWh)

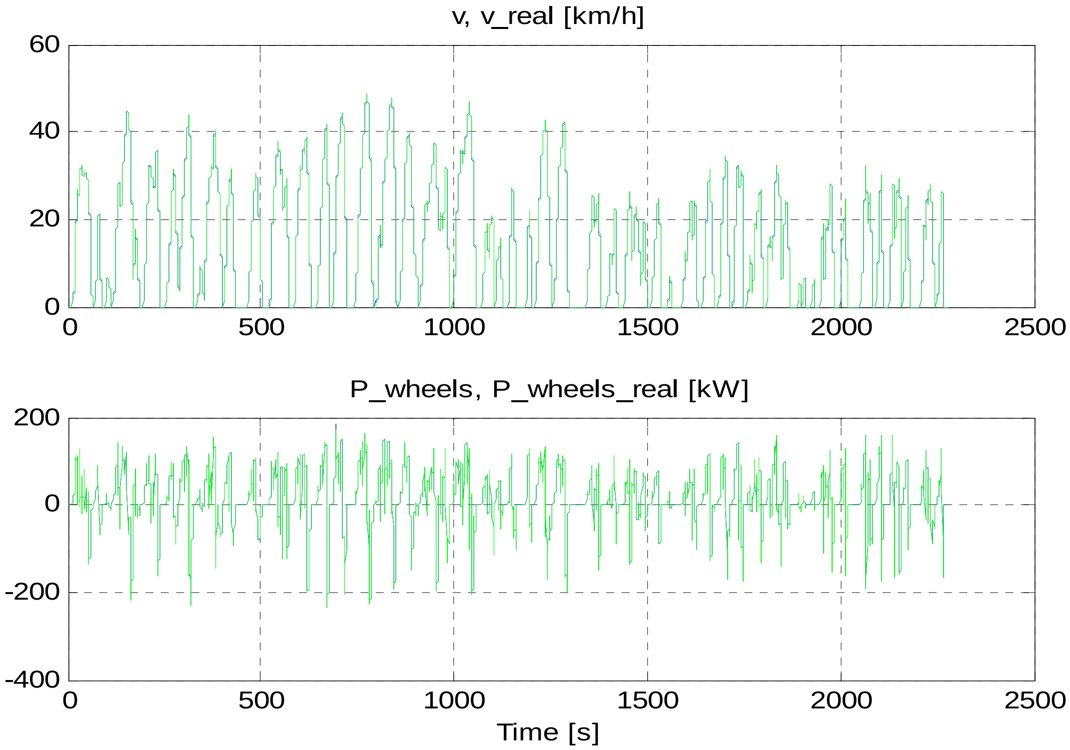


(d) The total distance (km)

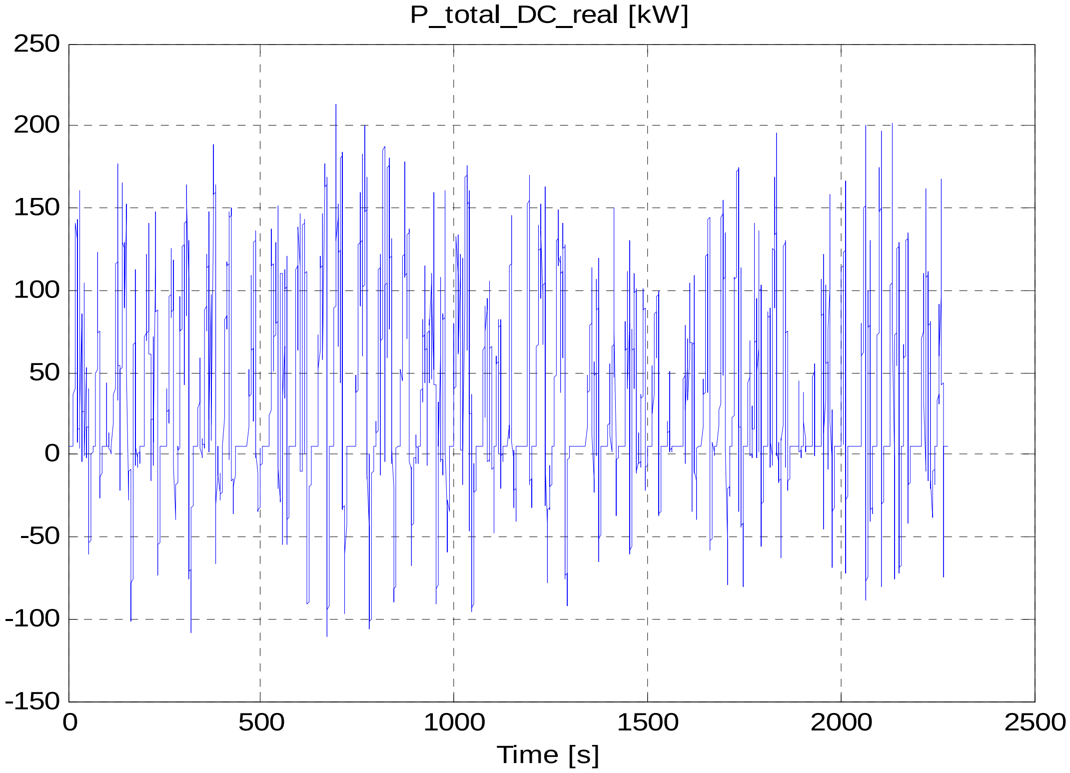
Figure 4 The performance of 7700 Volvo bus during SORT driving cycle

### 2.3.2.2 Power consumption during MLTB Driving Cycle

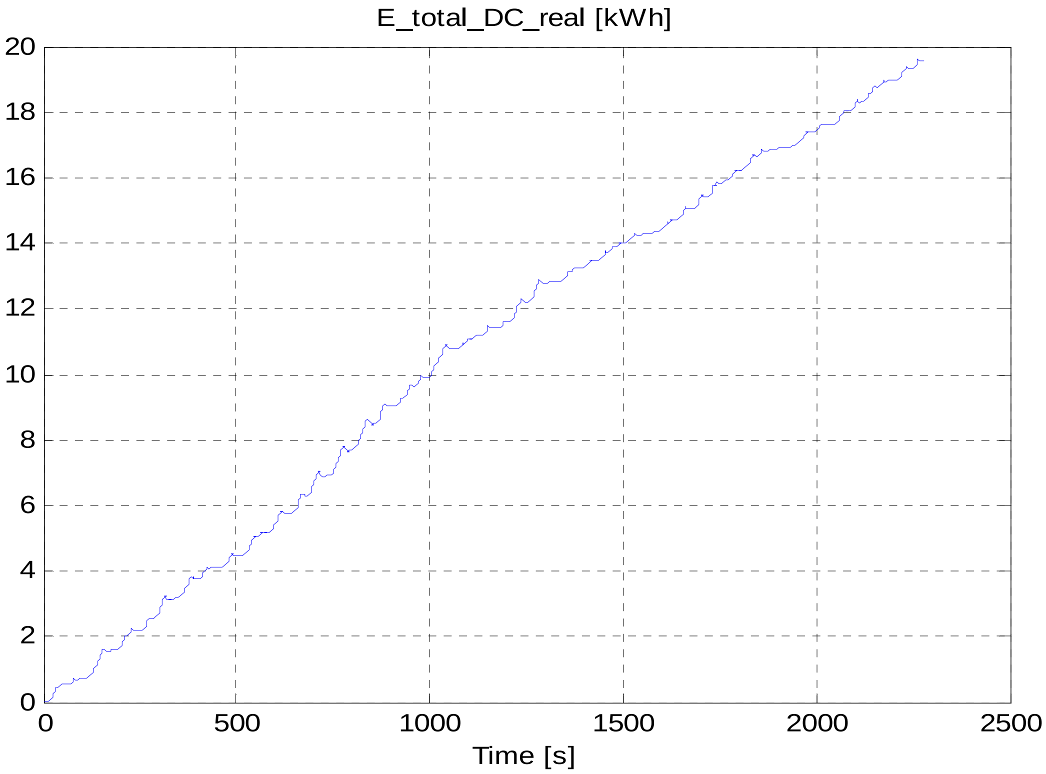
Figure 5 illustrates 7700 Volvo bus power and energy consumptions during MLTB driving cycle



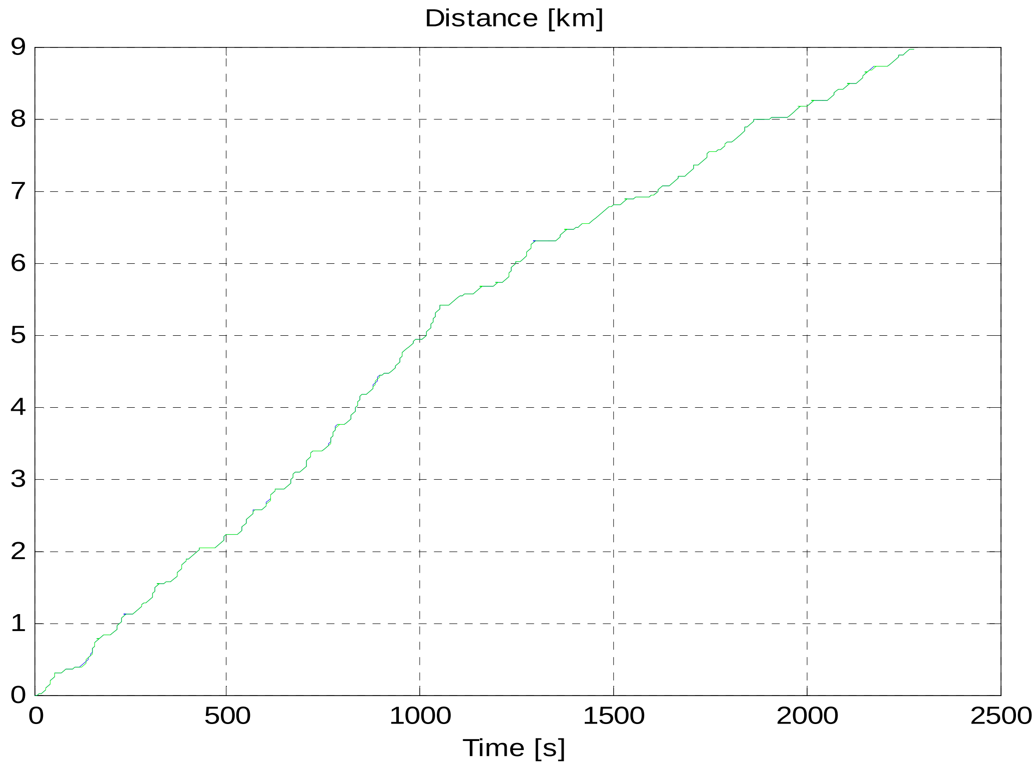
(a) The wheels power consumption (kW)



(b) The total DC power (kW)



(c) The total DC energy (kWh)



(e) The total distance (km)

Figure 5 The performance of 7700 Volvo bus during MLTB driving cycle

### 2.3.3 Small Passenger Car (CRF's EV)

The parameters of the CRF's EV vehicle are reported in Table 3.

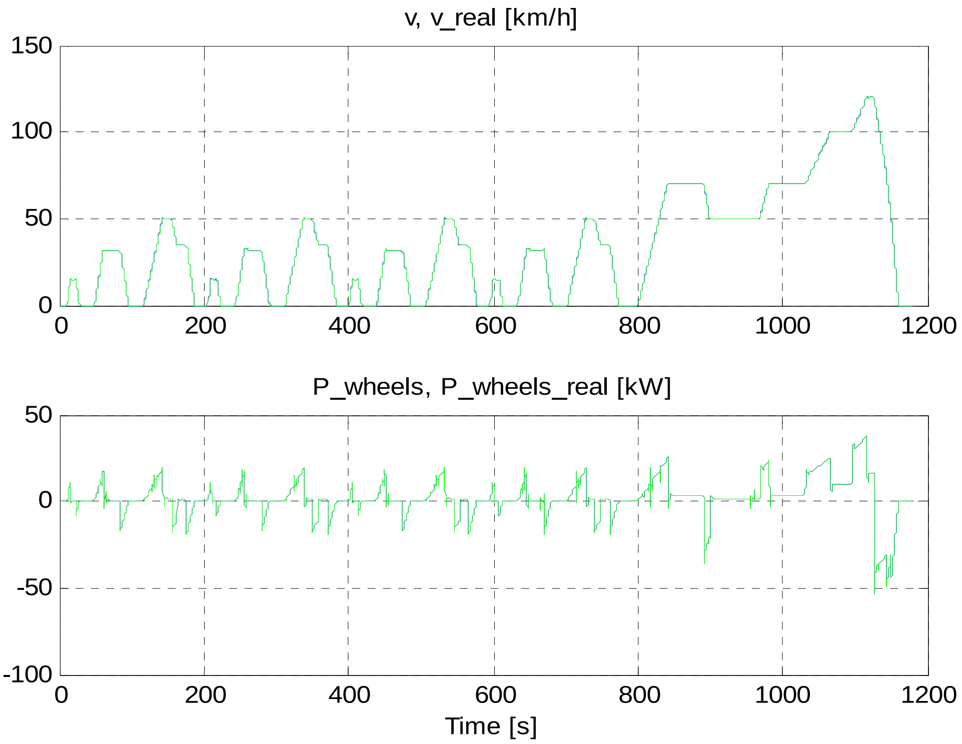
Table 3 EV Parameters

| | | |
|---|---|---|
| $M$ | Vehicle mass ($kg$) | 1350 |
| $f_r$ | Rolling Resistance Coefficient | 0.035 |
| $C_D$ | Aerodynamic Drag Coefficient ($C_D$) | 0.3 |
| $A_f$ | Front Area ($m^2$) | 2.2 |
| $r_w$ | Radius of the wheel (m) | 0.27 |

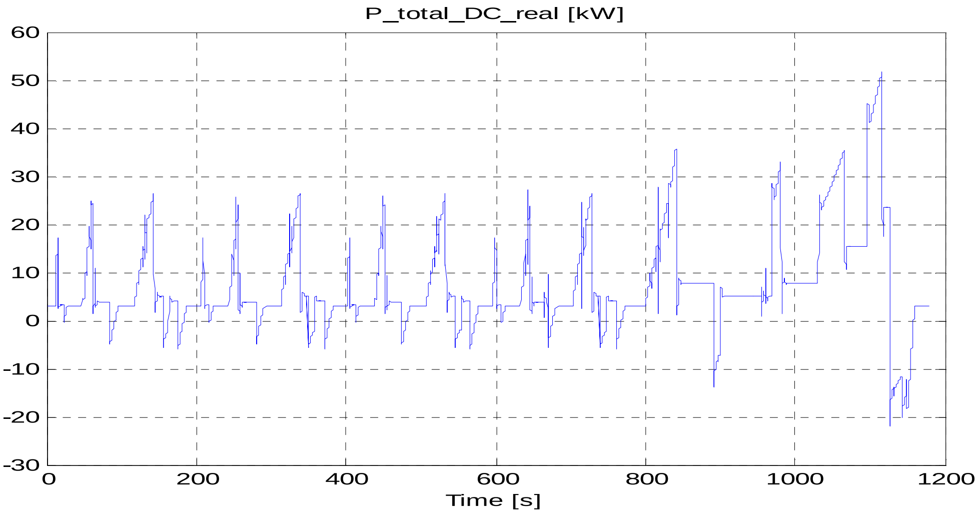
Power and energy consumptions analysis of this EV are performed on a standard NEDC driving cycle.

#### 2.3.3.1 Power Consumption during NEDC Driving Cycle

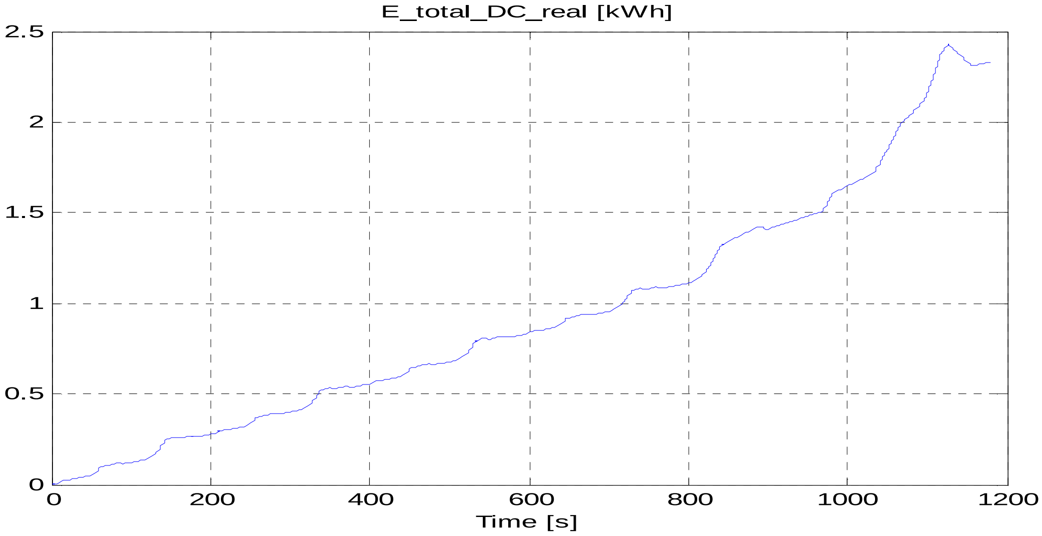
Figure 6 illustrates CRF's EV power and energy consumptions during NEDC driving cycle.



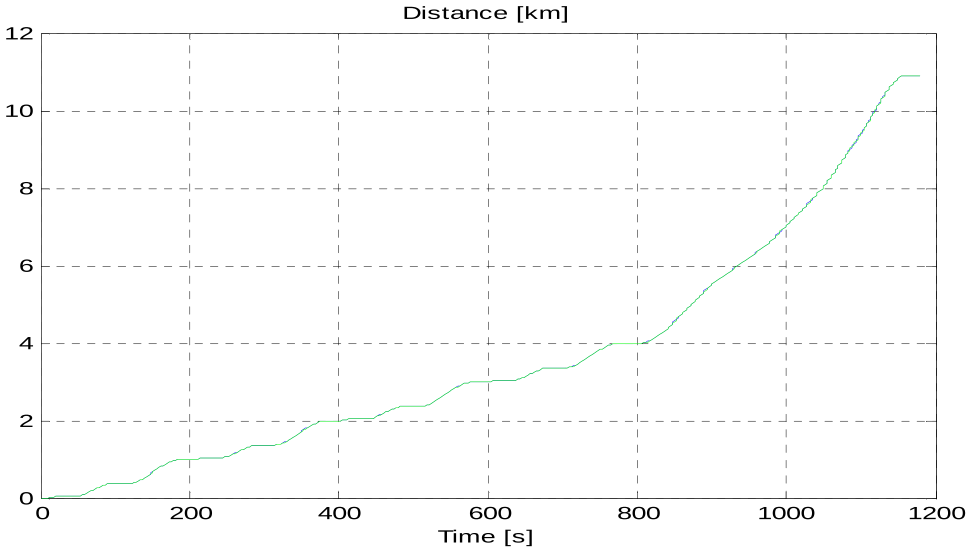
(a) The wheels power consumption (kW)



(b) The total DC power (kW)



(c) The total DC energy (kWh)



(d) The total distance (km)

Figure 6 The performance of EV during NEDC driving cycle

## 2.4 Comparison Study of Energy Consumption

Table 4 provides a comparative study of energy consumption in function of different vehicles and driving cycles.

| | Tecnobus Gulliver (Microbus) | | 7700 Bus (Volvo) | | Small Passenger Car (CRF's EV) |
|---|---|---|---|---|---|
| | Firenze Driving Cycle | SORT Driving Cycle | SORT Driving Cycle | MLTB Driving Cycle | NEDC Driving Cycle |
| Energy Consumption (kWh) | 6.9 | 2.3 | 5.6 | 19 | 2.3 |
| Distance (km) | 7.2 | 2.9 | 2.9 | 9 | 11 |
| Mass (kg) | 5636 | 5636 | 18900 | 18900 | 1350 |
| Energy per km (kWh/km) | 0.972 | 0.793 | 1.931 | 2.1 | 0.209 |

Table 4 Comparative Study of energy consumption

These values have been considered in the rest of analysis to understand the energy consumed that has to be restored.

# 3 Analysis of number and localizations of charging stations

In this chapter an analysis of possible future development of wireless recharge system will be presented. The city of Firenze has been used as case study to understand the infrastructure dimension and possible scenarios of implementation to sustain and guarantee the wireless mobility [2] [3].

The analysis focuses three different aspects:

1) Analysis of the infrastructure needed for the whole area bus system, considering the bus recharge at the terminal stop only; this solution has been chosen in order to decrease as possible the infrastructure need. The bus has only a reduced time of stop at the drive thru stops so the terminal ones are the most interesting from the point of view of return of the investment due to the higher time of usage.
2) Analysis of the infrastructure and battery sizing for the electrical busses that already are operational within the Firenze city center; the optimal choice of these two features has been carried out thanks to an economical optimization.
3) The cab service has been taken into account, analyzing the power need of a service based completely on wireless charged vehicles.

The analysis reflects the stationary charging and static en-route charging scenarios, respectively with a stop time greater and lower than 5 minutes.

For these scenarios have been assessed the impact on the power grid and the implementation needed to support the introduction of en-route static charging technology [4].

The private mobility has not been taken into account after the analysis of the preliminary results for the buses. As it is explained later in the document, the power required for the whole bus fleet of the Firenze city is affordable for the electrical grid of the city. Moreover this power need is concentrated during the daytime, when the grid is more intensively used respect to other timespan. On the other hand the power for public mobility would be probably concentrated during the nighttime and it will be drastically lower than the maximum power consumption evaluated for the busses (about 8 MW). If the power grid is able to support such power during the daytime also during the night this power will be available. Considering that the car would be charged during nighttime at a power of 3.7 kW this will enable the conservative estimation of more than 2000 wireless electric vehicles; this value could be even larger if it is considered that during nighttime the power grid is far less used than during daytime. For these reasons the introduction of wireless charged private cars is not an issue for the power grid sustainability. Also considering the midterm scenario about the diffusion of wireless charged private vehicles the number of nighttime recharge station that the grid is able to sustain is enough vehicles. However the private vehicles will be taken into account for the economic analysis that will be presented in deliverable 3.3 of the UNPLUGGED project.

## 3.1 Analysis of the optimal number of charging stations for a bus line

The public mobility service of a city is often based on busses because of their easiness of utilization and because of the low level of needed infrastructure. This is the reason why it is possible to find in mostly of the city the bus service instead of other kinds typologies of public transportation such as subways or tramways.

Another characteristic of the bus service is the low degree of uncertainty for the power consumption, thanks to paths that are fixed: it starts from a terminal station and finishes in another one. Uncertainty can only arise from the traffic conditions and not from the route the driver chooses. Furthermore, as it will be presented below in this chapter, this is a data with quite low standard deviation.

For what concern the vehicles, busses are very heavy weight transport vehicles and the electric ones have an higher weight percentage attributable to on board batteries.

So the widespread of the service, the low level of uncertainty and the possible reduction of on board batteries make the bus service a perfect application for an *en-route* wireless recharge technology.

City of Firenze backs its origins in the Renaissance period, but the continuing growth gave to the city a topography that is different between city center and urban area, divided by the ring road avenues. The city center has many large pedestrian areas, very narrow streets but a high density both of inhabitants and tourists. The urban area, instead, is more similar to an industrialized European city with very large streets. This differentiation of the city is also reflected by the bus service: in fact, as long as in the city center the public mobility is partially provided by low speed electric vehicles, whereas in the rest of the city are mostly used traditional internal combustion engine vehicles (both diesel and natural gas fueled), due to the large distance they have to travel and the average higher speeds they have to reach.

Public transportation in Firenze is provided by two integrated companies: ATAF S.p.A. and Li-Nea S.p.A. The network includes many bus routes and a tramway (two further tramways are under construction). The service covers the entire municipality of Firenze and the surrounding municipalities. As mentioned, two different areas can be defined:

- The city center, inside the ring road avenues, is served by small buses (lines C and D) many of which electric. These routes are in blue in Figure 7.
- The areas outside the city center, outside the ring roads avenues, is served by large buses . These routes are in orange in Figure 7.

The bus service is available 24 hours a day every day of the week. During the night , just a few lines remain in operation, in some cases with changed/shortened paths. The night busses routes are shown in dark blue in Figure 7.

The tramway, which connects Firenze to the neighboring town of Scandicci, is shown in gray in Figure 7.

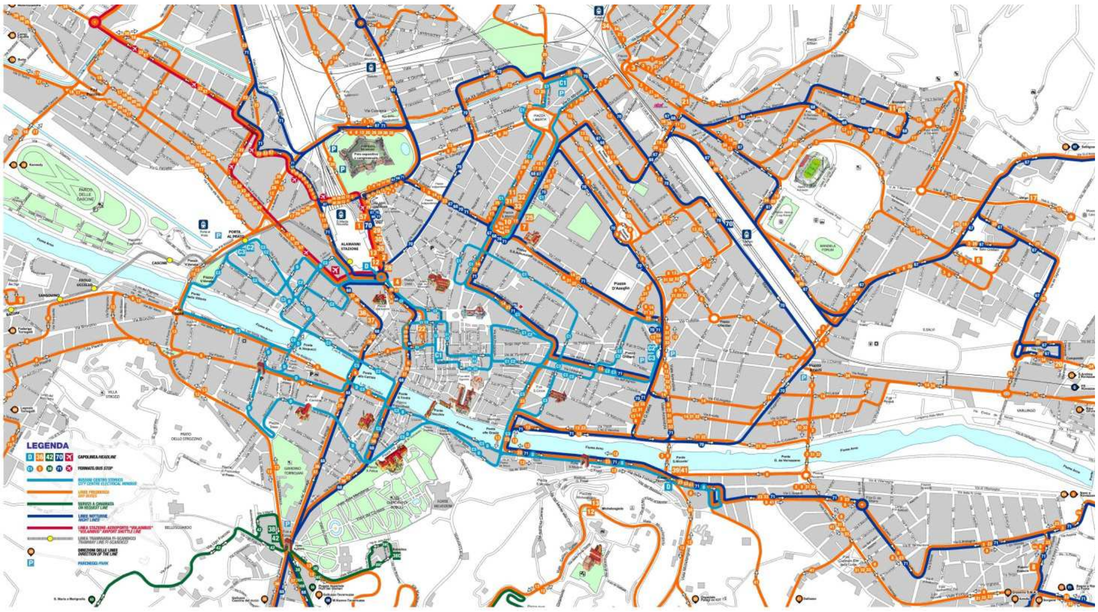


Figure 7 Firenze busses routes

The operating main routes are shown in Annex I. For each routes, the following data are reported:

- the average path length, or the average distance between two terminal stations (an average value has been considered because the actual length of the path may vary, for the same route, during the day);
- the average travel time (which can vary according to the route length and the traffic conditions);
- the average parking time at the terminal stations.

The values in Annex I (Table 32) were obtained by the official timetable, available at http://www.ataf.net, and refer to weekdays. Data of C1, C2, C3 routes are not reported. They are described in more detail in paragraph 3.1.1.

The terminals for the whole bus service are 116. Figure 8 shows an overview of the location of the bus terminal in the town center (area bounded by the red line) and in areas immediately adjacent.

In particular:

- the terminals inside the city center are shown in blue;
- the terminals of the electric buses that operate within the city center are shown in red;
- the terminals outside the city center are shown in green.

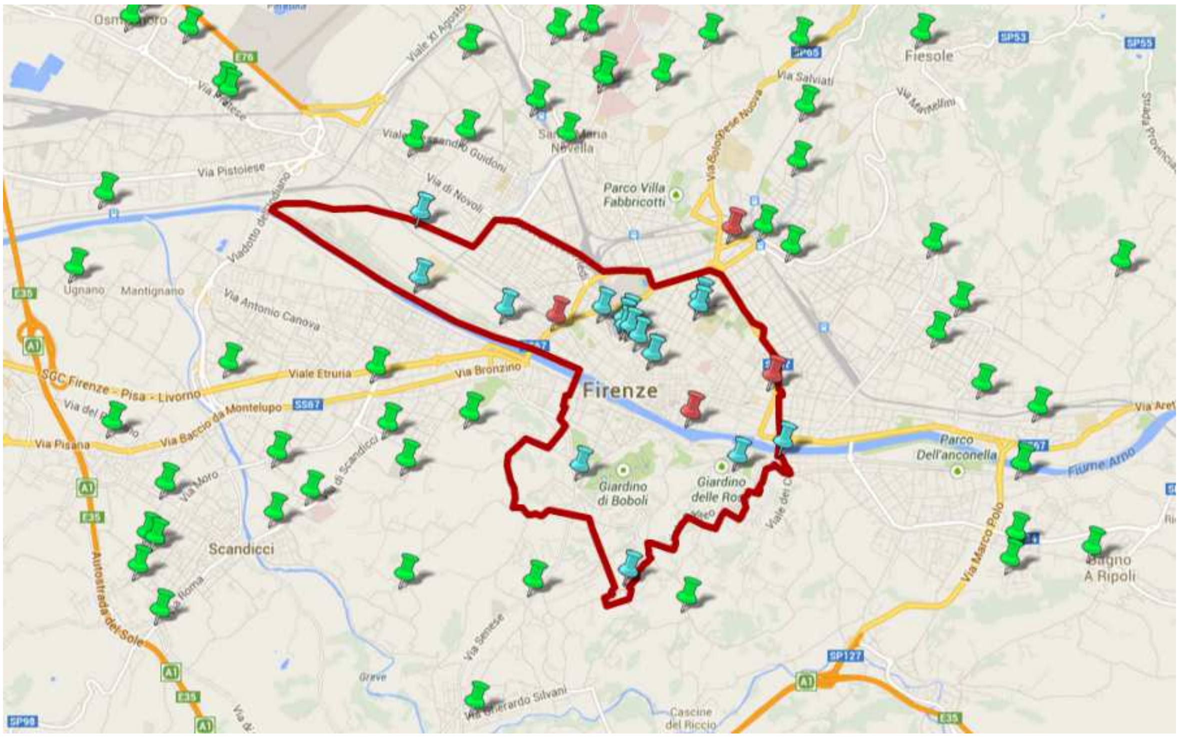


Figure 8 Bus terminal in the city center and surrounding areas

In November 2013 the fleet consists of 393 circulating vehicles including 31 electrical ones (for the lines that run through the city center). The types of buses are reported in Table 5.

Table 5 Firenze bus fleet

| **Number of vehicles** | **Model** | **Doors** | **Length [m]** |
|---|---|---|---|
| 31 | Tecnobus Gulliver U500 ESP electrical | 1 | 5 |
| 13 | Iveco Cacciamali TCC 635L | 2 | 6,5 |
| 2 | Rampini Alè | 2 | 7,5 |
| 3 | Rampini Alè | 3 | 7,5 |
| 4 | BredaMenarinibus Vivacity+ CNG | 2 | 7,5 |
| 13 | Iveco Europolis Cacciamali 200.9.15 | 3 | 9 |
| 29 | Iveco Cityclass 491.10.27 | 3 | 10,8 |
| 85 | BredaMenarinibus M240LU Mercedes | 3 | 12 |
| 22 | BredaMenarinibus Avancity+ | 3 | 12 |
| 16 | BredaMenarinibus Avancity+ CNG | 3 | 12 |

| | | | |
|---|---|---|---|
| 34 | Iveco CityClass 491.12.22 | 3 | 12 |
| 1 | Irisbus CityClass 491.12.29 | 3 | 12 |
| 61 | Iveco Cityclass 491.12.22 CNG | 3 | 12 |
| 79 | Irisbus Cityclass 491.12.24 CNG | 3 | 12 |

Starting from the available data, in terms of arrival timetables of each bus for all bus lines and routes of each bus line to understand the first and last station and the kilometers driven, the following hypotheses can be assumed for carrying out the analysis:

1. At each terminal stop the battery is charged. The terminal stops have been considered as the locations in which the battery can be restored to a 100% of its capacity, since buses usually spend the maximum time of their life in bus stop and this time should be established.
2. A power consumption value of 1,931 kWh/km, as results from the previous analysis to be valid for the Volvo Bus (type 7700) in the SORT driving cycle.
3. The charging stations are equipped with a power inverter of 50 kW while no hypothesis on batteries capacity has been done for the buses
4. Only the buses during the daytime (6:00 am to 8:00 pm) have been considered and not during the night service, in which the bus service is similar to that during the daytime with a reduced frequency. So this analysis is also valid for the night service, even if not directly studied and evaluated.
5. The service level of the busses has been maintained at the actual level: no bus has been delayed respect to the actual schedule in order to have a longer recharge time.

Therefore, an evaluation on how much time the buses have to stop to recover all the capacity of the batteries has been performed, considering an energy flow from the grid of 50 kWh steady during the time of charging. This analysis does not take into account the classic behaviour of the batteries during the charging, characterized by a first part necessary to reach the desired voltage value at fix current value, and another part with a fix voltage value.

The results of this first step consist of a list including

- Name of the terminal stop
- Longitude of the terminal stop
- Latitude of the terminal stop
- Bus line that stops at each terminal stop
- Time of arrival of the bus at terminal stop considered as the time the charging can start
- Charging time needed to fully charge the batteries
- Energy needed as the total amount of energy consumed to restore
- Information if the terminal stop is localized at the Firenze downtown or Firenze urban area

According to the first hypothesis “at each terminal stop the battery is charged”, the time of departure of each bus from the terminal stop is different from the real situation. For a real analysis, the charging time should be the time between last arrival and next departure for each bus, without having the full capacity for batteries.

Based on the previous results, in terms of bus line, terminal stops and time necessary to recover the capacity of the battery, a calculation of the number of inductive charging station has been carried out.

The algorithm used to determine the number of the station is detailed below:

a. Filtering of each terminal stop without differing the bus lines present

b. Calculation of the end time of charge No 0 as

$$t_{end_{charge_o}} = t_{start_{charge_o}} + \Delta t_0$$

in which $\Delta t_0$ and $t_{start_{charge_0}}$ are known from the previous part of the analysis

c. Comparison between $t_{end_{charge_o}}$ and $t_{start_{charge_1}}$

- If $t_{end_{charge_0}} < t_{start_{charge_1}}$ just one inductive charging station is necessary
- If $t_{end_{charge_o}} > t_{start_{charge_1}}$ is needed to compare the $t_{end_{charge_o}}$ and $t_{start_{charge_2}}$ and so on.

  This process is iterative until the $t_{end_{charge_o}} < t_{start_{charge_i}}$, in which $i = 1, .., n$ .

The number of the inductive charging stations has been estimated for the following three different cases:

1. Standard

   In this case, the battery is fully restored to 100% of its capacity, therefore the number of the charging stations is directly calculated from the equation

   $t_{end_{charge_o}} < t_{start_{charge_i}}$

   in which $i = 1, .., n$ .

   This represents the worst case for the number of charging stations and the best case for the charging, since no overlapping is considered and every bus is able to fully charge after its arrival at the terminal stop.

2. Option 1

   In this first optimization it is considered negligible a difference between $t_{end_{charge_o}}$ and $t_{start_{charge_1}}$ of 5 minutes, and so the number of stations is reduced accordingly.

   In fact in 5 minutes the power not transmitted is about 4 kW that means about 2 km lower than the total distance.

3. Option 2

   For this second optimization the charging time is reduced of 20% of the entire charging time. This value changes for each charging and it is not possible to set an absolute value.

Table 6 reports the comparison between the three different cases for the number of inductive charging stations with a power of 50 kW for each one.

| Cases | Number of stations | Power required [kW] |
|---|---|---|
| Standard | 291 | 14550 |
| Option 1 | 256 | 12800 |
| Option 2 | 252 | 12600 |

Table 6 Comparison number of charging stations

For the further study the number of stations resulted for Option 1 case has been considered.

The list of all charging stations for each terminal stop is reported in the Annex II.

To assess if the implementation of electric public transportation is feasible, a comparison between the total electric power need of the city and the additional power needs by the electric public transportation has been made. The results are presented in Figure 9:

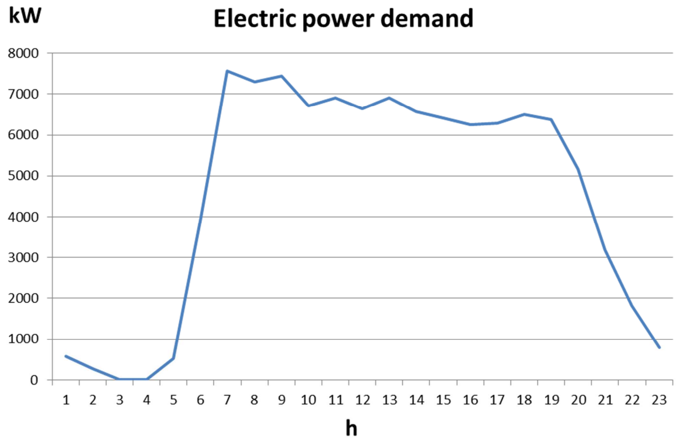


Figure 9 Daily electric power demand for whole city wireless recharge infrastructure

This study has shown that technology implementation is feasible because the peak is less than 8 MW that is very low in comparison to Firenze's electric demand peak.

In detail the whole power required by all charging stations bears on the Firenze's network for less than 1%, considering the primary substation involved in the development of electric mobility.

The analysis of power consumption in Firenze is reported in Annex III, focusing on the infrastructure and battery size for the electrical busses.

## 3.2 Analysis of the charging station needs for a cab service

Another analysis has been conducted for the taxi service. At the moment the taxi companies are operating in Firenze are two. These companies work synergistically, sharing the same taxi stations. Based on the available data, there are 654 taxis in Firenze municipality and 30 more taxis operate in the surrounding area. About 30% of the above mentioned 654 taxis are eco-fuel, and taxis mounting an hybrid engine are 80.
There are 51 taxi stations (Annex IV - Table 58), which provide approximately 280 parking spaces. The main stations are placed near the two main communication hubs of the city, the railway station of Santa Maria Novella and the Amerigo Vespucci Airport, and inside the city center, Piazza della Repubblica e Piazza San Marco.
Table 58 shows the locations of the taxi stations and, for each of them, the number of available parking spaces.

Figures below (Figure 10 and Figure 11) show the taxi stations distribution (in yellow), also together with the bus terminals (in green, blue and red).

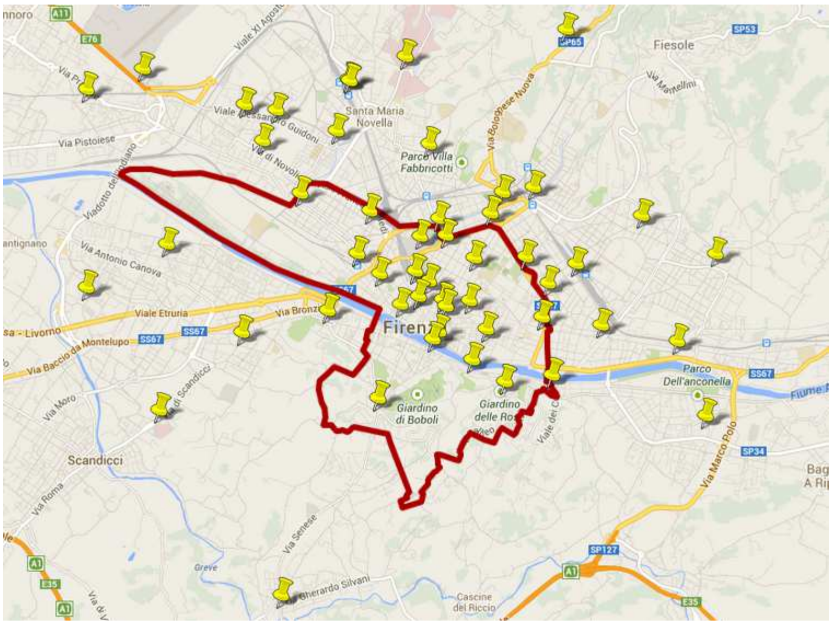


Figure 10 Taxi station distribution

Figure 11 Taxi station distribution and busses' terminal stops

The average waiting time can greatly vary, depending on the month, rather than the time in the day. On the basis of conversations with the taxi companies managers it can be assumed that during the summer there is an average wait of about 10 minutes, while in the less tourist seasons it can reach and exceed an average value of 60 minutes.
The annual distance traveled is on average about 35,000 km. This value also includes the distance travelled for private users.

Starting from the available data, and taking into consideration the actual technology a Nissan Leaf with an average consumption of 0.209 kWh/km, a battery capacity of 24 kWh and a power inverter capacity of 3.7 kW, has been used for a first analysis. The data reported in Table 7 can be obtained assuming that the 10% of the entire taxi fleet are electric vehicles

Table 7 Assumptions and results for taxi scenario, 3.7 kW case

| | |
|---|---|
| **Number of taxis** | 654 |
| **Parking spaces** | 280 |
| **Traveled distance per year [km]** | 35000 |
| **Working days per year** | 220 |
| **Traveled distance per day [km]** | 159 |
| **Assumed consumption [kWh/km]** | 0.209 |
| **Energy consumption per day [kWh]** | 33.25 |
| **Assumed available battery capacity [kWh]** | 24 |
| **Recharging energy per day [kWh]** | 9.25 |
| **Assumed power inverter capacity [kW]** | 3.7 |
| **Recharging time per day, one taxi [h]** | 2.5 |
| **Recharging time per day, all taxis [h]** | 1635 |
| **Assumed percentage of electric taxis** | 10% |
| **Minimum parking time per parking space [h].** | 0.58 |

With this solution the grid total demand would be about 250 kW while if all the circulating vehicles would be transformed in PEV and would be simultaneously connected to the grid the total grid net demand would be around 2.5 MW. Since the grid has showed no critical improvements when a request of more than 8 MW is applied by bus this solution could be sustainable also for taxis. Moreover a conversion of all the vehicles to PEV would require a long time, enough to improve the grid robustness.

This scenario however lacks the consistency with the taxi drivers need. The time that each taxi needs to stay in the charging station is too long. For the proficient use of wireless charging in the taxi service it would be needed the development of higher power transfer also for small vehicles. At least a power higher as the plug in fast charging one, 20 kW, would be necessary. Considering this scenario the mean charging time needed for each taxi every day is around 30 minutes. This timing would be more appreciated by taxi drivers because there is not the risk that any customer request could not be fulfilled because the battery level is too low for the requested service. The result of this scenario is reported in Table 8.

Table 8 Assumptions and results for taxi scenario, 20 kW case

| | |
|---|---|
| **Number of taxis** | 654 |
| **Parking spaces** | 280 |
| **Traveled distance per year [km]** | 35000 |
| **Working days per year** | 220 |
| **Traveled distance per day [km]** | 159 |
| **Assumed consumption [kWh/km]** | 0.209 |
| **Energy consumption per day [kWh]** | 33.25 |
| **Assumed available battery capacity [kWh]** | 24 |
| **Recharging energy per day [kWh]** | 9.25 |
| **Assumed power inverter capacity [kW]** | 20 |
| **Recharging time per day, one taxi [h]** | 0.5 |
| **Recharging time per day, all taxis [h]** | 3.3 |
| **Assumed percentage of electric taxis** | 10% |
| **Minimum parking time per parking space [h].** | 0.11 |

Respect to the evaluation of the number of charging stations necessary to guarantee a full public mobility service, for the taxi it is difficult to find the optimal number really necessary, since neither the stop time or the energy to be restored in the batteries are known, and the parameters are variable. For this reason, in this document to be able to have a preliminary estimation of the cost for the infrastructure, the number of charging stations necessary has been fix to 28, equal to 10% of the total parking slots available since the main hypothesis is to have a 10% of taxi electric vehicle. In further analysis in task 3.3 of UNPLUGGED project, with a detailed and deep study 3 different levels of penetration will be considered to evaluate the status of the grid.

# 4 Grid management and implementation

The first part of analysis consists of a simulation on a typical urban distribution network in Spain to evaluate the impact of 50 kW inductive charging stations, using a load flow software.

The second part of analysis refers to the cost evaluation for sustaining the full public transport service and cab service in Firenze, based on real data network.

Both analysis are focused on power grid management and feasibility.

## 4.1 Scenarios for the power grid in order to sustain a 50 kW inductive technology and effect of the locations of charging stations

This first part describes the studies carried out on the impact of 50-kW fast charging stations on a typical urban distribution network. The specific network topology which was chosen for the simulation model follows typical construction criteria of DSO in southern European countries, such as Spain and Italy. The main characteristics in this case are a weakly meshed MV level (ring) with distribution substations containing two transformers with typically 630 kVA of nominal power.

Therefore, the analysed network consists of a MV ring with 7 distribution substations containing two 630 kVA distribution transformers each. In order to complete the model, in addition 7 loads at MV level have been considered.

The proposed fast charging station implementation scenarios assume that in three of those seven substations, a 50-kW fast charging station is connected on the LV side. Total charger power (150 kW) represents roughly 1% of the network total design capacity, but for each substation a charger represents a 4% of its nominal load (8% of each transformer rated power).

The simulations have been carried out performing load flow analysis of the different scenarios. The program used has been NEPLAN, with some cases also programmed using PSS®E software in order to confirm the obtained results. NEPLAN from BCP (Switzerland) is a software tool to analyse, plan, optimise and simulate electrical, water, gas and district heating networks. PSS is a product Suite from Siemens and stands for “Power System Simulator”. PSS®E is a special product for transmission system planning.

The analysis considers a specific “instantaneous” worst-case situation in the system. The simulations have been performed under design load (i.e. maximum load) conditions and 10% overload in the network.

For the simulation the following scenarios have been demonstrated for MV network and LV as well:

1. MV1 – Reference scenario: this scenario is used to analyse and determine the best locations for the chargers, considering the voltage drop on each line.
2. MV2 – Base scenario: three charging stations (150 kW) are connected in the best locations
    a. MV2.1 analysis is conducted considering design load conditions.
    b. MV2.2 analysis considers an increase for each load of 10%

3. MV3 – Worst case: three charging stations (150 kW) are connected in the worst locations.
    a. MV3.1 analysis is conducted considering design load conditions.
    b. MV3.2 analysis considers an increase for each load of 10%

4. LV1 – Reference scenario: this scenario is used to analyse and determine the best locations for the chargers on the LV side of the transformer. The analysis on LV grid also considers unbalanced loads.

5. LV2 – Unbalanced LV loads: one charging station is connected to existing feeder in the best location
    a. LV2.1 analysis is conducted considering design load conditions.
    b. LV2.2 analysis considers an increase of 10%

6. LV3 – Unbalanced LV loads: one charging station is connected to existing feeder in the worst location
    a. LV3.1 analysis is conducted considering design load conditions.
    b. LV3.2 analysis considers an increase of 10%

7. LV4 – Unbalanced LV loads, connect fast charger to a dedicated feeder.
    a. LV3.1 analysis is conducted considering design load conditions.
    b. LV3.2 analysis considers an increase of 10%

The main difference between MV and LV scenarios is that in MV simulations, all the loads are balanced, whereas in LV scenarios, the effect of unbalanced loads has been included. The LV system is always present in all simulations, only the focus of analysis and scenarios changes.

## 4.1.1 Analysis of MV scenarios

### 4.1.1.1 MV1 – Reference scenario

The first analysed scenario is the initial configuration of the distribution network where it is intended to include inductive charging stations .

The scheme of the network is the one shown in Figure 12.

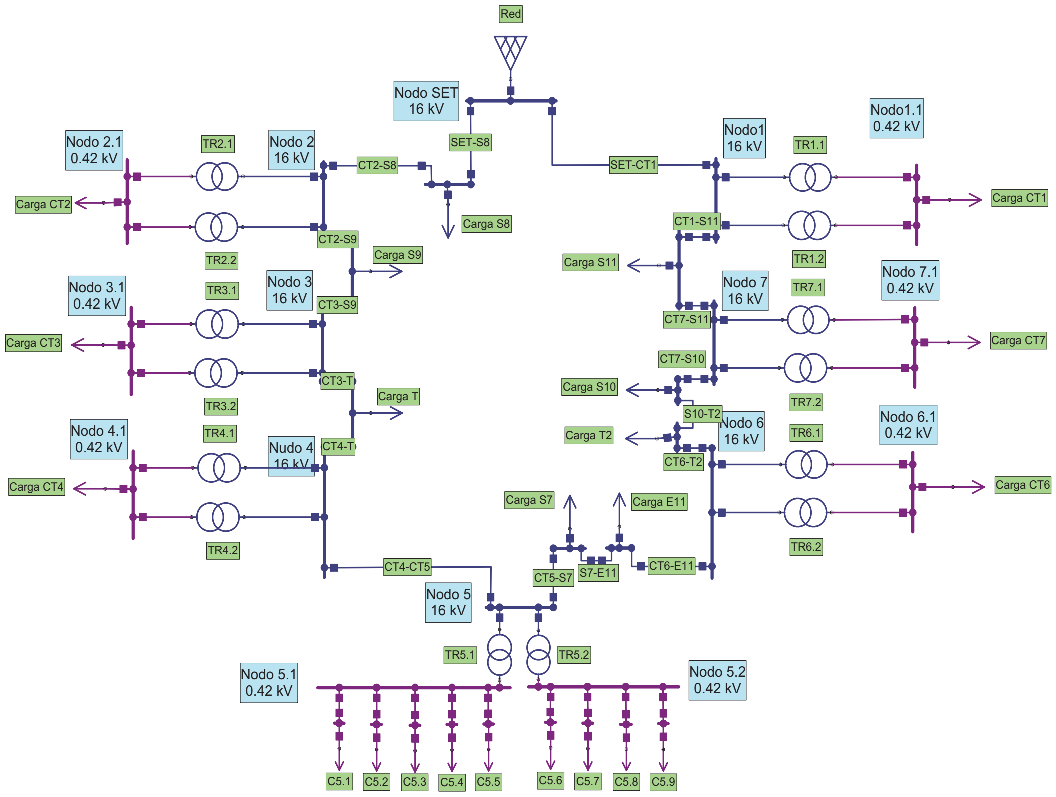


Figure 12 Model of the simulated MV/LV distribution system

The results obtained from the power flow simulation of the network are shown in Table 9. Considering MV voltages, the maximum voltage drop appears at node 5 (0.3%), something to be expected, since it is the node located farther from the substation, while the minimum voltage drop appears at node 1, node located closer to the substation.

Considering power losses, Table 10 shows that MV lines dissipate 45 kW, LV lines 26 kW, and transformers 180 kW, giving a total of 251 kW (2.22 %).

| Node | U (kV) | ΔU (%) |
|---|---|---|
| **Node SET** | 16 | 100 |
| **Node 1** | 15.979 | 99.87 |
| **Node 2** | 15.972 | 99.82 |
| **Node 3** | 15.961 | 99.76 |
| **Node 4** | 15.954 | 99.71 |
| **Node 5** | 15.951 | 99.7 |
| **Node 6** | 15.957 | 99.73 |
| **Node 7** | 15.968 | 99.8 |

Table 9 MV1 – Power flow simulation results (voltage drops)

| Description | Power losses (MW) |
|---|---|
| MV line | 0.045 |
| LV line | 0.026 |
| Transformers | 0.180 |
| **Total** | **0.251** |

Table 10 MV1 – Power flow simulation results (Power losses)

Another reference study, carried out to consider the worst possible condition, consists in connecting a charging station at each LV bar. This situation is reflected in Figure 13 and the results in terms of voltage drops are shown in Table 11 and Table 12.

It can be noticed that as the previous results, node 5 exhibits the largest voltage drop among the MV nodes (0.31%). Line and transformer losses increase slightly, up to a total of 260 kW.

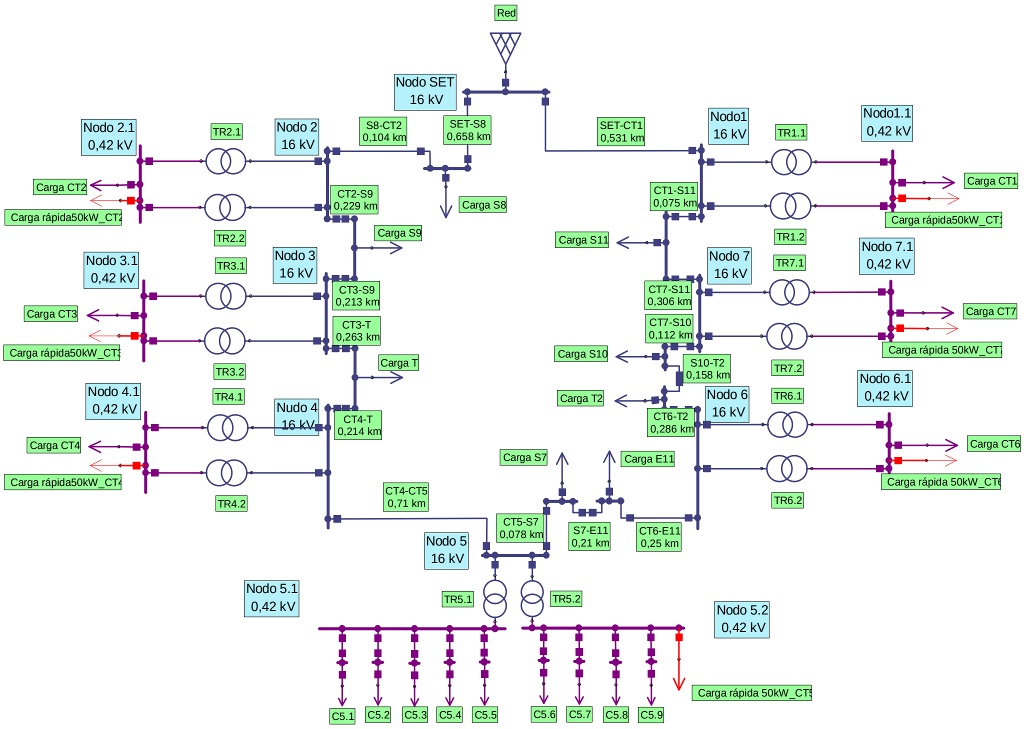


Figure 13 Scheme of the distribution network including one charger for each substation.

| Node | U (kW) | ΔU (%) |
|---|---|---|
| **Node SET** | 16 | 100 |
| **Node1** | 15.979 | 99.87 |
| **Node 2** | 15.971 | 99.82 |
| **Node 3** | 15.96 | 99.75 |
| **Node 4** | 15.953 | 99.7 |
| **Node 5** | 15.95 | 99.69 |
| **Node 6** | 15.955 | 99.72 |
| **Node 7** | 15.967 | 99.79 |

Table 11 MV1 – Power flow simulation results (voltage drops) with increased number of chargers

| Description | Power losses (MW) |
|---|---|
| MV line | 0.045 |
| LV line | 0.027 |
| Transformers | 0.188 |
| **Total** | **0.260** |

Table 12 MV1 – Power flow simulation results (power losses) with increased number of chargers

### 4.1.1.2 MV2 – Base scenarios

These scenarios consider that three 50kW charging stations are connected to the best locations according to MV1 results. Two situations are simulated:

1. the first one is performed under design load condition for the network
2. the second one is carried out considering increased loads (10% increase).

The number of charging stations has been set considering the most conservative estimate, 100% service and location in the centre of the city, with 5.7 chargers/km$^2$. Since the area under study is 0.5 km$^2$, 3 charging stations have been connected to the grid.

#### 4.1.1.2.1 MV2.1 – Design load conditions

The optimal location for charging stations installation is mainly defined by two magnitudes/factors: CT load conditions and length of the feeding line (substation – CT). According to load conditions, the most suitable CTs are CT5, CT6 and CT7. However, according to voltage drop, the most suitable are CT1, CT2 and CT7, since they are situated closer to the substation. Since all CTs have reserve capacity to feed the chargers, the second criteria has been chosen.

Results for this configuration are shown in Table 13. It can be observed that voltage drop is limited to 0.18% for the nodes feeding a charging station and to 0.31% considering all nodes.

| Node | U (kV) | ΔU (%) |
|---|---|---|
| **Node SET** | 16.000 | 100.00 |
| **Node 1** | 15.979 | 99.87 |
| **Node 2** | 15.971 | 99.82 |
| **Node 3** | 15.961 | 99.75 |
| **Node 4** | 15.954 | 99.71 |
| **Node 5** | 15.951 | 99.69 |
| **Node 6** | 15.956 | 99.73 |
| **Node 7** | 15.979 | 99.87 |

Table 13 MV2.1 – Power flow simulation results (voltage drops)

#### 4.1.1.2.2 MV2.2 – Increased load conditions (10%)

In this scenario, loads are set to 1.1 times their rated values. In this case, the total load is 9.084 MW, still below the MV network limit of 10.44 MVA. The maximum CT load is 1.23 MW, below the maximum transformation capacity of 1.26 MVA. Once more the simulation has been carried out placing the chargers at CTs 1, 2 and 7.

As results in Table 14, voltages are slightly lower than in the previous case, given the increased load, reaching a 0.23 % drop for CT7. Power losses in this case are 15% higher than in the base load scenario (see Table 15), representing 3.3 %.

| Node | U (kV) | ΔU (%) |
|---|---|---|
| **Node SET** | 16.000 | 100.00 |
| **Node 1** | 15.977 | 99.85 |
| **Node 2** | 15.968 | 99.80 |
| **Node 3** | 15.956 | 99.73 |
| **Node 4** | 15.949 | 99.68 |
| **Node 5** | 15.945 | 99.66 |
| **Node 6** | 15.952 | 99.70 |
| **Node 7** | 15.964 | 99.77 |

Table 14 MV2.2 – Power flow simulation results (voltage drops)

| Description | Power losses (MW) |
|---|---|
| MV line losses | 0.055 |
| LV line losses | 0.032 |
| Transformer losses | 0.213 |
| **Total** | **0.300** |

Table 15 MV2.2 – Power flow simulation results (power losses)

### 4.1.1.3 MV3 – Worst case scenarios

In these scenarios, the three chargers are connected at the worse locations according to the electrical parameters. The chosen CTs are CT4, CT5 and CT6, the ones located farther from the substation.

#### 4.1.1.3.1 MV3.1 – Design load conditions

The results obtained from the simulation of this configuration are shown in Table 16. In this case, maximum voltage drop takes place in CT5, and reaches 0.31 %.

| Node | U (kV) | ΔU (%) |
|---|---|---|
| **Node SET** | 16.000 | 100.00 |
| **Node 1** | 15.979 | 99.87 |
| **Node 2** | 15.971 | 99.82 |
| **Node 3** | 15.960 | 99.75 |
| **Node 4** | 15.953 | 99.71 |
| **Node 5** | 15.950 | 99.69 |
| **Node 6** | 15.956 | 99.72 |
| **Node 7** | 15.967 | 99.80 |

Table 16 MV3.1 – Power flow simulation results (voltage drops)

#### 4.1.1.3.2 MV3.2 – Increased load conditions (10%)

The simulation results with increased loads are shown in Table 17. It can be noticed that in the worst case, a 0.34% voltage drop occurs at CT5, a value that does not affect its correct operation in any way.

In fact, at MV level, even connecting one charger at every distribution substation would be possible without any problems.

| Node | U (kV) | ΔU (%) |
|---|---|---|
| **Node SET** | 16.000 | 100.00 |
| **Node 1** | 15.977 | 99.85 |
| **Node 2** | 15.969 | 99.80 |
| **Node 3** | **15.956** | **99.73** |
| **Node 4** | 15.949 | 99.68 |
| **Node 5** | 15.945 | 99.66 |
| **Node 6** | 15.951 | 99.70 |
| **Node 7** | 15.964 | 99.77 |

Table 17 MV3.2 – Power flow simulation results (voltage drops)

## 4.1.2 Analysis of LV scenarios

### 4.1.2.1 LV1 – Reference scenario with unbalanced loads

This scenario analyses the best option to locate the chargers, focusing the study on the LVgrid of one distribution substation (CT). The chosen CT is CT5, which has 9 low voltage lines (3 phase + neutral). A 10% total unbalance among phases has been considered. Figure 14shows the model implemented for the reference LV scenarios.

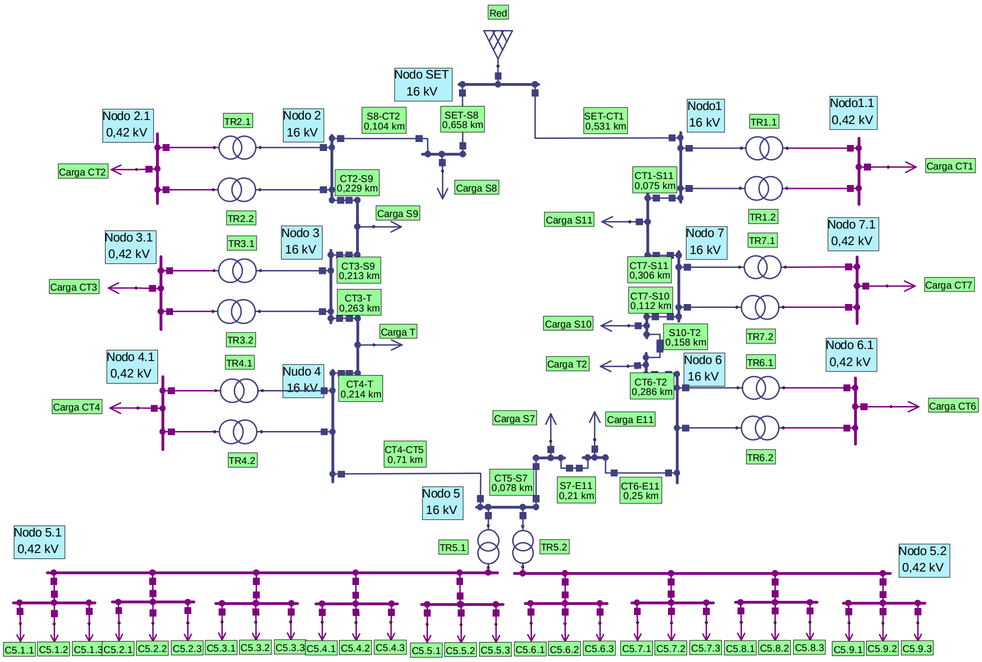


Figure 14 Reference network for LV simulations

The optimum point to connect the charging stations is determined based on the voltage drop and the saturation of the lines. A load flow analysis provides the node voltages reflected in Table 18.

It can be observed that the nodes having a voltage closest to the rated value are n5.1, n5.2 and n5.5.

Table 19 shows the load supplied by each LV line and the conductors which they are composed of. The one having lower load and larger margin is L5.2.

| Node | U (V) | ΔU (%) |
|---|---|---|
| **n5.1** | 404 | 96.29 |
| **n5.2** | 404 | 96.31 |
| **n5.3** | 395 | 94.14 |
| **n5.4** | 394 | 93.84 |
| **n5.5** | 401 | 95.42 |
| **n5.6** | 394 | 93.83 |
| **n5.7** | 395 | 93.96 |
| **n5.8** | 402 | 95.76 |
| **n5.9** | 397 | 94.46 |

Table 18 LV1.1 – Reference voltage values for nodes fed from CT5

| LV line | Cable type RV0,6/1kV | Load (kW) |
|---|---|---|
| **L5.1** | 3x1x240+150 Al | 158 |
| **L5.2** | 3x1x150+95 Al | 79 |
| **L5.3** | 3x1x240+150 Al | 169 |
| **L5.4** | 3x1x240+150 Al | 169 |
| **L5.5** | 3x1x240+150 Al | 188 |
| **L5.6** | 3x1x150+95 Al | 132 |
| **L5.7** | 3x1x240+150 Al | 131 |
| **L5.8** | 2(3x1x240+150) Al | 202 |
| **L5.9** | 3x1x150+95 Al | 136 |

Table 19 LV1.1 – Line conductors and reference load

In the following scenarios different connections of a 50 kW charging station will be simulated: most favourable point, less favourable, and using a dedicated line for the charger.

The study will be based on European regulation EN 50160 [1], part 4.2.2.4, which indicates the allowed voltage limit in distribution networks, being a ±10 % of rated voltage.

### 4.1.2.2 LV2 – Unbalanced loads and connection to an existing line

#### 4.1.2.2.1 LV2.1 – Design load conditions

In this scenario the charger is connected to node n5.2, the best location according to the analysis preformed in the previous section. The obtained voltage values are shown in Table 20. It can be noticed that the connection of the charger causes a 1.3 % increase in the voltage drop in the line, but it remains comfortably within the allowed limits (5 % total drop).

| Node | U (V) | ΔU (%) |
|---|---|---|
| **n5.1** | 404 | 96.17 |
| **n5.2** | 399 | 95.01 |
| **n5.3** | 395 | 94.02 |
| **n5.4** | 394 | 93.72 |
| **n5.5** | 400 | 95.30 |
| **n5.6** | 394 | 93.83 |
| **n5.7** | 395 | 93.96 |
| **n5.8** | 402 | 95.76 |
| **n5.9** | 397 | 94.46 |

Table 20 LV2.1 – Voltage values for nodes fed from CT5. Charger connected to node n.5.2

#### 4.1.2.2.2 LV2.2 – Increased load conditions (10%)

In this scenario all loads are increased by 10% over their design value, and the charging station is connected to the most suitable node, which is n5.2. The obtained results are summarized in Table 21, and they show that voltage drops are slightly increased. In the case of node n5.2 it grows from 4.99 % to 5.22 %.

| Node | U (V) | ΔU (%) |
|---|---|---|
| **n5.1** | 403 | 95.95 |
| **n5.2** | 398 | 94.78 |
| **n5.3** | 393 | 93.56 |
| **n5.4** | 396 | 94.19 |
| **n5.5** | 401 | 95.53 |
| **n5.6** | 391 | 93.16 |
| **n5.7** | 392 | 93.29 |
| **n5.8** | 400 | 95.30 |
| **n5.9** | 394 | 93.84 |

Table 21 LV2.2 – Voltage values for nodes fed from CT5. Charger connected to node n5.2

### 4.1.2.3 LV3 – Unbalanced loads and connection to an existing line

#### 4.1.2.3.1 LV3.1 – Design load conditions

According to results obtained in para 4.1.2.1, Table 18 indicates that the less favourable location, considering voltage drop, is n5.6, since it presents with 394 V the lowest voltage, which corresponds to a 6.17 % voltage drop. Considering line saturation, the worst node is n5.5, with 188 kW. Line L5.8 carries a higher load (202 kW), but conductor section is larger (two 240 mm$^2$ conductors in parallel per phase). Both cases have been simulated, and the results are shown in Table 22 and Table 23.

Simulation results show that the charger could be connected in any of the considered nodes, since in both cases voltage drop is below 10 % (8.21 % and 6.47 %, respectively). It is worth pointing out that in all the cases it has been considered that the charger is connected at the end of the line, which is the less favourable position when calculating voltage drop.

| Node | U (V) | ΔU (%) |
|---|---|---|
| **n5.1** | 404 | 96.29 |
| **n5.2** | 404 | 96.31 |
| **n5.3** | 395 | 94.14 |
| **n5.4** | 394 | 93.84 |
| **n5.5** | 401 | 95.41 |
| **n5.6** | 386 | 91.79 |
| **n5.7** | 394 | 93.82 |
| **n5.8** | 402 | 95.63 |
| **n5.9** | 396 | 94.32 |

Table 22 LV3.1 – Voltage values for nodes fed from CT5. Charger connected to node n5.6

| Node | U (V) | ΔU (%) |
|---|---|---|
| **n5.1** | 404 | 96.16 |
| **n5.2** | 404 | 96.18 |
| **n5.3** | 395 | 94.01 |
| **n5.4** | 394 | 93.71 |
| **n5.5** | 397 | 94.53 |
| **n5.6** | 394 | 93.83 |
| **n5.7** | 395 | 93.96 |
| **n5.8** | 402 | 95.76 |
| **n5.9** | 397 | 94.46 |

Table 23 LV3.1 – Voltage values for nodes fed from CT5. Charger connected to node n5.5

#### 4.1.2.3.2 LV3.2 – Increased load conditions (10%)

This section snows the results obtained in the simulation of the low voltage grid supplied by CT5, when the loads are increased a 10% over their design values. The less favourable position for the fast charger is considered (node n5.6). The obtained voltages are shown in Table 24. Voltage drops have increased slightly, but in all nodes it is within permitted limits (8.91 % drop in node n5.6).

| Node | U (V) | ΔU (%) |
|---|---|---|
| **n5.1** | 403 | 96.07 |
| **n5.2** | 404 | 96.08 |
| **n5.3** | 393 | 93.68 |
| **n5.4** | 396 | 94.31 |
| **n5.5** | 402 | 95.64 |
| **n5.6** | 383 | 91.09 |
| **n5.7** | 391 | 93.15 |
| **n5.8** | 400 | 95.16 |
| **n5.9** | 394 | 93.70 |

Table 24 LV3.2 – Voltage values for nodes fed from CT5. Charger connected to node n5.6. Increased loads.

### 4.1.2.4 LV4 – Unbalanced loads and connection of the fast charger to a dedicated feeder

In this scenario the charging station is connected to transformer TR5.2 through its own LV line. Several simulations have been carried out in order to determine the maximum line length that would allow the system to remain within voltage drop limits. The model used to carry out the simulations is shown in Figure 15.

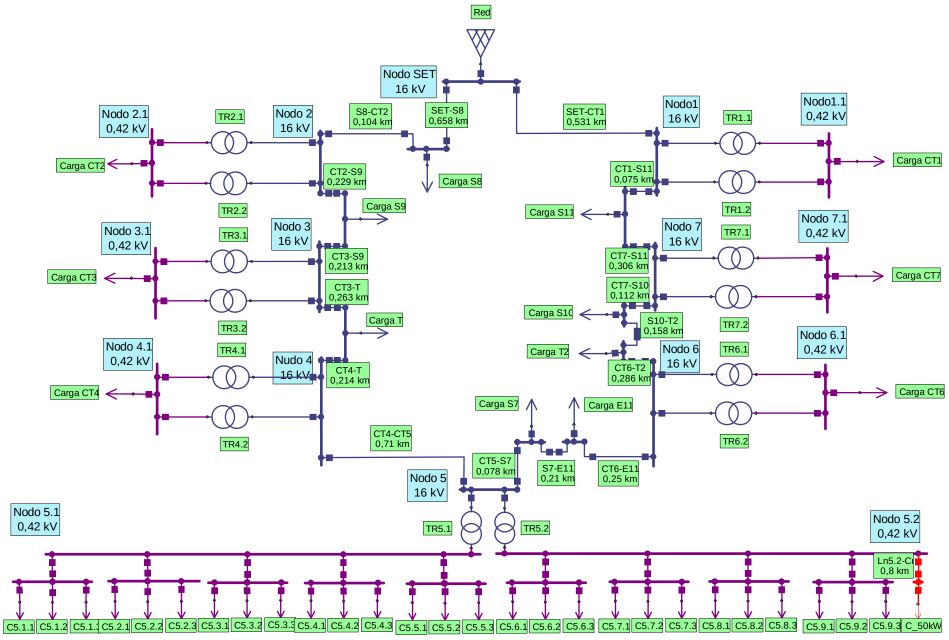


Figure 15 Connection of the charger to Node 5.2 using a dedicated feeder

#### 4.1.2.4.1 LV4.1 – Design load conditions

In this scenario design load conditions are considered for the network, and the charging station is connected to Node n5.2 with its own 800 m line (3x1x150 mm$^2$ Al). The results presented in Table 25 show that with the simulated line length, the voltage drop is 8.25%, which is still within the limits imposed by the regulations.

| Node | U (V) | ΔU (%) |
|---|---|---|
| **n5.1** | 404 | 96.29 |
| **n5.2** | 404 | 96.31 |
| **n5.3** | 395 | 94.14 |
| **n5.4** | 394 | 93.84 |
| **n5.5** | 401 | 95.41 |
| **n5.6** | 394 | 93.71 |
| **n5.7** | 394 | 93.84 |
| **n5.8** | 402 | 95.64 |
| **n5.9** | 396 | 94.34 |
| **Charger** | 385 | 91.75 |

Table 25 LV4.1 – Voltage values for nodes fed from CT5. Charger connected to dedicated 800 m feeder line

#### 4.1.2.4.2 LV4.2 – Increased load conditions (10%)

In this scenario, increased load conditions are considered for the network (10 %). All other conditions are the same as in the previous case. As can be observed in Table 26, voltage drops have increased in all nodes, as expected, but voltages still remain above 90%. The worst line, the one used to feed the charger, remains at a voltage of 91.56 %.

| Node | U (V) | ΔU (%) |
|---|---|---|
| **n5.1** | 403 | 96.07 |
| **n5.2** | 404 | 96.08 |
| **n5.3** | 393 | 93.68 |
| **n5.4** | 396 | 94.31 |
| **n5.5** | 402 | 95.64 |
| **n5.6** | 391 | 93.03 |
| **n5.7** | 391 | 93.17 |
| **n5.8** | 400 | 95.18 |
| **n5.9** | 394 | 93.72 |
| **Charger** | 385 | 91.56 |

Table 26 LV4.2 – Voltage values for nodes fed from CT5. Charger connected to dedicated feeder line

## 4.2 Feasibility and implementation needed to support the introduction of inductive charging technology in Firenze

A cost analysis has been accomplished to understand the economic effort for the introduction of several charging stations in Firenze area. In general, the analysis is composed by a first study for buses service in downtown area and the whole urban area, obtained with a load flow software, and a second study for the taxi service with a parametric analysis.

### 4.2.1 Bus analysis

Based on the collected data of the previous analysis, considering the number of charging stations necessary to sustain a full public service transport in Firenze, a technical – economical evaluation of the impact of inductive charging in Firenze has been finalized using an Enel internal software, called Atlante.

The relevant hypotheses for this study are detailed below:

- Power for each charging station is set at 50 kW as passive users
- The charging profile is considered to be steady during all day with a power fixed at 50 kW
- For each terminal stop up to 3 charging stations the connection is directly on LV grid with a new line, while in case of more than 3 stations a new secondary substation is needed to be built due to high power to be connected (more than 150 kW).

Based on the 2nd hypothesis, it results an analysis enough conservative since it does not reflect the real load charging profiles but a value fixed to 50 kW for all daytime.

Atlante is designed to perform a load flow analysis: after adding the single loads in the existing network with their relevant connection, the system evaluates the difference between the MV network status before and after the insertion in the network, highlighting the critical situation and providing suggestions to improve the electrical components with their average costs in order to be able to sustain all loads. The simulation is carried out studying each primary substation and the network downstream to this one.

Based on the real consumption behaviour in Firenze, Atlante considers for the analysis the worst case for the network, in which the passive users absorb the greatest power value and the active users do not provide any power to be introduced in the network.

After fixing the worst case, the power required for all charging stations is added and the software verifies that the introduction of charging station does not carry out/make any critical situation on MV network, such as exceeding the maximum permissible current in the conductors, excessive voltage drops and saturation of the transformer in the secondary substation.

The costs can be considered as all the costs to be faced on MV and LV grid, necessary for installing each charging station. The real costs can be different, they are usually greater than those estimated.

Moreover, these costs resulting by Atlante are independent from the place in which the charging station is installed. In different cities there can be additional costs to be considered; for example, in Firenze, where our analysis takes place, the civil works require about +37% in the downtown and +22% for urban area respect to the cost provided by Atlante.

For carrying out the analysis, the number estimated for Option 1 (para 3.1 Table 6) for inductive charging stations has been differentiated in number of stations located in Firenze downtown from those located in Firenze urban area (included stations in downtown):

- Number of stations located in downtown area: 51
- Number of stations located in urban area: 256

In general, to perform the analysis the process consists of following steps:

- Locating the charging station using the longitude and latitude inside Atlante software
- Connecting the closest secondary substation with new or existing LV lines, to evaluate the real distance. For a number greater 3 charging stations in the same place, a new secondary substation has been built
- Setting the value of 50 kW for each charging station and the value directly proportional in case of more than one station
- Setting the utilization parameters as the transformer, MV customers with a power greater and lower of 500 kW, in addition to cos phi set to 0.9 for electrical devices
- Performing the load flow process before and after the connection
- Processing the results. The results are described in terms of the cost necessary for the grid to able to support these loads

As said before the cost has been differentiated for the installation of charging stations located in the downtown respect to all charging stations required to have a bus public service.

These costs correspond to all necessary economic effort to install a charging station from the substation to the desired locations in charge to the DSO.

Actually, in accordance with the Italian regulation, the companies and customers requiring the installation have to contribute some money to a part of the entire costs for the new LV connection for the permanent installation of stations.

Those are constituted by an amount for the power and another for the distance between the point of delivery and the existing substation, and for LV connections are described as:

$$cost = \ f(distance, power) = a + b$$

$$a = fixed\ value + amount\ for\ distance$$

$$fixed\ value = 184.11\ €$$

$$amount\ for\ distance = \begin{cases} additional\ part\ when\ 200\ m \le d \le 700\ m \rightarrow 92.29\ € \\ additional\ part\ when 700\ m < d \le 1200\ m \rightarrow 184.11\ € \\ additional\ part\ when\ d > 1200\ m \rightarrow 368.22\ € \end{cases}$$

These costs are applicable for each 100 meters or fraction greater than 50 meters.

$$b = amount\ for\ power = 69.22\ €/kW$$

In general, this cost effort analysis does not take in consideration the technology of the charging system, so the results are valid for the installation inductive charging station as well as conductive ones.

Inside the project other tasks will address the inductive charging technology in the grid management and evaluation of real impact.

### 4.2.1.1 Impact of the inductive charging stations installed in Firenze downtown

The list of the charging stations located in the Firenze downtown is reported in the Annex V – Table 59.

From the table it results

- 16 buses terminal stops
- 51 charging stations
- Total required power of 2550 kW

The simulation shows some critical situation and the necessity of installing two new secondary substations, with the following details

- Secondary substation A
    1. Transformer with a power of 630 kVA
    2. Transformer with a power of 400 kVA
- Secondary substation B
    1. Transformer with a power of 400 kVA

The total amount of distance in air is about 1,4 km while the distance with the cable buried is about 1,6 km.

The cost necessary for installing the 51 charging stations in Firenze downtown is about 155 k€, without considering the additional cost for the civil works in Firenze area. In this case the cost is about 213 k€.

The cost for the TIC is about 180 k€ greater if the cost would be charged by DSO without the additional costs.

### 4.2.1.2 Impact of the inductive charging stations installed in Firenze urban area

A second part of the analysis has been conducted considering all charging stations forecast in Firenze to guarantee the full public service with buses. The list of these charging stations is reported in Annex VI - Table 60.

In general, it results:

- 113 buses terminal stops
- 256 charging stations including the 51 for the downtown area
- 12800 kW as a total required power value

The results show that there are necessary 13 new secondary substations, including the 2 for the downtown, with new different LV lines; below the details of the power for each transformer is reported

- Secondary substation A
    1. Transformer with a power of 630 kVA
    2. Transformer with a power of 400 kVA
- Secondary substation B
    1. Transformer with a power of 400 kVA
- Secondary substation C
    1. Transformer with a power of 400 kVA
- Secondary substation D

    - i. Transformer with a power of 400 kVA
- Secondary substation E
    - i. Transformer with a power of 630 kVA
- Secondary substation F
    - i. Transformer with a power of 400 kVA
- Secondary substation G
    - i. Transformer with a power of 400 kVA
- Secondary substation H
    - i. Transformer with a power of 400 kVA
- Secondary substation I
    - i. Transformer with a power of 630 kVA
- Secondary substation J
    - i. Transformer with a power of 400 kVA
- Secondary substation K
    - i. Transformer with a power of 630 kVA
- Secondary substation L
    - i. Transformer with a power of 250 kVA
- Secondary substation M
    - i. Transformer with a power of 400 kVA

From the analysis the total cost results about 1350 k€, whereas for TIC is 910 k€.

This cost does not reflect the real cost since it is not affected by the additional cost for civil operations in Firenze area, which bring the entire cost to about 1650 k€.

### 4.2.2 Taxi analysis

Respect to the previous analysis performed for the buses deployment, for the taxi service it has been conducted a parametric analysis, based on the average distance between each locations and the secondary substation.

So, in this case, no analysis regarding the power required, set to 20 kW, has been performed and evaluated with the load flow software. Further studies in deliverable 3.3 of UNPLUGGED project will be taken in consideration a detailed analysis for the taxi, considering 3 different levels of penetration of the electric vehicles in this scenario, and will study the real effort necessary for the grid.

This parametric analysis is a preliminary step for the evaluation of the total costs, and it is only function of the average distance between each location and the secondary substation, without focusing on the cost of new secondary substations or transformers, which could be necessary after a load flow analysis.

Considering an all inclusive cost of 60 € for each meter of buried cable, and an average distance of 156 meters from the locations to the secondary substation, based on the real distance resulted from the public mobility service analysis, the preliminary cost to be addressed to each charging station for cab service is about 9400 €. For all 28 stations (equal to 10% of the total available parking slots set at 280), the whole cost is about 263 k€, just for the cables and civil works.

The all inclusive cost is a standard cost applied in the beginning analysis by Enel to connect the customers to the LV grid, and it includes the cost for operators, material and civil works.

# 5 Analysis of the effect of inductive charging stations in the urban environment

This chapter describes the impact of the inductive charging in the urban environment, with a preliminary cost analysis reported in Annex VIII. The whole cost analysis will be performed in task 3.6 of the UNPLUGGED project.

## 5.1 'The Future of Wireless Charging' automotive industry survey results

### 5.1.1 Executive Summary

This survey aims to collect views surrounding the viability of inductive (wireless) charging technology for vehicles in future markets. This has been achieved by fielding responses from a variety of industry sectors that undertake business in, or provide services to, the automotive industry. The survey results are anonymous, with respondents being identified only by their industry sector. TfL hopes to reflect, via a range of open-ended questions, a broad variety of anecdotal opinions that will provide a high level overview of the trends and opinions currently available about this subject.

### 5.1.2 Participants

A total of 29 participants completed the questionnaire.

### 5.1.3 Methodology

The survey was created, distributed, and the results collected using SurveyMonkey (http://www.surveymonkey.com). Distribution was facilitated by the Society of Motor Manufacturers and Traders (SMMT), the UK's premier automotive trade body.

### 5.1.4 Data Collected

The facilitator collected two forms of data:

1. *Qualitative*: Seven questions requiring open ended, verbatim responses. The resultant comments have been collated into broad categories and have been quantified in terms of the percentage of the respondents concurring with each comment.
2. *Quantitative*: Two multiple choice questions; one pertaining to the respondents' industry sector and another concerning prospective wireless charging markets. In both cases the respondents have been able to select multiple sectors and markets.

### 5.1.5 Results

The results are listed by question in Annex VII .

### 5.1.6 Survey Key Findings

1. Public transport organizations are acknowledged as playing a primary role in the development and utility of induction charging technology for vehicles.

2. Crucial to the further development of this technology is a need for infrastructure standardization, government legislation, and investment in publicly accessible inductive charging infrastructure to incentivise the take up of the technology.

3. The organizations surveyed were largely confident that induction charging technology for vehicles would move beyond the R&D stage and into the public realm within the next five years.

## 5.2 Bus route selection for inductive charging

### 5.2.1 Environmental challenges for London's buses; rationale for induction charging

TfL operates one of the largest bus fleets in the world; over 8,700 buses serving more than 700 routes with 6.5 million passenger journeys every working day. TfL began trialling hybrid buses in 2008 and began volume roll-out in 2012. Today (December 2013) there are over 540 hybrid buses operating in London, with around 30% lower fuel consumption and lower air quality emissions. The latest generation series-hybrid bus – the New Bus for London, delivers almost 50% lower fuel consumption (and is able to operate for a few kilometers in zero emission or EV mode) and, when Euro VI is fully introduced, will emit minimal air quality emissions. 600 of the New Bus for London vehicles have been ordered, and TfL expects around 1,700 hybrid buses to be in operation in the UK's capital city by 2016.

Despite this progress, TfL recognizes that it has an obligation to go further and research methods and technologies to continue to reduce emissions from its bus fleet – especially climate change (predominantly carbon dioxide) emissions. TfL plans to trial a number of pure electric buses, starting in winter 2013/14 on central London bus routes 507 and 521. These routes are relatively short and two single deck buses will form part of a multi-year trial. In summer 2014, a further four electric single deck buses from another manufacturer will be trialled on an outer London bus route. However, at the present capability of battery and recharging technology, pure EV buses are best suited to shorter routes with operational flexibility and scope to recharge these vehicles in the inter-peak periods. This does require a greater number of vehicles (Total Vehicle Requirement – TVR) greater than the Peak Vehicle Requirement (PVR) of conventional vehicles due to the need for additional vehicles while some are recharging.

Due to London's topography and history of public transport development, the double deck bus has become a unique feature which is not widely matched outside of the UK – especially across Europe where single deck (and articulated single deck) buses predominate. Around two-thirds of London's buses are double deck configuration, which poses a technical challenge for pure electric versions at the current state of battery technological maturity. An additional complication with a dense urban road network across much of London which cannot (easily or inexpensively) be expanded is the need to respond in real time to incidents on the network (such as accidents, roadworks, severe congestion). Route schedulers at TfL's bus operating companies are able to monitor in real time the position of all buses and adapt routes and schedules to minimize disruption. Exceptionally this might mean terminating a route early to enable a reverse flow of buses to maintain some service, rather than completely abandon a bus service. Finally, London's 24-hour economy requires very high levels of service and asset utilization, with many of London's buses in operation for up to 20 hours a day.

These factors suggest a very challenging London use-case. One solution is to extend the zero-emissions range of diesel-electric series-hybrid buses through induction opportunity charging, thereby delivering significant environmental benefits (reduced or zero air quality emissions, $CO_2$ reduction). Such a technical solution could still provide the operational flexibility to deal with unexpected events, where vehicles requiring a fixed infrastructure (e.g. pure electric vehicles) could run out of battery charge. TfL has been researching the potential for wireless charging for a number of applications (cars, taxis, buses) for several years. Given this experience, TfL has started planning a demonstration project in which a number of hybrid double deck bus routes in London could include high-power induction charging to extend their zero-emission capability. Part of this planning has included an assessment of suitable bus routes and the necessary infrastructure to install the induction charging ground stations. This has been an iterative process, whose basic steps & considerations are described in the sections below.

### 5.2.2 Bus route selection criteria for induction charging

The first step in the route selection process was to identify bus routes which serve double-deck vehicles (this is the most important and technically demanding London bus use case) and to sort them by running length (km). Because high-power (60-120kW) induction charging infrastructure is not commercially available (by most definitions of 'commercial'), TfL decided to limit the planned installation of induction charging infrastructure (ground stations) to controlled locations and those which TfL owns or has control. In practice this means TfL bus stations.

Table 27 below is an extract from a database of double deck bus routes with a running length less than 10 miles (16km), which are served by bus stations at each end. Additional criteria in Table 27 includes the bus garage which maintains & refuels the buses on the route (usually overnight), frequency (vehicles per hour) and PVR. Of key importance to the environmental benefits is the amount of grid energy transferred to the vehicle while stationary on its stand ('stand' or 'layover' time) at each bus station. Table 1 lists the range of layover times which vary throughout the day – typically shortest at peak periods (e.g. 0700-0900, 1600-1900 hrs). A limit of 16 km was chosen by TfL in order to minimise the impact of very large (heavy) battery packs and the reduction in passenger carrying capacity which would arise with very long bus routes being operated by a series-hybrid vehicle predominantly in EV (zero-emissions) mode. This route length can be varied, depending on the desired outcomes (e.g, environmental benefits) and the vehicle configuration, along with variables such as stand times.

| **Route** | **Start** | **End** | **Route Length (km)** | **Bus Garage** | **Max freq** | **PVR** | **Min Layover (mins)** | **Max Layover (mins)** |
|---|---|---|---|---|---|---|---|---|
| 257 | WALTHAMSTOW CENTRAL BUS STATION | STRATFORD BUS STATION | 8.307 | Northumberland Park | 8 | 15 | 8 | 12 |
| 41 | TOTTENHAM HALE BUS STATION, NORTH SIDE | ARCHWAY STATION, MACDONALD ROAD | 8.514 | Tottenham | 12 | 21 | 5 | 13 |
| 340 | HARROW BUS STATION | EDGWARE STATION, BUS STATION | 9.934 | Watford | 5 | 9 | 5 | 19 |
| 69 | WALTHAMSTOW CENTRAL STATION | CANNING TOWN BUS STATION | 10.59 | West Ham | 7.5 | 17 | 7 | 14 |
| 67 | WOOD GREEN BUS GARAGE | ALDGATE BUS STATION | 12.017 | Stamford Hill | 6 | 16 | 7 | 17 |
| 210 | FINSBURY PARK BUS STATION | BRENT CROSS SHOPPING CENTRE, BUS STATION | 12.147 | Cricklewood | 7.5 | 16 | 7 | 14 |
| 253 | EUSTON BUS STATION, NORTH STAND | CLAPTON BUS GARAGE | 12.371 | Stamford Hill | 12 | 27 | 8 | 17 |
| 48 | WALTHAMSTOW CENTRAL STATION | LONDON BRIDGE STATION, LONDON BRIDGE STREET | 12.551 | Leyton | 8 | 21 | 7 | 13 |
| 240 | GOLDERS GREEN STATION FORECOURT | EDGWARE STATION, BUS STATION | 12.671 | Edgware | 5 | 11 | 5 | 17 |
| 97 | STRATFORD CITY BUS STATION | CHINGFORD BUS STATION | 13.134 | Leyton & W Ham | 7.5 | 19 | 5 | 15 |
| 217 | WALTHAM CROSS BUS STATION | TURNPIKE LANE STATION | 14.127 | Potters Bar | 5 | 11 | 5 | 18 |
| 149 | LONDON BRIDGE STATION, LONDON BRIDGE STREET | EDMONTON GREEN BUS STATION | 14.689 | Tottenham | 12 | 36 | 9 | 17 |

Table 27 TFL induction charging double deck bus route selection parameters

### 5.2.3 Bus route & induction charging location selection process

The next stage in bus route selection was to rank the expected (or modelled) environmental benefits which induction charging could permit. Table 28 below shows the bus routes (as shown in Table 27) together with the impact of the various layover times on the environmental benefits from a (nominal) 60kW induction charging system for a range-extended diesel-electric series-hybrid double-deck London bus. 60kW was chosen as a base specification as pre-commercial induction charging systems of this power rating are currently available. An example is the IPT system from Conductix-Wampfler.

| **Route** | **Start** | **End** | **Route Length (km)** | **Min Layover (mins)** | **Max Layover (mins)** | **Fraction of route length powered by grid energy** | | | **Projected fuel savings vs diesel** | **RANK** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | **60 kW - min** | **60 kW - max** | **60 kW - ave stand** | | |
| 257 | WALTHAMSTOW CENTRAL BUS STATION | STRATFORD BUS STATION | 8.307 | 8 | 12 | 47.0% | 70.5% | 58.7% | 73.2% | **2** |
| 41 | TOTTENHAM HALE BUS STATION, NORTH SIDE | ARCHWAY STATION, MACDONALD ROAD | 8.514 | 5 | 13 | 25.2% | 65.4% | 45.3% | 64.4% | **3** |
| 340 | HARROW BUS STATION | EDGWARE STATION, BUS STATION | 9.934 | 5 | 19 | 30.1% | 114.4% | 72.2% | 81.9% | **1** |
| 69 | WALTHAMSTOW CENTRAL STATION | CANNING TOWN BUS STATION | 10.59 | 7 | 14 | 28.8% | 57.6% | 43.2% | 63.1% | **6** |
| 67 | WOOD GREEN BUS GARAGE | ALDGATE BUS STATION | 12.017 | 7 | 17 | 29.1% | 70.7% | 49.9% | 67.5% | **5** |
| 210 | FINSBURY PARK BUS STATION | BRENT CROSS SHOPPING CENTRE | 12.147 | 7 | 14 | 27.6% | 55.2% | 41.4% | 61.9% | **9** |
| 253 | EUSTON BUS STATION | CLAPTON BUS GARAGE | 12.371 | 8 | 17 | 37.8% | 80.3% | 59.0% | 73.4% | **4** |
| 48 | WALTHAMSTOW CENTRAL STATION | LONDON BRIDGE STATION | 12.551 | 7 | 13 | 24.8% | 46.0% | 35.4% | 58.0% | **11** |
| 240 | GOLDERS GREEN STATION | EDGWARE STATION, BUS STATION | 12.671 | 5 | 17 | 19.9% | 67.7% | 43.8% | 63.5% | **8** |
| 97 | STRATFORD CITY BUS STATION | CHINGFORD BUS STATION | 13.134 | 5 | 15 | 17.0% | 51.1% | 34.0% | 57.1% | **12** |
| 217 | WALTHAM CROSS BUS STATION | TURNPIKE LANE STATION | 14.127 | 5 | 18 | 19.0% | 68.5% | 43.8% | 63.5% | **10** |
| 149 | LONDON BRIDGE STATION | EDMONTON GREEN BUS STATION | 14.689 | 9 | 17 | 36.4% | 68.7% | 52.5% | 69.2% | **7** |

Table 28 TFL induction charging double deck bus route projected benefits

The calculations presented in Table 28 use average (double-deck) bus energy consumption data from a typical inner London bus route which TfL has modelled. The MLTB cycle (see Figure 16) was developed to represent a typical inner London bus route. The test cycle was generated using real time data collected from a London Bus working on Route 159 from Streatham to Baker Street via Whitehall and Oxford Street. TfL uses this cycle to test each and every new bus model to derive real-world emission, fuel and energy consumption factors which are used to report on the environmental impact of TfL's bus operations each year.

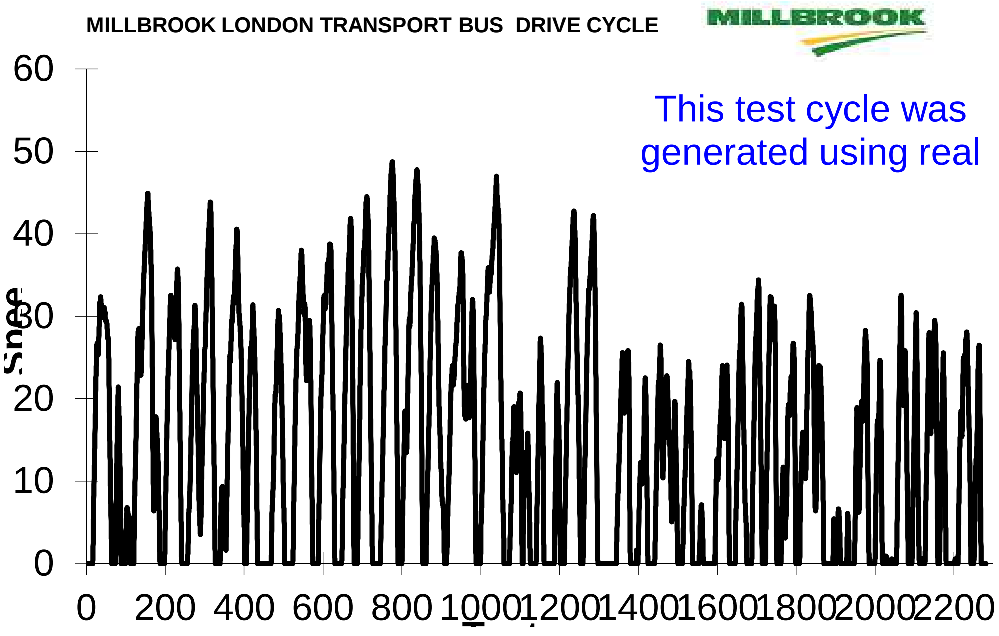


Figure 16 MLTB London bus test cycle

From the average bus energy consumption data, together with the layover time(s) and route length, it was possible to estimate the proportion of the total route length which could be operated in EV (zero-emissions) mode. From this percentage, it was then possible to model the total fuel & energy consumption reduction potential of each bus route. Table 28 shows these, ranked by proportion of each route operated in EV mode and by total (diesel) fuel saving over a conventional diesel bus. This ranking has been used by TfL to focus resources on the next stages of route evaluation which include a raft of additional criteria and considerations, and include physical characteristics of bus stations and a range of commercial issues. From TfL's experience, these include:

- Contract dates. The date at which an existing bus route contract expires will directly affect the cost-effectiveness of installing induction charging and converting (or ordering new) buses compatible with wireless charging. The optimum approach is to introduce this technology at the beginning of a new bus route contract rather than mid-way. At TfL, bus route contracts are initially awarded for 5 years and usually have a contract extension period of a further 2 years. However, given the variation in contract dates of the (relatively few) candidate bus routes considered for induction charging for the London double-deck bus use case, commercial issues might be a secondary consideration for a demonstration project. However, for longer term planning of significant infrastructure roll-out, contract renewal dates will be important, as will other issues such as a mechanism to incentivize fuel/energy cost savings. For an initial demonstration project, TfL would pay for the electricity consumed at the bus stations, but this would not be a long term sustainable model;
- Bus operating company selection. This is related to the contract renewal dates (see the section immediately above), although there are several wider issues to additionally consider. Bus companies will have their own preferred bus OEM suppliers and may have different environmental priorities / approaches to minimizing emissions from the buses in their fleets. This requires extensive engagement with the commercial, engineering and environmental managers at bus companies to ensure alignment of technology (such as compatibility of vehicles with ground stations) and the optimum commercial arrangements to deliver best value;

- Operational requirements. There are a number of operational issues to consider with the adoption of induction charging, such as how to adapt an existing bus schedule for including induction-charged range-extended series-hybrid buses (see section 5.3: Service Adjustment for Bus Routes Operating Inductively Charged Vehicles) and issues of additional to PVR or the buses being assimilated into the existing PVR;
- Physical space. Because of the technology-specific infrastructure there is a requirement for dedicated bus stands at bus stations. In addition, adequate vehicle turning space / maneuvering room is needed to ensure vehicles are correctly parked / aligned with the induction charging ground stations. In addition, sufficient room for the installation, commissioning and maintenance of induction charging ground stations must be planned and adequate space maintained;
- Services. The key service is a sufficient electricity supply to either the existing electricity distribution network at the bus station or a (new) dedicated connection for the induction charging ground station. The locations of other services (communications, drainage, gas mains etc.) must also be well understood and this could additionally require site-specific topographical surveys to ensure the proposed site of the induction charging ground station is clear of obstructions; and
- Structural suitability. The suitability of a given location for the installation of a wireless induction charging ground station is dependent on a number of site-specific features, such as cantilevered slabs (rather than solid earth foundations), adjacent underground ticket halls and the presence of existing services (see section above).

After consideration of these issues / factors, the next step is to design and install the ground stations, the process for which is described in a TfL internal standard – see section 5.4: Wireless Bus Charging Infrastructure Installation Guidelines.

## 5.3 Service Adjustment for Bus Routes Operating Inductively Charged Vehicles

To undertake a trial of inductively charged vehicles, in which the charging infrastructure is located in a controlled environment such as a bus station or garage, a key consideration will be the provision of adequate charging time being built into the given route’s schedule to support the vehicle’s duty cycle.

To optimize the amount of time the EV bus spends engaging with the charging infrastructure, while minimizing the impact on the bus service (from the customers’ perspective), there are a number of methods that can be explored. These options will depend on whether the intention is to run a route’s entire service using inductively charged buses, or, alternatively, run a service in which a small number of inductively-charged vehicles are run as a supplement, or as part of, a majority diesel bus service.

In this document an outline of the options that are available is provided.

### 5.3.1 Key to terms used:

**Run time** – This refers to the duration of either the outbound or return journey run of a particular route, expressed in minutes.

**Stand time** – This refers to the amount of time the vehicle sits at a bus stand after the end of one run and before the beginning of another. Essentially a rest period following the outbound and/or return run of the cycle, this is also referred to as layover time and is expressed in minutes. This is also the period that will be used for the vehicles to engage with the charging infrastructure.

**Cycle time** - Includes both outbound and return Run times and the Stand times at each end of the route. This total is expressed in terms of minutes.

**Headway** - Also in minutes, denotes the frequency that the bus route is serviced. If the route is operated using only a single stand at either end of the route, this figure cannot be significantly less than the Stand time values at those stands.

**PVR** - The number of buses required to service a route at any given time. This figure is calculated by dividing the total duration of the **Cycle time** by the **Headway** value:

**Cycle time / Headway = PVR**

Therefore, any adjustments made to the **Run times, Stand times** or **Headway** will affect the **PVR,** and vice versa.

### 5.3.2 To run a service entirely equipped with EV buses *or* with EV buses supplementary to/as part of a diesel bus service

To begin with, we shall look at a sample route. Table 29 below provides a summary of the current route cycle schedule for bus route number 69, which runs between Walthamstow Central Bus Station and Canning Town Bus Station, both in East London. TfL has selected this route for analysis due to its suitability for running an inductively charged bus trial.

As can be seen from the Table 27, the Stand time varies from as little as seven minutes during peak weekday periods to 13 minutes on a Sunday cycle, with the corresponding Headway value being between these two. As discussed, it is important that the Stand time is increased where possible to maximise the vehicles' engagement with the charging infrastructure at each end of the route.

| **Current** | **Period 1** | **Period 2** | **Period 3** | **Period 4** | **Period 5** | **Period 6** |
|---|---|---|---|---|---|---|
| | **AM** | **Mid** | **PM** | **Evening** | **Sat** | **Sun** |
| | **8.00** | **12.00** | **17.00** | **20.00** | **13.00** | **13.00** |
| **Run time A to B** | 53 | 52 | 60 | 44 | 57 | 50 |
| **Run time B to A** | 55 | 55 | 62 | 46 | 60 | 52 |
| Total | 108 | 107 | 122 | 90 | 117 | 102 |
| **Stand time at B** | 10 | 12 | 10 | 8 | 10 | 8 |
| **Stand time at A** | 7 | 7 | 7 | 11 | 10 | 13 |
| Total | 17 | 19 | 17 | 19 | 20 | 21 |
| **Cycle time** | 125 | 126 | 139 | 109 | 137 | 123 |
| Headway (mins) | 9 | 8 | 8.5 | 8.5 | 7.33 | 11.67 |
| **PVR** | 14 | 16 | 17 | 13 | 19 | 11 |

Table 29 Stand Time

Table 30 shows how far the stand times can be extended if the PVR is increased by only one bus per period. Depending on the period, the Stand time can be increased by 45% to as much as 82%. However, if the Headway time is to remain unchanged, it would be necessary to allocate two stands at the end of each leg to accommodate a second bus arriving at the end of a run while the preceding bus is *in situ*, as a consequence of the Stand times far exceeding the Headway time.

| **Proposed 1** | **Period 1** | **Period 2** | **Period 3** | **Period 4** | **Period 5** | **Period 6** |
|---|---|---|---|---|---|---|
| | **AM** | **Mid** | **PM** | **Evening** | **Sat** | **Sun** |
| | **8.00** | **12.00** | **17.00** | **20.00** | **13.00** | **13.00** |
| **Run time A to B** | 53 | 52 | 60 | 44 | 57 | 50 |
| **Run time B to A** | 55 | 55 | 62 | 46 | 60 | 52 |
| Total | 108 | 107 | 122 | 90 | 117 | 102 |
| **Stand time at B** | 15 | 18 | 16 | 15 | 15 | 18 |
| **Stand time at A** | 12 | 11 | 15 | 14 | 14 | 20 |
| Total | 27 | 29 | 31 | 29 | 29 | 38 |
| **Cycle time** | 135 | 136 | 153 | 119 | 146 | 140 |
| Headway (mins) | 9 | 8 | 8.5 | 8.5 | 7.33 | 11.67 |
| **PVR** | 15 | 17 | 18 | 14 | 20 | 12 |

Table 30 Stand time in case the PVR is increased by only one bus

If increasing the stand allowance is not feasible, then it would be necessary for the Headway value to be increased to match the Stand time allocation, in order to avoid congestion at the end of each run. This would have consequences operationally as this will in turn reduce the number of vehicles required by the PVR, thus reducing the frequency of the service, as illustrated by Table 31. However such an adjustment may be mitigated by the use of higher capacity vehicles on the PVR.

| **Proposed 3** | Period 1 | Period 2 | Period 3 | Period 4 | Period 5 | Period 6 |
|---|---|---|---|---|---|---|
| | AM | Mid | PM | Evening | Sat | Sun |
| | 8.00 | 12.00 | 17.00 | 20.00 | 13.00 | 13.00 |
| **Run time A to B** | 53 | 52 | 60 | 44 | 57 | 50 |
| **Run time B to A** | 55 | 55 | 62 | 46 | 60 | 52 |
| Total | 108 | 107 | 122 | 90 | 117 | 102 |
| **Stand time at B** | 15 | 18 | 16 | 15 | 15 | 18 |
| **Stand time at A** | 12 | 11 | 15 | 14 | 14 | 20 |
| Total | 27 | 29 | 31 | 29 | 29 | 38 |
| **Cycle time** | 135 | 136 | 153 | 119 | 146 | 140 |
| Headway (mins) | 15 | 18 | 16 | 14 | 14 | 18 |
| **PVR** | 9 | 8 | 10 | 9 | 11 | 8 |

Table 31 increasing of headway value to avoid congestion

### 5.3.3 To run a service with EV buses supplementary to/as part of a diesel bus service

Alternatively, it is feasible to adjust a service to accommodate a small number of EV buses within a PVR made up largely of diesel buses by increasing the Stand time for the EV buses only, keeping the Stand time of the diesel buses to the original schedule.

This would be achievable by allowing each diesel bus that follows an EV bus to move past, or ‘leapfrog’, the EV bus in the running order when the EV bus is on the stand, allowing the EV bus to benefit from increased Stand time. The amount of times a diesel bus would be required to leapfrog an EV bus during its duty cycle would depend on the ratio of EV to diesel buses; dividing the amount of diesel buses by the amount of EV buses will provide a figure for how many stand visits each of the EV buses will make once each of the diesel buses in the PVR have made at least one leapfrog manoeuvre. E.g., if you have eight diesel buses and two EV buses, by the time the EV buses have completed four runs each diesel bus would have completed one leapfrog manoeuvre.

The above is assuming that at the end of each run there are two stand spaces available; one for the EV bus, and one for the diesel bus. If there is only one stand space available, then it would be necessary for each diesel bus to miss a Stand time period, and complete two runs (e.g the outbound and return runs) consecutively without a break every time they leapfrog an EV bus on the stand. This would obviously have operational consequences that would require adjustments to the route’s service control strategy. However, these should be easier to manage during this trial due to both ends of the run being located at bus stations where operational support would be readily available.

### 5.3.4 Other considerations

- A 10% to 12% ‘engineering float’ of vehicles would be required above the PVR to act as a fail safe should any of the vehicles suffer breakdowns or accidents, mitigating disruption to the service should such issues arise.
- For any of the above strategies to trialed, analysis of traffic flows through the selected bus stations would be required to quantify the availability and usage of bus stands and to assess the impact that an inductively charged vehicle may have on concurrent operations/ the wider fleet.

- Consideration should be given to scheduling a trial at the commencement of a new route contract; this would provide greatest flexibility when undertaking adjustments to the schedule and PVR, as well as mitigate any cost concerns a bus operating company may have.

## 5.4 Wireless Bus Charging Infrastructure Installation Guidelines

### 5.4.1 Introduction

The purpose of this chapter is to provide general guidance on the process of the design and installation of wireless charging infrastructure in bus premises.

The report will aim to provide a step by step process from the inception stage through to project completion. This report contains the following;

- The Concept
- Site Investigations/ Surveys/ Enquiries
- Design
- Installation
- Commissioning

It is emphasised that each site will have to be assessed and the general design made site specific.

### 5.4.2 The Concept (Based on Conductix Wampfler's Technology)

The use of wireless technology to power on road transport is not a new concept and the use of hybrid and/ or fully electric vehicles have been in circulation in various countries for many years. Figure 17 below details just a few examples where the technology has been used elsewhere in Europe.

Genoa, Italy I since 2002

**Type of vehicles / Manufacturer:**
Electric buses 120 kW Motor / EcoPower Technology s.r.l.
**Energy storage:**
Lead-Gel battery 180 Ah
**Vehicle weight:** Empty approx. 7,5 t / Max. approx. 10,2 t
**Charging power per load point:** 60 kW
**Number of vehicles:** 8

Turin, Italy I since 2003

**Type of vehicles / Manufacturer:**
Electric buses 120 kW Motor / EcoPower Technology s.r.l.
**Energy storage:** Lead-Gel battery 180 Ah
**Capacity / Length of vehicle:** 15 seats + 22 stances / 7,5 m
**Vehicle weight:** Empty approx. 7,5 t / Max. approx. 10,2 t
**Charging power per load point:** 60 kW
**Number of vehicles:** 23
**Daily road performance:** Up to 200 km

Den Bosch, Netherlands I since 2012

**Type of vehicle / Manufacturer:**
Volvo 7700 (converted to electrical) / Bluekens Truck & Bus BV
**Energy storage:**
120 kWh LiFePO$_4$ batteries
**Vehicle weight:** 12,0 t (empty weight)
**Charging power per load point:**
120 kWh (2 modules of 60 kW)
**Number of vehicles:** 1
**Daily road performance:** Approx. 289 km

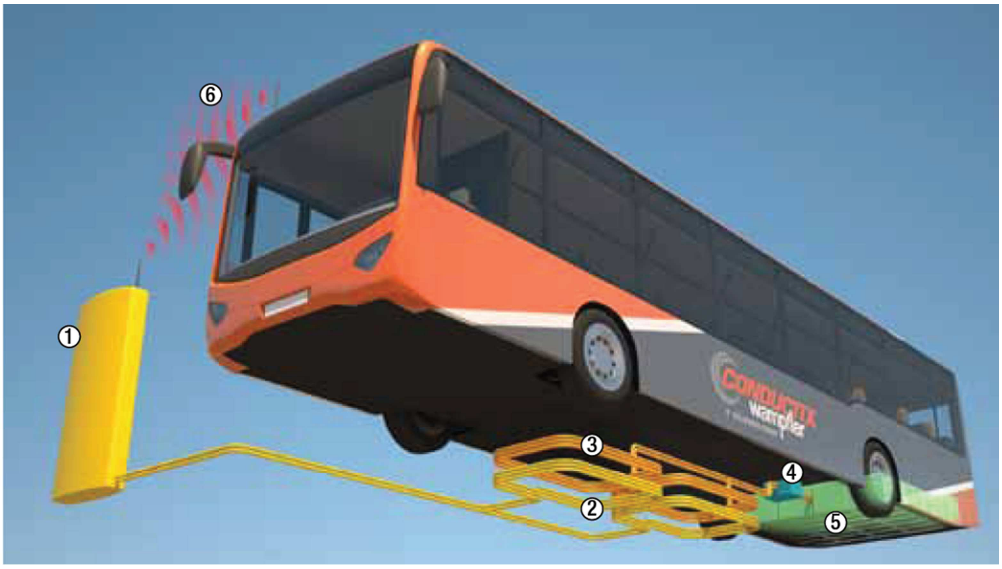
Figure 17 Existing schemes (information supplied courtesy of Conductix Wampfler)

One of the greatest issues faced in the past with a fully electric bus has been the size and weight of the battery in order to power the vehicle and the limited range it can travel until it requires to be recharged. However, technological advancements have enabled developers to reduce the battery size and weight, resulting in a fully electric bus being more comparable in weight to that of a standard bus, without impacting on travel distances.

As the title suggests the difference between wireless inductive charging and more conventional systems such as conductive or plugged systems is that the system does not require the use of plugs and is therefore, completely wireless.

The system works by electro-magnetic currents fed between two main components. The first component is the primary transmitter coil which is located in an in-ground module/ charging pad and is connected to the local electricity grid via an in-feed converter and the second component is the secondary receiver coil located in the floor of the bus.

The charging process only begins once the wireless infrastructure has identified that the bus has stopped over the charging pad via a communication system. The charging process only begins when the both the transmitter coils and receiver coils are in align and therefore, accessibility over the charging unit is key to establishing a successful charge.



1. Track supply.
2. Primary Coil.
3. Secondary Coil.
4. Rectifier.
5. Battery.
6. Communication System.

In charging mode the secondary coil located on the bus lowers to about 40mm above the ground level. Once lowered charging commences automatically via an electro-magnetic current fed between the primary transmitter coils located in the charging pad on the ground and the secondary receiver coils located on the bus/ vehicle *(Refer to section 5.4.4.1 of this document which will describe the equipment used in greater detail).*

Due to the close proximity to the charging plate there is very little loss of current between both the primary and secondary coils and any stray electro-magnetic fields remain restricted to the immediate vicinity of the coil.

When not in activation the charging pads lay dormant therefore, making it completely safe for pedestrians to walk across.

The fact that the system is wireless helps alleviate many of the operational issues faced with a more conventional system as it does not require the user to exit the vehicle and plug it into the charging point.

As the cables and charging components are located underground this helps to prevent vandalism and the build up of dirt, therefore lowering maintenance costs.

### 5.4.3 Site Investigations/ Surveys/ Enquiries

Once a site has been identified as a possible location where wireless charging infrastructure could be installed, a number of checks can be carried out to ensure the suitability of its location both physically and operationally prior to any design and construction work taking place.

The site should be reviewed in terms of its build-ability and the following question should be asked:

*Can the wireless infrastructure be physically installed in this location and can the bus access the charging unit to ensure a successful charge?*

In order to answer this question the following can be carried out;

(a) *Initial Site visit/ Investigation.*

(b) *Locate a potential power source.*

(c) *Obtain underground utility records.*

(d) *Obtain details of any below ground structures, i.e. London Underground Infrastructure.*

(e) *Obtain an accurate plan of the site, i.e. Topographical Survey.*

(f) *Obtain details of current stop/ standing arrangements (if located inside an operational bus station).*

All of the above can be carried out fairly quickly and will help in deciding whether it is feasible to install the wireless charging infrastructure in this location.

#### 5.4.3.1 Site Visit/Investigation

The initial site visit will be a review of the site to see whether there are any practical locations where a wireless charging unit can be installed. There will be a number of unknowns at this stage but it will give you an opportunity to determine whether it is feasible to install wireless charging infrastructure at a potential site. To help determine whether a site is feasible the following should be considered;

- The existing layout.
- The location of the existing power supply.
- Physical constraints, i.e. location of existing services, street furniture, vegetation, permanent structures etc...
- Operational constraints, i.e. stop/ standing arrangements.

#### 5.4.3.2 Locating a potential power source

Although, the initial investigation will look at potential locations, the proposed location will largely depend on whether a power source can be easily obtained.

Most potential sites should have at least one of the following where power can be sourced;

- A supply taken from the existing station.
- A supply taken from the local DNO .

Most off highway bus premises will have an existing power source and an assessment should be made as to whether or not there is enough capacity for the new infrastructure to be fed from this source.
The assessment should be carried out by an approved electrical contractor who should provide a report on their findings.

If the existing distribution board is able to take the additional load then a direct connection should be feasible.

If the assessment finds that the existing supply to the off highway facility is unable to take the additional power increase then the local DNO should be contacted.

When contacting the local DNO it is likely that you will have two options available;

- Option 1: Apply for an upgrade to the existing supply.
- Option 2: Apply for a new separate connection.

In determining which is the best option for your scheme will largely depend on the outcome of the initial electrical assessment and whether any issues have been identified with the existing supply which may cause the system to trip/ fail.

The location of the proposed infrastructure in relation to either the existing distribution board or the DNO service located within the public highway will also prove decisive as this will have a huge impact on the overall construction cost.

#### 5.4.3.3 Obtaining underground utility records

For on highway records details of existing statutory undertaker plant can be obtained directly from the statutory authorities relevant to the area of your works. There are five main types of underground utilities which should be obtained. They are as follows;

- Drainage (Foul, Surface and Combined Water)
- Water
- Gas
- Electricity
- Telecommunications

Which companies to contact will largely depend on the area where your works are proposed to take place.

For off highway/ private land sites if records can't be obtained from the free holder then the services of a specialised surveying company should be considered.

There is likely to be a significant cost involved with appointing a specialist surveying company to carry out a utility survey and therefore, careful consideration should be made as to what stage you require these to be carried out.

##### 5.4.3.3.1 Types of Underground Services Surveys

When appointing the services of a company to carry out underground utility surveys it is important to realise that there are four types of survey available.

(a) Record information: Underground service information to be taken from Statutory or other Authorities' record drawings and plotted to agree as closely as possible with surveyed surface features.
(b) Direct visual surveys: Accessible inspection chamber covers should be lifted where permissible and services positively identified.
(c) Direct visual surveys supplemented by record drawings: Accessible inspection chamber covers should be lifted where permissible and services positively identified. Routes of services between access points to be taken from record drawings and plotted to agree as closely as possible with surveyed surface features and trench scars where obvious.
(d) Full investigation including electronic tracing: Services to be fully investigated by visual survey supplemented by electronic or other tracing of inaccessible routes.

##### 5.4.3.3.2 Detail of Survey Required

When having a survey carried out it is important to ensure that the correct level of detail is obtained. The following specifies the features and the level of information required.

Drainage

- All drainage, including minor connections
- Cover levels
- Invert levels, including drop pipes
- Pipe sizes
- Direction of flow
- Cesspits, septic tanks, interceptors (identify only)
- Pumping stations and pumping mains

Water

- Pipe sizes
- Approximate depth
- Minor connections to buildings, standpipes, etc.
- Pipe material

Gas

- Pipe sizes
- Approximate depth
- Pipe material
- Pressure category: low, medium or high

Electricity

- Cable voltage: low or high
- Approximate depth

Telecommunications

- Number and sizes of duct
- Approximate depth
- Identification of ownership

#### 5.4.3.4 Obtain details of any below ground structures

In certain locations there may be evidence of an existing sub-surface structure adjacent to the area where you plan to carry out your works. The owner of the structure should be contacted prior to any works taking place to ensure that your proposed works will not affect the structure below.

The depth of this structure will have a significant impact on whether or not you can carry out the construction of the wireless charging infrastructure.

#### 5.4.3.5 Obtain an accurate plan of the site (Topographical Survey)

The accessibility of the bus into the proposed charging location is essential in ensuring that a successful charge can take place. The accuracy of the existing layout is essential as it will help determine whether or not any works are required to ensure that the bus can stop directly over the charging unit. Therefore, an accurate plan of the existing site should be obtained.

The most common way of obtaining an accurate site plan is in the form of a topographical survey. The purpose of the survey is to gather accurate data/ information about the features of a site. The type of features a topographical survey would normally gather includes determining the accurate positions of the following;

- Planimetric buildings/ structures.
- Temporary/ mobile buildings.
- Visible boundary features, i.e. walls, fences and hedges.
- Roads, tracks, footways and paths.
- Street furniture.
- Statutory Authorities' plant and service covers where visible.
- Changes of surface.
- Isolated trees/ wooded areas/ limits of vegetation.
- Private gardens or grounds (off-site areas).
- Water features.
- Earth works.
- Railway features with arranged access.

### 5.4.3.6 Obtain details of current stop/ standing arrangements (only relevant to operational bus stations or where there is a designated stop/ standing arrangement)

The existing operational use of a bus station needs to be taken into consideration when considering a potential location. The introduction of any additional services into a station is likely to have a huge impact to the station operationally and therefore, liaison with the relevant bus station manager at an early stage is critical.

When liaising with the relevant bus station contact it would be best to have a couple of outline design options available showing where the system can be physically built, as a result of the information gathered in sections 5.4.3.1 to 5.4.3.5 of this document.

It should be noted that the preferred location build-ability wise may not be the best location operationally and therefore, a compromise is likely to be needed to ensure that wireless infrastructure can be installed within the station identified.

## 5.4.4 Design

Once the results of the initial investigations, surveys and/ or enquiries have been gathered, the preferred location for the wireless charging infrastructure can start to be established. The results will help identify physical build-ability constraints and therefore, you can start to look in greater detail about the locations available within the extents of the site where the system can be built.

When considering a potential location there are a number of factors which need to be taken into consideration. These are as follows;

- The Equipment.
- Space Requirements, i.e. is there enough room for the infrastructure equipment to be installed.
- Accessibility, i.e. can the bus pull directly over the charging unit.
- Construction Impact.
- Future Maintenance Considerations, i.e. if the equipment needs to be maintained what operational impact will this have on the station/ surrounding area.
- Crime and Disorder, i.e. does the proposed location have a history of crime and disorder. If so the equipment will need to be located in a secure/ safe place or failing that properly protected.
- Operational Constraints. (As discussed in paragraph 5.4.3.6).
- Potential Implications on Cost.
- Consultation.
- CDM regulations.

The majority of the above should already have been established as a result of the initial investigations and enquires as described in section 5.4.3 of this report. However, this section will help explain in greater detail the type of equipment wishing to be installed and hopefully help highlight the key elements when establishing a location.

### 5.4.4.1 The Equipment (Details courtesy of Conductix Wampfler)

#### 5.4.4.1.1 On road charging components

There are essentially four primary pieces of on road equipment which a typical 60 kW charging system comprises of. They are;

- The monitoring unit
- The cooling system
- The in-ground module
- The charge module

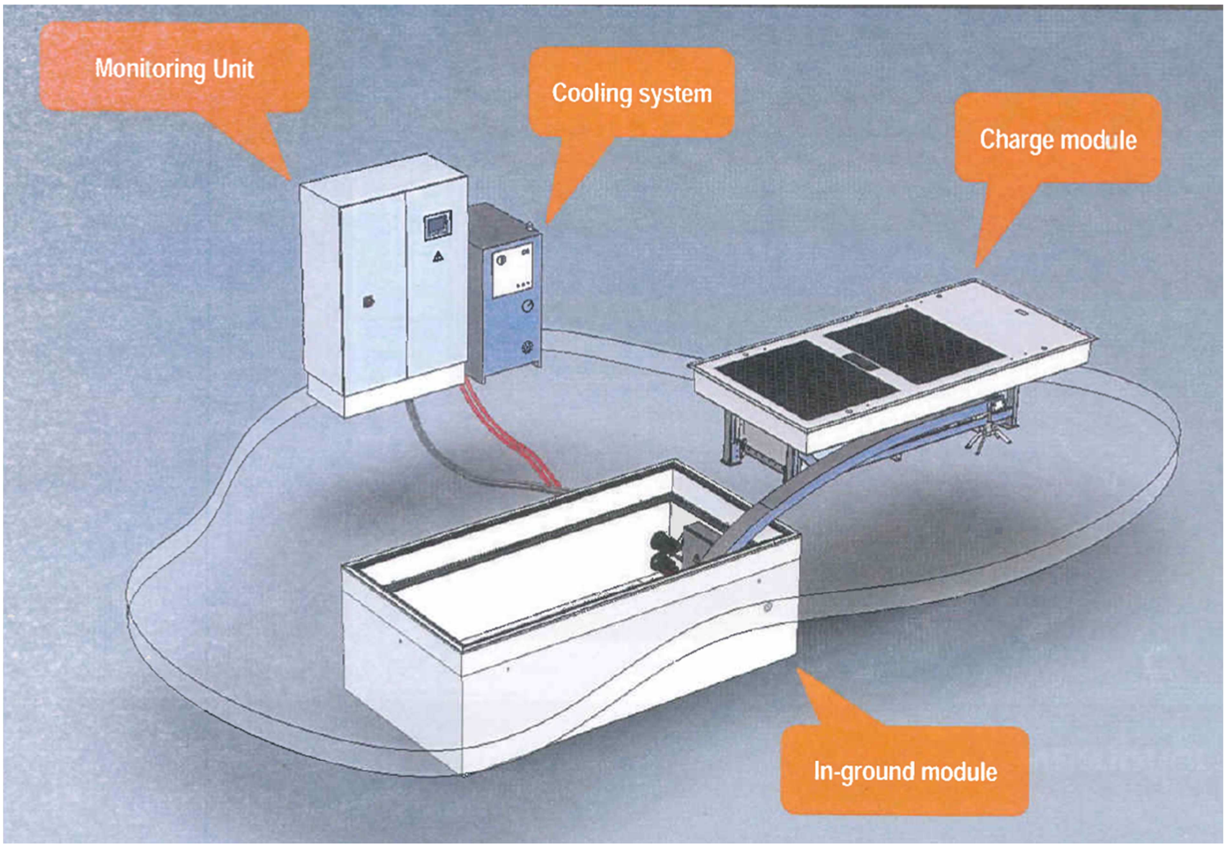


Figure 18 Primary (on road) components (Image courtesy of Conductix Wampfler)

The monitoring unit allows for the data recorded during the charge process to be obtained without the need to open or de-install the charge module. The type and size of the monitoring unit varies however, it should be noted that the monitoring unit will be installed on the road side and will therefore, need adequate protection.

The cooling system helps to ensure the system does not over heat when in use. As per the monitoring unit the cooling system varies in size and type and it will also be installed on the road side.

The in-ground module is a pre-fabricated steel reinforced concrete structure approximately 3.1m x 1.55m x 1.02m in size (externally). The structure weighs approximately 5.300 kg and has four lifting points, two located on either length side, to enable the unit to be picked up and put into place by the use of an appropriate lifting aid. The unit also has two entry points in the form of cable bushings which will enable the proposed ducting from the monitoring and cooling units to be connected to the module allowing for the proposed cabling from these units to be fed through.

The charge module is effectively the active part of the system and it sits inside of the in-ground module once it is in place resulting in the top surface to sit flush within the road way. The charge module comprises of the power electronics in the lower area and two primary coils on its top surface. The module consists of two charge pads each with an output of approximately 30 kW, meaning each module has an output of approximately 60 kW in total.

### 5.4.4.1.2 Vehicle charging components

In addition to the on road equipment there are also components located on the vehicle. These components are known as the secondary components to the system and are as follows;

- The Pickup 30kW
- The Rectifier 30kW
- The remote battery charging interface (RBCI)
- The Communication module

### F-Pickup

| | |
|---|---|
| **Nominal power:** | 30 kW at 100% Duty Cycle |
| **Nominal voltage:** | 300 V (alternatively: 600 V / 50 A) |
| **Output current:** | 100 A (alternatively: 600 V / 50 A) |
| **Dimensions:** | 1025 x 875 x 60 mm |
| **Lowering required:** | 40 mm air gap to surface of Charge Pad |

### Rectifier 30 kW

| | |
|---|---|
| **Nominal power:** | 30 kW at 100% Duty Cycle |
| **Nominal voltage:** | 300 V (alternatively: 600 V / 50 A) |
| **Output current:** | 100 A (alternatively: 600 V / 50 A) |
| **Dimensions:** | 600 x 310 x 111 mm |

### Remote Battery Charging Interface (RBCI)

| | |
|---|---|
| **Dimensions:** | 362 x 125 x 82 mm |
| **Output voltage:** | +/- 12 V DC / 5 V DC |
| **Interface:** | CAN, other on request<br>Different I/O's |

### Communication Module (custom)

| | |
|---|---|
| **Basic options:** | Radio<br>Inductive<br>etc. |

Figure 19 Secondary (vehicle) components (Information courtesy of Conductix Wampfler)

The Pickup collects electro-magnetic frequency released from the primary coil located in the charge module in the form of an induced current. The number of pickups required depends on the number of primary coils as one pickup pairs with one primary coil. Therefore, on a 60Kw system 2 no. pickups will be required.

The rectifier helps to convert the electromagnetic frequency to a charge current which can then be fed into the onboard batteries of the vehicle.

The RBCI is the link between the charge module and the BMS. It is intended to sensor and control the battery conditions.

The communication module helps to manage the charging process by providing a closed communication loop between the vehicle and charging infrastructure.

#### 5.4.4.2 Space Requirements

Due to the size of the infrastructure, the location of where it can be installed needs to be taken into consideration.

As stated in paragraph 5.4.4.1.2 both the monitoring unit and cooling system vary in size and type. However as a guide, a road size space of approximately 1.5m in width and approximately 3m in length should be considered enough room for both units to sit side by side.

In addition to this, if it is decided that the system should run from its own power source obtained from the local DNOs service, then the space for a feeder pillar will also need to be considered. As per the monitoring unit and cooling system the type of feeder pillar required varies in size and type and it is likely to be the decision of the DNO stating what the requirement is. The feeder pillar can sit next to the road side equipment and therefore as a guide, an additional space requirement of 0.4mto 0.8m in width and between 0.5m to 1.5m in length should normally be considered.

The in ground module itself is a large piece of equipment however depending on its orientation it should be able to fit within a standard width (3.0m) bus stand/ stop.

As stated in section 5.4.4.1, the equipment described is for a typical 60kW charging system. For a 120kW system the amount of equipment required will double and therefore if a 60kW system is initially installed the space required for future expansion to a 120kW may also need to be considered.

#### 5.4.4.3 Accessibility

As stated previously in the document in order for a successful charge to take place both the transmitter coils located in the charge pad and the receiver coils located on the bus need to align.

In order for this to take place the bus needs enough entrance room leading up to the charge pad to ensure it aligns properly. Therefore, the charge module will be ideally located in places where there are no obstructions leading up to it.

#### 5.4.4.4 Construction Impact

When considering a location, you will also need to take into account how the project will be built and what impact it will have on its surroundings. For example in a bus station where space is of a premium the location you pick may require the bus station to be partially or fully closed whilst it is installed.

Traffic and pedestrian management will also need to be considered and adequately designed, installed and maintained to ensure those who are not part of the works are segregated from it.

#### 5.4.4.5 Future Maintenance Considerations

Maintenance and repair is essential to ensure the longevity of the system. When considering a location it is important to take this into account, to ensure that any future maintenance/ repair does not have any adverse impact on its surroundings. This is particularly important in bus stations where there is very limited space and maintaining the bus service and is essential.

One thing to consider is the orientation of the charge module. When the charge module is opened it lifts out to its full length. Therefore, when opened the charge module will be approximately 6.0m in length. In very narrow bus stations for example, if the charge module was placed vertically within a stand/ stop it could essentially close the entire bus station whilst work is carried out. In this instance it would be better to orientate the module so it sits horizontally within the stand/ stop, helping to minimise disruption.

#### 5.4.4.6 Crime and Disorder

Public crime and disorder is unfortunately part of society and therefore, the safety and security of the road side equipment needs to be taken into account.

Ideally you would want to place the equipment away from any areas where the general public are likely to pass/ congregate but in on highway locations this will be virtually impossible. Therefore, a protective housing should be considered which can be locked and accessed only by authorised personnel.

#### 5.4.4.7 Potential Implications on Cost

Major cost differences involved within the installation of the infrastructure is likely to come from the work involved with the supply and lay of the ducting from the power source to the wireless infrastructure and subsequent reinstatement of the trench.

Ideally the infrastructure should be installed as close to the original power source as possible as this will help limit the amount of work involved and help keep the installation costs down.

#### 5.4.4.8 Consultation

Once a design has been established, consultation with the relevant stakeholders will be required to ensure that all those who could be affected by the works are fully informed of the issues regarding the potential build. A typical list of those who may be concerned with the proposals are as follows;

- Land owner (if located on private land).
- Local Authority/ Council (if located on the public highway).
- Site Operator (if located on a bus station/ garage).
- Safety Team/ representative (internal/ external).
- Design Department (internal/ external).
- Emergency services.
- Transportation services.
- Local residents (if located adjacent to private residential properties).
- Local retailers (if located adjacent to shops/ kiosks/ stalls, etc).
- Other.

#### 5.4.4.9 Construction regulations

Everyone involved in site work has health and safety responsibilities. Whether you are a client, designer, principal contractor or sub contractor under the project it is important to ensure that you carry out your duties under the latest local construction regulations.

Ensuring that working conditions prior to the start of work and that the proposed work does not adversely put others at risk requires sufficient planning and organisation. Ideally all risks should be identified prior to the start of works and where possible designed out. Where risks can’t be designed out a plan and/ or method statement for carrying out the work safely will be required.

# 6 Conclusion

In this document different analysis for wireless/ inductive charging has been carried out regarding the grid management, simulating the effect of different locations of charging station and evaluating the economic impact for installing of the charging stations, and social environment of the spread of inductive charging.

As a preliminary result, it has been conducted a comparison of the estimation of the energy consumption for different types of vehicles (EV or ICE) on four driving cycles.

The results of the study for the evaluation of the effect of the positions for charging stations are obtained simulating a typical urban distribution network with a load flow software and considering a steady power of 50 kW for each charging stations.

The first part of the study is focused on the MV network, in which the best and worst locations for the charging stations have been determined to able to study the effects. The results show that the position does not influence the grid, since the voltage drops are in the admissible range as for European standard regulation (EN 50160[1]). Therefore it is possible to connect the charging stations to any substation, with voltage levels always above the values required by regulations. The same results have been obtained considering a 10% overload in the grid.

The second part of the simulation considers the impact of the charging stations on the existing LV network. In this case the most vulnerable LV grid has been chosen, the one fed by the transformation centre located at the largest distance from the substation, and it has been analysed under imbalanced loads, both with design loads and under a 10% overload. In all cases the voltage at the end of the line used to feed the charger remains within acceptable limits.

Finally, the use of a dedicated feeder for the charger has been considered. As in the previous case, this feeder has been connected to the LV side of the transformation centre situated at the largest distance from the main substation. Simulations have shown that it is possible to feed a charger situated up to 800 m away from the transformer while keeping voltage at the charger end of the feeder above the minimum required by regulations.

In addition to this simulation, the evaluation of the cost has been performed to understand how much a massive installation of charging stations could cost in a real power grid. The study has been conducted considering the city of Firenze, using a load flow software and a parametric analysis.

A first part of study addressees the cost for the infrastructure to guarantee a full public service with the buses in Firenze: this cost is made up by the costs for the electrical components, for the cables and for the civil works and operators; this cost corresponds to the cost from the substation to charging station, in charge of the distributor. Afterwards, this cost can be pinpointed in part to the distributor and in part to companies which require the installation. The results show that the grid in Firenze is enough strong to avoid excessive economic effort.

A second part of study considers the introduction of the charging stations to guarantee an electric taxi service. In this case the study has not been performed using a load flow but with a parametric analysis, based on an average distance, obtaining a rough value of the cost for the installation of the charging stations. Next analysis in further tasks will provide the correct value of this introduction.

As a last point of this document, the evaluation of the social – economical impact of the inductive charging shows a live interesting around this kind of EV charging technology. The guidelines will be applied in the real scenario and will indicate how to proceed upon confirming the bus premises and routes. The preliminary cost analysis compares the inductive buses vs conductive buses and ICE buses (Euro III and Euro V). As results the costs can be compared for inductive buses and ICE buses, but the benefits for the environment are doubtless greater. Moreover, inductive buses can replace the existing ICE buses, without any constraints for the range respect to the pure EV buses, which can be used for specific and limited routes.

# 7 References

[1] EN 50160 “Voltage characteristics of electricity supplied by public distribution networks”

[2] S. Steinhilber, P. Wells and S. Thankappan, "Socio-technical inertia: understanding the barriers to electric vehicles," *Energy policy,* vol. 60, September 2013.

[3] Y. Yamagata and H. Seya, "Simulating a future smart city: an integrated land use - energy model," *Applied Energy,* vol. 122, pp. 1466-1474, December 2013.

[4] N. P. W. Kempton, R. Guensler and V. Elango, "Electric vehicles: how much range is required for a day's driving?," Transportation research part C: emerging technologies, vol. 19, no. 6, pp. 1171-1184, December 2011.

[5] M. Metz and C. Doetsch, "Electric vehicles as flexible loads - a simulation approach using empirical mobility data," *Energy,* vol. 48, no. 1, pp. 369-374, December 2012.

[6] ATAF web site www.ATAF.net

# 8 Annex I – List of the buses main routes in Firenze

This Annex reports the list of the operating buses main routes in Firenze

Table 32 Buses main routes

| Route | Path lenght [km] | Average travel time [m] | Average parking time [m] |
|---|---|---|---|
| 1 Stazione SMN <=> Le Cure - Via Boccaccio/Via Faentina | 4.8 | 16 | 14 |
| 2 Stazione Palazzo Dei Congressi <=> Calenzano | 15.5 | 54 | 44 |
| 3 Cure <=> Nave A Rovezzano | 8.0 | 31 | 23 |
| 4 Piazza Unità Italiana - Poggetto - Piazza Unità Italiana | 9.2 | 35 | 26 |
| 5 Soffiano - Via del Filarete <=> Rifredi FS - Via de Gama | 13.5 | 42 | 39 |
| 6 Coverciano - Via Novelli <=> Ospedale Torregalli | 12 | 47 | 34 |
| 7 San Marco - Via La Pira <=> Fiesole | 7.5 | 20 | 22 |
| 8 Bagno a Ripoli - I Ponti <=> Ospedale Careggi | 11.1 | 39 | 32 |
| 10 San Marco - Via Dogana/Via Pacinotti <=> Settignano | 7.6 | 26 | 22 |
| 11 Salviatino <=> Due Strade | 9.9 | 44 | 29 |
| 12 Stazione SMN/St. Campo Marte <=> P. Michelangelo | 8.3 | 28 | 24 |
| 13 Stazione SMN <=> Piazzale Michelangelo/P. Ferrucci | 7.9 | 28 | 23 |
| 14 Il Girone/Ripa/Stazione Valfonda/Via Dogana/Viale Strozzi Mugnone <=> Careggi/Da Tolentino/Largo Alinari | 13.3 | 55 | 38 |
| 15 Scuola Russell - T1 De Andrè <=> Badia a Settimo | 8.1 | 25 | 23 |
| 17 Coverciano - Viale Verga <=> Via Boito/Parco Cascine | 9.5 | 43 | 28 |
| 19 San Marco - Stazione CM - San Marco | 5.1 | 20 | 15 |
| 20 Gignoro - Via Comparetti/San Marco - Via La Pira <=> Le Panche - Largo Caruso | 11.7 | 40 | 34 |
| 21 Via Pacinotti <=> Fiesole - La Querciola | 11.8 | 28 | 34 |
| 22 Piazza Santa Maria Maggiore <=> Novoli - Via Lippi e Macia | 5.5 | 29 | 16 |
| 23 Nave a Rovezzano/Sorgane <=> Firenze Nova - Nuovo Pignone | 13.4 | 57 | 40 |
| 24 Sorgane Piazza Rodolico <=> Grassina/Osteria Nuova | 10.8 | 29 | 23 |
| 25 San Marco - Via La Pira <=> Pian di San Bartolo/Pratolino | 8.9 | 23 | 26 |
| 26 Ospedale Torregalli <=> Badia A Settimo/San Colombano | 9 | 26 | 26 |
| 27 Casellina - Largo Spontini <=> Vingone - Largo San Zanobi | 8.8 | 40 | 26 |
| 28 Stazione Palazzo Congressi <=> Sesto Fiorentino - Volpaia | 11.9 | 35 | 34 |
| 29 Stazione Via Alamanni <=> Adige/Deposito Peretola/Motorizzazione Civile/Piazza Marconi/Ticino | 7.2 | 29 | 19 |
| 30 Ponte Alle Mosse/Stazione Via Alamanni <=> Campi | 14.4 | 45 | 40 |

| | | | |
|---|---|---|---|
| Bisenzio Galilei/Campo La Villa/Piazza Togliatti | | | |
| 31 San Marco - Via della Dogana <=> Grassina | 10.4 | 36 | 30 |
| 32 San Marco - Via della Dogana <=> Antella | 11.3 | 36 | 32 |
| 37 Porta S. Frediano/Palazzo Congressi <=> Tavarnuzze | 10.2 | 31 | 29 |
| 40 Dalmazia 05 <=> Incontri/La Lastra /Villa Cancelli | 3.5 | 10 | 12 |
| 41 Piazza Ferrucci <=> Galluzzo - Via Pietriboni | 8.8 | 23 | 26 |
| 42 Piazza della Calza <=> Marignolle | 3.4 | 8 | 10 |
| 44 Piazza della Francesca <=> Ugnano - Mantignano | 7.7 | 22 | 22 |
| 45 San Francesco <=> Caldine Nuove/La Querciola | 8.8 | 16 | 24 |
| 46 San Lorenzo a Greve/Soffiano - Via Starnina <=> Galluzzo | 6.3 | 16 | 19 |
| 47 Media Compiobbi/San Francesco <=> Il Girone | 12.9 | 25 | 38 |
| 48 Sorgane <=> Vallina/Villamagna | 10 | 27 | 32 |
| 49 Grassina <=> San Polo | 9.8 | 24 | 28 |
| 50 Piazza della Francesca - T1 Federiga <=> Cim. Soffiano | 1.6 | 8 | 5 |
| 56 Ospedale di Careggi <=> Piagge FS | 9.1 | 33 | 27 |
| 57 Stazione SMN <=> Sesto F.no - Viale Grasmci | 10.1 | 31 | 29 |
| 59 Rifredi FS - Via de Gama <=> Polo Scientifico Sesto | 6 | 15 | 17 |
| 60 T1 Cascine <=> Ospedale Careggi | 5.3 | 20 | 16 |
| 64 Sesto - Piazza V. Veneto <=> Sesto - Biblioteca Doccia | 4.5 | 12 | 13 |
| 66 Osmannoro - Via Pratese <=> Calenzano - Cimitero | 17.7 | 33 | 46 |
| 73 Lastra a Signa <=> Spazzavento/San Vincenzo a Torri | 14.4 | 35 | 42 |
| 76 Sesto - Piazza Vittorio Veneto <=> Sesto - Viale Togliatti | 2.9 | 11 | 8 |
| 77 T1 Federiga - La Casella - Canova - T1 Federiga | 5.9 | 19 | 17 |
| 78 T1 Federiga - Canova - La Casella - T1 Federiga | 6.7 | 19 | 19 |
| 83 Ospedale Torregalli/78° Reggimento <=> Porto Di Mezzo/Signa FS | 16 | 50 | 48 |
| 303 Piagge FS <=> Calenzano Centro | 19.5 | 47 | 56 |
| D Stazione - Galleria <=> Piazza Ferrucci | 5.9 | 31 | 17 |
| G San Marco - Via della Dogana <=> Palazzo Giustizia | 5.9 | 18 | 17 |
| M T1 Resistenza <=> Nuova Scuola Magistrati | 5.3 | 15 | 16 |

# 9 Annex II – List of the charging stations in Firenze (Use case public mobility)

This Annex reports the list of the charging stations in Firenze for a complete public mobility service.

| | | | | No of charging stations | | |
|---|---|---|---|---|---|---|
| Id | Place | Latitude | Longitude | Standard | Option 1 | Option 2 |
| 1 | Legri | 43,91406600 | 11,22411930 | 1 | 1 | 1 |
| 2 | Calenzano centro | 43,86361280 | 11,16688970 | 2 | 2 | 2 |
| 3 | Cimitero Calenzano | 43,86156300 | 11,16171410 | 2 | 2 | 2 |
| 4 | Calenzano | 43,86106570 | 11,16090070 | 4 | 3 | 3 |
| 5 | il rosi | 43,85725190 | 11,14014290 | 1 | 1 | 1 |
| 6 | Caponnetto | 43,84866720 | 11,16213410 | 1 | 1 | 1 |
| 7 | Caduti di Radio Cora | 43,84510680 | 11,26236570 | 1 | 1 | 1 |
| 8 | GKN | 43,84477100 | 11,14139400 | 1 | 1 | 1 |
| 9 | Manetti | 43,84387690 | 11,16917260 | 1 | 1 | 1 |
| 10 | Officine Galileo | 43,84241920 | 11,14937430 | 1 | 1 | 1 |
| 11 | La Querciola | 43,84134140 | 11,31963030 | 3 | 3 | 3 |
| 12 | Campi Bisenzio Galilei | 43,83935800 | 11,12928080 | 2 | 2 | 2 |
| 13 | Caldine Nuove | 43,83911280 | 11,30849240 | 1 | 1 | 1 |
| 14 | Volpaia | 43,83855000 | 11,17763860 | 2 | 2 | 2 |
| 15 | Biblioteca di doccia | 43,83655740 | 11,21446580 | 1 | 1 | 1 |
| 16 | Togliatti | 43,83701510 | 11,18234670 | 1 | 1 | 1 |
| 17 | Piazza Togliatti | 43,83440090 | 11,13150890 | 2 | 2 | 2 |
| 18 | Sesto Fiorentino Vittorio Veneto | 43,83191380 | 11,19952320 | 2 | 2 | 2 |
| 19 | Pian di San Bartolo | 43,83174070 | 11,28696330 | 2 | 2 | 2 |
| 20 | Sesto Fiorentino mille | 43,82863140 | 11,20702780 | 2 | 2 | 2 |
| 21 | Serpiolle | 43,82336880 | 11,25641410 | 1 | 1 | 1 |
| 22 | Campi di Bisenzio Verdi | 43,82148490 | 11,14115030 | 1 | 1 | 1 |
| 23 | Schiff | 43,82070280 | 11,19375810 | 2 | 1 | 1 |
| 24 | Careggi | 43,81299270 | 11,25105100 | 4 | 4 | 4 |
| 25 | Motorizzazione Civile | 43,81229120 | 11,16533900 | 1 | 1 | 1 |
| 26 | Sant'Angelo a Lecore | 43,81191400 | 11,08332650 | 2 | 1 | 1 |
| 27 | Ticino | 43,81083920 | 11,17842200 | 1 | 1 | 1 |
| 28 | Adige | 43,80886630 | 11,17618640 | 3 | 2 | 2 |
| 29 | Niccolo' da Tolentino | 43,80785650 | 11,24351110 | 4 | 3 | 3 |
| 30 | Piazza Marconi | 43,80768390 | 11,18482900 | 1 | 1 | 1 |
| 31 | Caruso | 43,80748280 | 11,23892210 | 4 | 4 | 3 |
| 32 | Fiesole - Vinandro Osteria | 43,80708340 | 11,29219310 | 5 | 4 | 4 |
| 33 | Villa Cancelli | 43,80703980 | 11,26116860 | 1 | 1 | 1 |
| 34 | La Lastra | 43,80656600 | 11,27439680 | 1 | 1 | 1 |
| 35 | Nuovo pignone | 43,80595390 | 11,22580230 | 6 | 5 | 5 |
| 36 | Patologia1 | 43,80310920 | 11,24563480 | 6 | 5 | 5 |
| 37 | Incontri | 43,80267420 | 11,25407170 | 1 | 1 | 1 |
| 38 | Patologia | 43,80247430 | 11,24549450 | 1 | 1 | 1 |
| 39 | Michelacci | 43,80191900 | 11,18967210 | 2 | 2 | 2 |
| 40 | Deposito peretola | 43,80118330 | 11,19064670 | 1 | 1 | 1 |
| 41 | Rifredi - Vasco de | 43,79999970 | 11,23576940 | 5 | 5 | 5 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Gama | | | | | |
| 42 | Salviati FS | 43,79937140 | 11,27518020 | 2 | 1 | 2 |
| 43 | Barsanti | 43,79673520 | 11,22551610 | 1 | 1 | 1 |
| 44 | Dalmazia | 43,79655270 | 11,24029900 | 3 | 3 | 3 |
| 45 | Lippi e Macia | 43,79565570 | 11,21774420 | 4 | 3 | 3 |
| 46 | San Donnino | 43,79543100 | 11,15062150 | 1 | 1 | 1 |
| 47 | Boccaccio | 43,79350200 | 11,27407640 | 2 | 1 | 1 |
| 48 | Piagge FS | 43,79012690 | 11,17233050 | 5 | 4 | 4 |
| 49 | Boito | 43,78809090 | 11,21882250 | 3 | 3 | 3 |
| 50 | Cure | 43,7866800 | 11,2690160 | 1 | 1 | 1 |
| 51 | Salviatino | 43,78488860 | 11,29402020 | 2 | 2 | 2 |
| 52 | Mulino biondi | 43,78452890 | 11,27309460 | 2 | 2 | 2 |
| 53 | Sosta del rosellino | 43,78299070 | 11,32160000 | 2 | 2 | 2 |
| 54 | Piovano Arlotto | 43,78222280 | 11,16801320 | 1 | 1 | 1 |
| 55 | Kennedy | 43,78108610 | 11,21862920 | 3 | 2 | 2 |
| 56 | Badia a settimo | 43,78044830 | 11,14612320 | 3 | 3 | 3 |
| 57 | Via della dogana | 43,7791710 | 11,2597491 | 7 | 6 | 5 |
| 58 | Porto di Mezzo | 43,77901030 | 11,07951760 | 2 | 2 | 1 |
| 59 | Verga | 43,77862180 | 11,29795800 | 5 | 4 | 4 |
| 60 | La Pira | 43,77824970 | 11,25965770 | 4 | 3 | 3 |
| 61 | San Colombano | 43,77810670 | 11,13606740 | 2 | 2 | 2 |
| 62 | Stazione via alamanni | 43,77806660 | 11,24544240 | 7 | 6 | 5 |
| 63 | Cascine | 43,77793640 | 11,23117850 | 2 | 1 | 2 |
| 64 | Stazione palazzo dei congressi | 43,77746030 | 11,24911500 | 9 | 8 | 7 |
| 65 | Stazione deposito bagagli | 43,77705220 | 11,24856330 | 6 | 5 | 5 |
| 66 | Stazione galleria | 43,77616150 | 11,24868710 | 2 | 1 | 1 |
| 67 | Stazione parcheggio | 43,77602890 | 11,24955500 | 4 | 3 | 3 |
| 68 | Il roseto | 43,77547620 | 11,36314430 | 1 | 1 | 1 |
| 69 | Novelli | 43,77543580 | 11,29446520 | 7 | 6 | 5 |
| 70 | Stazione Mercato centrale | 43,77506040 | 11,25067100 | 3 | 3 | 3 |
| 71 | Santa Maria Maggiore | 43,77304210 | 11,25278540 | 2 | 1 | 2 |
| 72 | La casella | 43,77219050 | 11,19055600 | 2 | 1 | 1 |
| 73 | di sotto | 43,77188050 | 11,10552750 | 2 | 1 | 2 |
| 74 | Foggini | 43,77174190 | 11,21220060 | 2 | 1 | 1 |
| 75 | Pier della Francesca | 43,77072610 | 11,21220220 | 2 | 2 | 2 |
| 76 | Comparetti | 43,76994880 | 11,30118160 | 4 | 3 | 3 |
| 77 | Il Girone | 43,76975810 | 11,34019690 | 4 | 3 | 3 |
| 78 | Cadorna | 43,76949550 | 11,10670010 | 3 | 3 | 3 |
| 79 | Ripa | 43,76756310 | 11,30924170 | 4 | 4 | 4 |
| 80 | Spontini | 43,76593570 | 11,17360100 | 3 | 2 | 2 |
| 81 | Via del filarete | 43,76572040 | 11,21396640 | 3 | 3 | 2 |
| 82 | Ferrucci | 43,76396010 | 11,27193190 | 3 | 3 | 3 |
| 83 | San Lorenzo a Greve | 43,76276140 | 11,19783610 | 1 | 1 | 1 |
| 84 | Pia.le Michelangelo | 43,76244720 | 11,26521930 | 4 | 3 | 3 |
| 85 | Cimitero di Soffiano | 43,76190910 | 11,21676150 | 1 | 1 | 1 |
| 86 | Villamagna | 43,76175440 | 11,38248920 | 1 | 1 | 1 |
| 87 | Nave a Rovezzano | 43,76156340 | 11,30688540 | 5 | 4 | 4 |
| 88 | San Giusto della Calza | 43,76134640 | 11,24215720 | 2 | 2 | 2 |
| 89 | Scuola magistrati | 43,76089000 | 11,13906170 | 2 | 2 | 2 |
| 90 | 68esimo reggimento | 43,75944680 | 11,18134560 | 5 | 5 | 5 |
| 91 | Ospedale torri galli | 43,75873500 | 11,20248530 | 10 | 9 | 9 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 92 | Bagnese | 43,75617410 | 11,19739160 | 1 | 1 | 1 |
| 93 | De Andrè | 43,75424050 | 11,17868060 | 2 | 2 | 2 |
| 94 | Sorgane Piazza Rodolico | 43,75417380 | 11,30610140 | 2 | 2 | 2 |
| 95 | Scuola Russell | 43,75370550 | 11,17977200 | 2 | 2 | 2 |
| 96 | I ponti | 43,75276700 | 11,31732850 | 3 | 2 | 2 |
| 97 | Sorgane | 43,75154650 | 11,30512630 | 7 | 6 | 6 |
| 98 | Scandicci | 43,75072760 | 11,17740630 | 1 | 1 | 1 |
| 99 | Scuola Rodari | 43,75404320 | 11,17906070 | 1 | 1 | 1 |
| 100 | Fermi | 43,75031100 | 11,24935000 | 1 | 1 | 1 |
| 101 | Marignolle | 43,74992750 | 11,21655700 | 1 | 1 | 1 |
| 102 | Malavolta | 43,74913860 | 11,23526230 | 2 | 2 | 2 |
| 103 | Pian dei Giullari | 43,74736640 | 11,25791360 | 1 | 1 | 1 |
| 104 | Vingone | 43,74609470 | 11,18071890 | 2 | 2 | 2 |
| 105 | Pietriboni | 43,73640130 | 11,22688920 | 2 | 2 | 1 |
| 106 | Osteria Nuova | 43,72994800 | 11,34663700 | 1 | 1 | 1 |
| 107 | Antella | 43,72649020 | 11,32203210 | 2 | 2 | 2 |
| 108 | Grassina | 43,72399150 | 11,29319890 | 4 | 4 | 4 |
| 109 | Slargo Lippi | 43,71782580 | 11,29272080 | 1 | 1 | 1 |
| 110 | Tavarnuzze primo maggio | 43,7087201 | 11,2126062 | 2 | 2 | 2 |
| 111 | Artigiani | 43,70542610 | 11,08460410 | 2 | 2 | 2 |
| 112 | San Vincenzo a Torri | 43,70019800 | 11,09625110 | 3 | 3 | 3 |
| 113 | San Polo | 43,67089780 | 11,35994150 | 1 | 1 | 1 |

| | | | |
|---|---|---|---|
| Total | 291 | 256 | 252 |
| Power required [kW] | 14550 | 12800 | 12600 |

# 10 Annex III – Analysis of power consumption in Firenze

## 10.1 Firenze city center bus service

In this paragraph the analysis for the bus lines operating in the city center of the city of Firenze is described. It is important to notice that this analysis is much more detailed than the one for the whole city because the characteristics of the city center service could allow an easiest implementation of the wireless recharge technology. The buses used for this are, in fact, already electric ones and this technology could be easily updated in order to have the pick-up device and the power electronics needed to have a bus wireless charging. Moreover any proposal that could reduce cost, dimension and maintenance of the battery will provide the basis to adopt and/or extend the green electric mobility.

The bus service within the Firenze city center is provided by three lines called C1, C2 and C3. Respectively, 5, 7 and 5 busses run at the same time to ensure the needed service level for the end user. Routes and stops are represented in Figure 20.

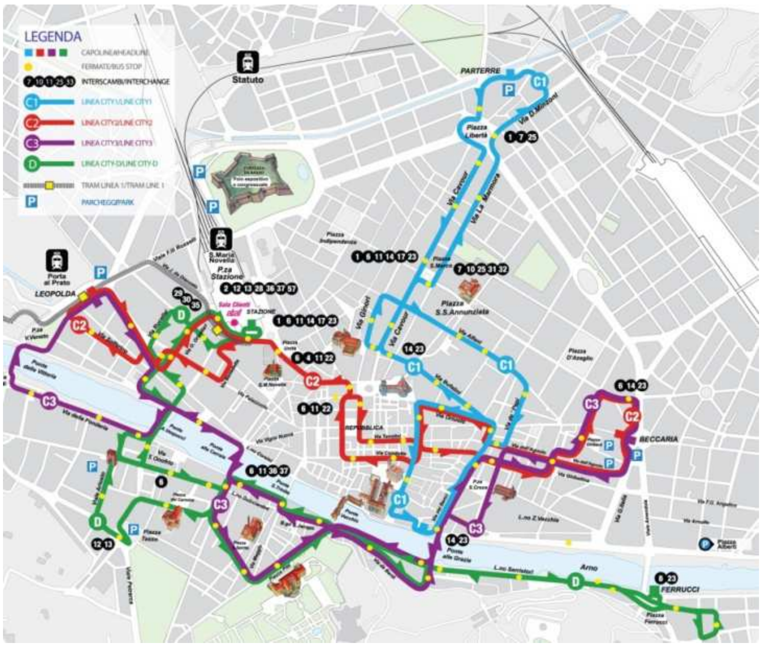


Figure 20 C1, C2 and C3 routes

Length and spatial disposition of the terminal stops of each of them are reported in Table 33 and Table 34 here below:

Table 33 Terminal stops geo-localization

| Station name | Lat. | Lon. |
|---|---|---|
| Parterre (C1) | 43.786291 | 11.264238 |
| Diaz (C1) | 43.767006 | 11.258306 |
| Leopolda (C2-C3) | 43.777231 | 11.238857 |
| Beccaria (C2-C3) | 43.770611 | 11.270305 |

Table 34 Lines' length

| Line | Total length [km]. |
|---|---|
| Line C1 | 7.7 |
| Line C2 | 9.2 |
| Line C3 | 10.9 |

It is interesting to notice that two terminal stops are in common with two lines, Leopolda stop and Beccaria stop. It will reduce the total cost of installation, but overlapping problems at the recharge stations have to be studied carefully to allow the necessary recharge time for each vehicle.

C1, C2 and C3 are not the only routes that serve the city center. In fact other lines cross this part of the city, but only these three have been taken into account within this part of the study because are the only exclusively dedicated to the city center district.

The division between city center and city urban areas is reported in Figure 21:

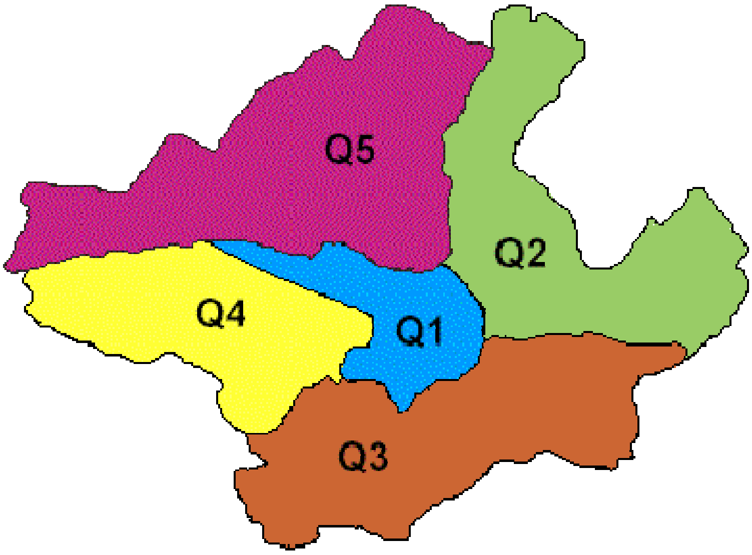


Figure 21 District division of Firenze municipality

Firenze city center is the part in the map marked with "Q1" legend. The total area of that polygon is 10.89 km$^2$, where the remaining part of Firenze municipality is 91.53 km$^2$.

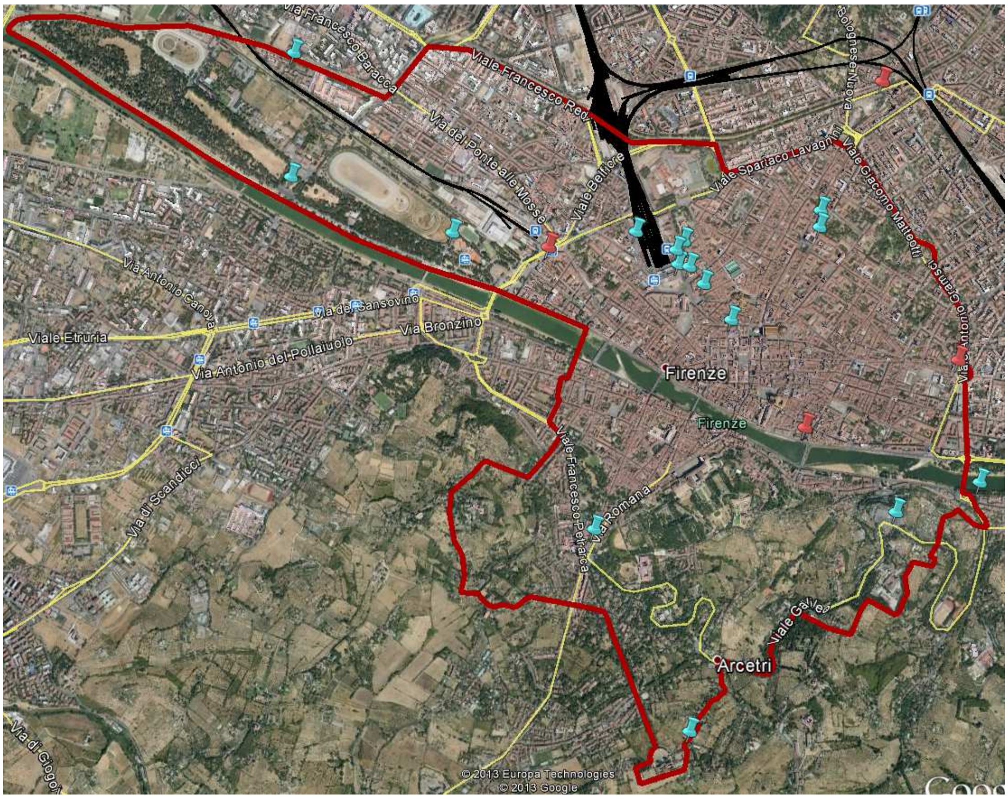


Figure 22 Q1 area with terminal stops

In Figure 22 the area of the Q1 district overlapped to the satellite image is shown. The pins are the terminal stops, divided in two sub groups: the red pins refer to the C1, C2 and C3 lines and the blue pins refer to the other lines.

The vehicles actually in use can be divided into two macro categories, pure electric minibus and traditional internal combustion engines minibus (ref to Figure 23).

Figure 23 Electric Tecnobus Gulliver [a] and Iveco Cacciamali TCC 635L [b]

As mentioned above, within the city center it is mandatory to use minibus instead of the classical 12 meters long vehicles because of the narrow streets. However, the length of the routes does not allow the use of only pure electric bus for the service due to autonomy issues. The only line that is able to use pure electrical vehicles is the C2, that is the shorter of the three.

In addition, the batteries equipped on board are not enough to ensure the service for all the 13 hours of the day-time (from 07.00 AM to 08.00 PM) and so it is mandatory for each vehicle to reach, at about half workday, the central vehicles parking to replace the empty battery with a full charged one. This difficult management makes the PEV adoption not cost convenient due to the large number of workers involved in this loop. The lower price of electricity is not enough to cover management cost.

The buses are used within the city center mainly for environmental and noise issue but this approach it is not easily replicable to the whole urban area.

The above issues are easily overcome with the adoption of an *en-route* recharge that refills the battery during the service itself and extend the autonomy of the vehicle. Wireless recharge technology, in addition to these features, can also provide safety and user friendly features for the bus service provider.

Vehicle’s parameters used for analysis are reported in Table 35:

Table 35 Vehicle’s parameters

| | |
|---|---|
| **Vehicle mass [kg]** | 5636 |
| **Length [m]** | 5.320 |
| **Width [m]** | 2.035 |
| **Front Area [$m^2$]** | 5.340 |
| **Radius of the wheel [m]** | 0.28 |

For an exhaustive study, data have been collected from the ATAF web site [6] and by using a GIS software. The geo-localization is needful to perform also geometric calculations and considerations. Data regarding the normal stop of each line have been collected from the website ATAF timetable. The bus stops geo-localization has been performed by using Google Earth software. In Table 36, Table 37, Table 38, Table 39, Table 40, Table 41 it is possible to find the name, latitude and longitude of each bus stop for C1, C2 and C3 routes.

Table 36 C1 ~ Going route

| Station name | Latitude | Longitude |
|---|---|---|
| Parterre | 43.786291 | 11.264238 |
| Ponte Rosso | 43.784925 | 11.262106 |
| Sant'anna | 43.782589 | 11.261927 |
| Salvestrina | 43.780562 | 11.260344 |
| Arazzieri | 43.778651 | 11.258835 |
| Cavour | 43.776051 | 11.256678 |
| San Lorenzo | 43.775014 | 11.255283 |
| Ginori | 43.776261 | 11.255624 |
| Brunelleschi | 43.775359 | 11.260346 |
| Alfani | 43.774506 | 11.262189 |
| Pilastri | 43.773067 | 11.264182 |
| Agenzia del Territorio | 43.770632 | 11.262646 |
| Oriuolo | 43.772452 | 11.258822 |
| Proconsolo | 43.771871 | 11.257887 |
| Galleria degli Uffizi | 43.768538 | 11.256734 |
| Diaz | 43.767006 | 11.258306 |

Table 37 C1 ~ Return route

| **Station name** | **Latitude** | **Longitude** |
|---|---|---|
| Diaz | 43.767006 | 11.258306 |
| Benci | 43.767423 | 11.259333 |
| Verdi | 43.769875 | 11.261291 |
| Salvemini | 43.771325 | 11.262428 |
| Sant'Egidio | 43.772373 | 11.260982 |
| Santa Maria Nuova | 43.773372 | 11.259187 |
| Pucci | 43.774663 | 11.256366 |
| San Marco | 43.777572 | 11.258771 |
| Venezia | 43.781177 | 11.261943 |
| Libertà | 43.783711 | 11.263016 |
| Parterre | 43.786291 | 11.264238 |

Table 38 C2 ~ Going route

| **Station name** | **Latitude** | **Longitude** |
|---|---|---|
| Leopolda | 43.777231 | 11.238857 |
| Il Prato | 43.775361 | 11.242191 |
| Santa Lucia | 43.774605 | 11.243431 |
| Stazione Orti Oricellari | 43.776531 | 11.245824 |
| Stazione Via Panzani | 43.774686 | 11.250146 |
| Pecori | 43.772719 | 11.253446 |
| Roma | 43.772301 | 11.254435 |
| Orsanmichele | 43.770901 | 11.254634 |
| Canto alla Quarconia | 43.770836 | 11.256844 |
| Ghibellina | 43.770556 | 11.258513 |
| Teatro Verdi | 43.770022 | 11.262501 |
| Malborghetto | 43.769812 | 11.265529 |
| Annigoni | 43.770919 | 11.267563 |
| Leopardi | 43.772486 | 11.270415 |
| Beccaria | 43.770611 | 11.270305 |

Table 39 C2 ~ Return route

| Station name | Latitude | Longitude |
|---|---|---|
| Beccaria | 43.770611 | 11.270305 |
| Agnolo | 43.769934 | 11.266008 |
| Salvemini | 43.771305 | 11.262456 |
| Oriuolo | 43.772531 | 11.258837 |
| Proconsolo | 43.771869 | 11.257941 |
| Condotta | 43.770204 | 11.255351 |
| Porta Rossa | 43.770288 | 11.253723 |
| Repubblica | 43.771276 | 11.253651 |
| Olio | 43.773021 | 11.254002 |
| Stazione Piazza dell'unità | 43.774902 | 11.250166 |
| Stazione Scalette | 43.775397 | 11.248003 |
| Palazzuolo | 43.774121 | 11.245517 |
| Rotonda Barbetti | 43.774934 | 11.242609 |
| Solferino | 43.775823 | 11.239081 |
| Leopolda | 43.777231 | 11.238857 |

Table 40 C3 ~ Going route

| Station name | Latitude | Longitude |
|---|---|---|
| Leopolda | 43.777231 | 11.238857 |
| Il Prato | 43.775361 | 11.242191 |
| Curtatone | 43.773797 | 11.242037 |
| Ponte Vespucci | 43.772087 | 11.245181 |
| Sauro | 43.769377 | 11.246701 |
| Porta Romana | 43.761181 | 11.242257 |
| Pitti | 43.765903 | 11.249938 |
| Bardi | 43.766844 | 11.254425 |
| Mozzi | 43.765293 | 11.257901 |
| Benci | 43.767423 | 11.259333 |
| Verdi | 43.769875 | 11.261291 |
| Teatro Verdi | 43.770022 | 11.262501 |
| Malborghetto | 43.769812 | 11.265529 |
| Annigoni | 43.770919 | 11.267563 |
| Leopardi | 43.772486 | 11.270415 |
| Beccaria | 43.770611 | 11.270305 |

Table 41 C3 ~ Return route

| **Station name** | **Latitude** | **Longitude** |
|---|---|---|
| Beccaria | 43.770611 | 11.270305 |
| Agnolo | 43.769934 | 11.266008 |
| Pepi | 43.770327 | 11.263071 |
| Magliabechi | 43.768372 | 11.261756 |
| Tintori | 43.767622 | 11.259501 |
| Torrigiani | 43.767012 | 11.258482 |
| Ponte Vecchio | 43.76843 | 11.253937 |
| Coverelli | 43.768759 | 11.249354 |
| Guicciardini | 43.769553 | 11.247268 |
| Ognissanti | 43.771995 | 11.245241 |
| Soderini | 43.771659 | 11.241449 |
| Fonderia | 43.772453 | 11.238726 |
| Santa Maria al Pignone | 43.773347 | 11.235512 |
| Vittorio Veneto | 43.776225 | 11.237634 |
| Leopolda | 43.77723 | 11.238857 |

ATAF website also provides the timetable for each stop. Just as an example, Table 42 shows the schedule of the first two hours of line C1.

Table 42 First two hours time schedule of line C1

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Parterre | 07:00 | 07:15 | 07:30 | 07:40 | 07:50 | 08:00 | 08:10 | 08:20 | 08:30 | 08:40 |
| Ponte Rosso | 07:01 | 07:16 | 07:31 | 07:41 | 07:51 | 08:01 | 08:11 | 08:21 | 08:31 | 08:41 |
| Sant'Anna | 07:03 | 07:18 | 07:33 | 07:43 | 07:53 | 08:03 | 08:13 | 08:23 | 08:33 | 08:43 |
| Salvestrina | 07:04 | 07:19 | 07:34 | 07:44 | 07:54 | 08:04 | 08:14 | 08:24 | 08:34 | 08:44 |
| Arazzieri | 07:06 | 07:21 | 07:36 | 07:46 | 07:56 | 08:06 | 08:16 | 08:26 | 08:36 | 08:46 |
| Cavour | 07:07 | 07:22 | 07:37 | 07:47 | 07:57 | 08:07 | 08:17 | 08:27 | 08:37 | 08:47 |
| San Lorenzo | 07:08 | 07:23 | 07:38 | 07:48 | 07:58 | 08:08 | 08:18 | 08:28 | 08:38 | 08:48 |
| Ginori | 07:09 | 07:24 | 07:39 | 07:49 | 07:59 | 08:09 | 08:19 | 08:29 | 08:39 | 08:49 |
| Brunelleschi | 07:12 | 07:27 | 07:42 | 07:52 | 08:02 | 08:12 | 08:22 | 08:32 | 08:42 | 08:52 |
| Alfani | 07:13 | 07:28 | 07:43 | 07:53 | 08:03 | 08:13 | 08:23 | 08:33 | 08:43 | 08:53 |
| Pilastri | 07:15 | 07:30 | 07:45 | 07:55 | 08:05 | 08:15 | 08:25 | 08:35 | 08:45 | 08:55 |
| Agenzia del Territorio | 07:17 | 07:32 | 07:47 | 07:57 | 08:07 | 08:17 | 08:27 | 08:37 | 08:47 | 08:57 |
| Oriuolo | 07:19 | 07:34 | 07:49 | 07:59 | 08:09 | 08:19 | 08:29 | 08:39 | 08:49 | 08:59 |
| Proconsolo | 07:20 | 07:35 | 07:50 | 08:00 | 08:10 | 08:20 | 08:30 | 08:40 | 08:50 | 09:00 |
| Galleria degli Uffizi | 07:22 | 07:37 | 07:52 | 08:02 | 08:12 | 08:22 | 08:32 | 08:42 | 08:52 | 09:02 |
| Diaz | 07:24 | 07:39 | 07:54 | 08:04 | 08:14 | 08:24 | 08:34 | 08:44 | 08:54 | 09:04 |

## 10.2 Drive cycles acquisition campaign

To have a more accurate estimation of busses consumption, drive cycles analysis have been necessary. Within this study, a measurement campaign of drive cycles has been carried out. The used tool was the IMU MTi-G, produced by Xsense and showed in Figure 24, with an acquisition frequency of 10 Hz. The tool is also equipped with GPS receiver, accelerometers, gyroscopes and magnetometers in order to determine and log vehicle position, its speed and acceleration in the three dimensions, IMU orientation, angular speeds, data about the Earth magnetic field and number of visible satellites.

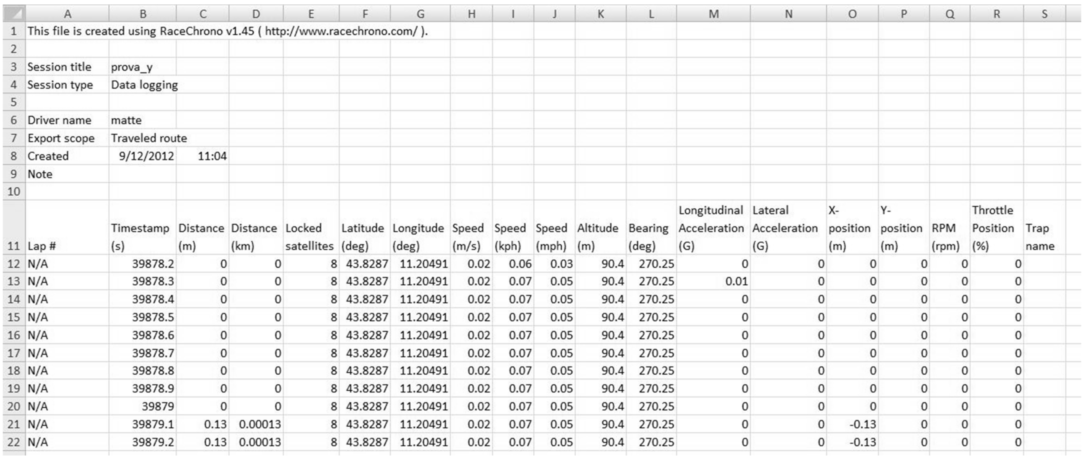
Figure 24 MTi-G Inertia Measurement Unit by Xsense

The tools itself is also equipped with an “on Board Kalman filter” settable on *Automotive* to reduce the “noise” coming from the vehicle vibrations. However the on board filter has not been used in order to have raw data to be filtered in the post processing phase. In addition, it is also possible to directly create a .kmz file. This particular kind of file allows to visualize a set of points (the busses’ routes) overlapped on a satellite image by using a GIS software, in order to have a visual feedback on measurement accuracy (Figure 25).

Figure 25 .kmz file with travelled routes (C1 route)

Data has been collected on weekly basis, from Monday to Friday, from 09.00 AM to 07.00 PM and involving as much drivers as possible in order to have data not affected by one driver behavior. For each route, about 10 repetitions have been recorded.

The recorded variables are shown in Figure 26.



| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | This file is created using RaceChrono v1.45 ( http://www.racechrono.com/ ). | | | | | | | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | | | | | | | |
| 3 | Session title | prova_y | | | | | | | | | | | | | | | | | |
| 4 | Session type | Data logging | | | | | | | | | | | | | | | | | |
| 5 | | | | | | | | | | | | | | | | | | | |
| 6 | Driver name | matte | | | | | | | | | | | | | | | | | |
| 7 | Export scope | Traveled route | | | | | | | | | | | | | | | | | |
| 8 | Created | 9/12/2012 | 11:04 | | | | | | | | | | | | | | | | |
| 9 | Note | | | | | | | | | | | | | | | | | | |
| 10 | | | | | | | | | | | | | | | | | | | |
| 11 | Lap # | Timestamp (s) | Distance (m) | Distance (km) | Locked satellites | Latitude (deg) | Longitude (deg) | Speed (m/s) | Speed (kph) | Speed (mph) | Altitude (m) | Bearing (deg) | Longitudinal Acceleration (G) | Lateral Acceleration (G) | X-position (m) | Y-position (m) | RPM (rpm) | Throttle Position (%) | Trap name |
| 12 | N/A | 39878.2 | 0 | 0 | 8 | 43.8287 | 11.20491 | 0.02 | 0.06 | 0.03 | 90.4 | 270.25 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 13 | N/A | 39878.3 | 0 | 0 | 8 | 43.8287 | 11.20491 | 0.02 | 0.07 | 0.05 | 90.4 | 270.25 | 0.01 | 0 | 0 | 0 | 0 | 0 | |
| 14 | N/A | 39878.4 | 0 | 0 | 8 | 43.8287 | 11.20491 | 0.02 | 0.07 | 0.05 | 90.4 | 270.25 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 15 | N/A | 39878.5 | 0 | 0 | 8 | 43.8287 | 11.20491 | 0.02 | 0.07 | 0.05 | 90.4 | 270.25 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 16 | N/A | 39878.6 | 0 | 0 | 8 | 43.8287 | 11.20491 | 0.02 | 0.07 | 0.05 | 90.4 | 270.25 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 17 | N/A | 39878.7 | 0 | 0 | 8 | 43.8287 | 11.20491 | 0.02 | 0.07 | 0.05 | 90.4 | 270.25 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 18 | N/A | 39878.8 | 0 | 0 | 8 | 43.8287 | 11.20491 | 0.02 | 0.07 | 0.05 | 90.4 | 270.25 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 19 | N/A | 39878.9 | 0 | 0 | 8 | 43.8287 | 11.20491 | 0.02 | 0.07 | 0.05 | 90.4 | 270.25 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 20 | N/A | 39879 | 0 | 0 | 8 | 43.8287 | 11.20491 | 0.02 | 0.07 | 0.05 | 90.4 | 270.25 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 21 | N/A | 39879.1 | 0.13 | 0.00013 | 8 | 43.8287 | 11.20491 | 0.02 | 0.07 | 0.05 | 90.4 | 270.25 | 0 | 0 | -0.13 | 0 | 0 | 0 | |
| 22 | N/A | 39879.2 | 0.13 | 0.00013 | 8 | 43.8287 | 11.20491 | 0.02 | 0.07 | 0.05 | 90.4 | 270.25 | 0 | 0 | -0.13 | 0 | 0 | 0 | |

Figure 26 Variables recorded during the routes

The speed is calculated by using time of acquisition and the Haversine formulation of distance between two points on a sphere defined by a latitude λ and a longitude φ. By deriving the speed, the software is able to find the longitudinal acceleration. The "located satellites" column reports the number of satellites visible by the device: this variable is used to assess the goodness of the data. It is necessary, in fact, that at least seven satellites are visible to be sure of the geo-localization precision.

1. $$d = 2r\ \arcsin\left(\sqrt{sin^2\left(\frac{\phi_2 - \phi_1}{2}\right) + \cos(\phi 1)\cos(\phi 2)\, sin^2\left(\frac{\lambda_2 - \lambda_1}{2}\right)}\right)$$

First operation of the post processing phase has been the correction of the "canyoning effect" on geo-localization precision (Figure 27).

Figure 27 Route record without [a] and with [b] canyoning effect

All the data-log records with a less than eight number of visible satellites have been deleted and replaced with linearly interpolated data between last record with eight or more visible satellite and first record with eight or more visible satellites. About 2% of records had less than eight visible satellites.

After the correction, data has been then filtered using a biweight Kernel filter because the signals were very noisy and could not be used to represent the effective drive cycle. Noisy signal problems were even more obvious with regard to the acceleration, calculated by deriving the speed signal (Figure 28).

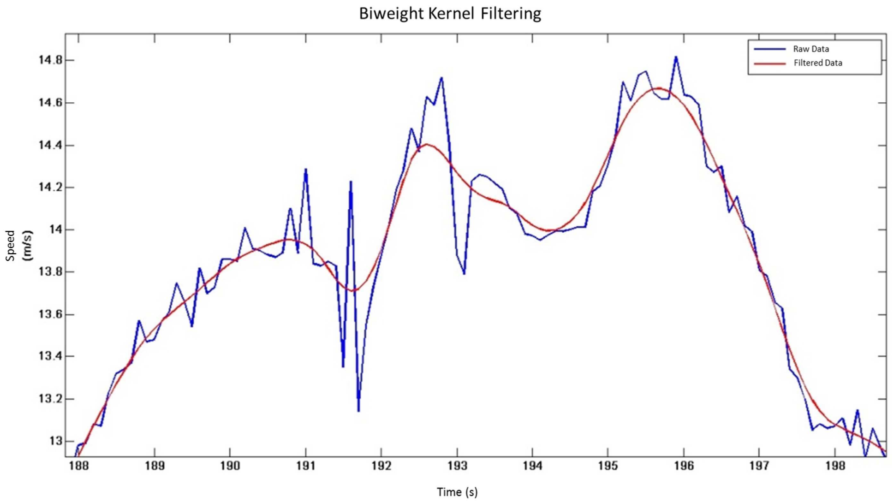


Figure 28 Comparison between raw and filtered data

Once the filtering procedure has been done, each of the routes has been divided between the stops, in order to fill the database of vehicles dwell time. In addition, also stop percentage at each stop has been calculated. In the tables below, the “0” value means that the bus did not stop that time. The blank cell, instead, means that the recorded data was too noisy and the related value has been deleted from report. The results are presented in Table 43, Table 44 and Table 45.

Table 43 Stop times of line C1 [s]

| Station name | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Stop percentage |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Parterre | 413.4 | 600.6 | 605.5 | 358.2 | 20.5 | 559.6 | 697.4 | 697.4 | 585.6 | 587.3 | 1.00 |
| Ponte Rosso | 101.7 | 31.3 | 27.6 | 0 | 21.1 | 28.8 | 30 | 30 | 9.8 | 50.7 | 0.80 |
| Sant'anna | 20.2 | 11.5 | 0 | 0 | 7.1 | 0 | 0 | 0 | 16.3 | 22.5 | 0.40 |
| Salvestrina | 12.8 | 14.8 | 9.8 | 14.2 | 0 | 14.4 | 0 | 0 |  | 0 | 0.44 |
| Arazzieri | 12.8 | 14 | 16 | 48.3 | 19.8 | 24.8 | 18.2 | 18.2 |  | 29.6 | 1.00 |
| Cavour | 25.1 | 9.7 | 12.8 | 0 | 0 |  | 0 | 0 |  | 0 | 0.25 |
| San Lorenzo | 17 | 25.9 | 22.8 | 20.1 | 11.8 |  | 15 | 15 |  | 18.1 | 1.00 |
| Ginori | 11 | 1.8 | 0 | 13.2 | 23.3 |  | 0 | 0 |  | 9.5 | 0.38 |
| Brunelleschi | 15.2 | 11.8 | 10.2 | 0 | 0 | 2 | 0 | 0 |  | 11.1 | 0.44 |
| Alfani | 0 | 8.9 | 12.4 | 0 | 0 | 0 | 0 | 0 |  |  | 0.13 |
| Pilastri | 19.3 | 13.9 | 26.9 | 0 | 0 |  | 0 | 0 |  |  | 0.43 |
| Agenzia del Territorio | 22 | 9.3 | 13.4 | 24.3 | 7 |  | 10.5 | 10.5 |  | 14.5 | 0.75 |
| Oriuolo | 0 | 0 | 12.1 | 0 | 9.4 | 0 | 10.2 | 10.2 |  | 9.1 | 0.33 |
| Proconsolo | 0 |  | 0 | 10.8 | 0 | 0 | 0 | 0 |  | 10.8 | 0.25 |
| Galleria degli Uffizi | 11.3 |  | 10.5 | 13.4 | 0 | 0.7 | 0 | 0 |  | 0 | 0.38 |
| Diaz |  | 71.7 |  | 18.6 | 429.2 | 188.4 | 35.3 | 35.3 | 27.4 | 224.5 | 1.00 |
| Benci |  | 14.6 | 12 | 74.9 | 24.7 | 13.3 | 12 | 12 | 10 | 15.3 | 0.89 |
| Verdi |  | 24.9 | 20.3 | 27.4 |  | 20.6 | 28.2 | 28.2 | 35.7 | 9.4 | 0.88 |
| Salvemini | 34.8 | 1.5 | 34.4 | 32.5 |  |  | 26.3 | 26.3 | 40.5 | 24.5 | 0.88 |
| Sant'Egidio | 0 | 0 | 0 | 0 | 0 |  | 42.5 | 42.5 | 0 | 7 | 0.22 |
| Santa Maria Nuova | 13 | 19.1 | 16.4 | 0 | 0 | 10.7 | 18.9 | 18.9 | 18.5 | 16.4 | 0.80 |
| Pucci | 31.4 | 17.4 | 44.2 | 23.4 | 21.8 | 11.1 | 14.4 | 14.4 | 13.1 | 18.7 | 1.00 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| San Marco | 16.9 | 18.7 | 20.7 | 29.5 | 17 | 22.2 | 21.4 | 21.4 | 17.4 | 93.8 | 1.00 |
| Venezia | 0 | 11.7 | 10.6 | 14.2 | 12.1 | 3.1 | 0 | 0 | 12.1 | 7.4 | 0.50 |
| Libertà | 63 | 51.8 | 50.5 | 57.6 | 67.8 | 36.5 | 48.7 | 48.7 | 53.1 | 48.5 | 1.00 |

Table 44 Stop times of line C2 [s]

| **Station name** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **Stop percentage** |
|---|---|---|---|---|---|---|---|---|---|
| Leopolda | 465.3 | 300 | | | 93 | 23.7 | | 16.1 | 1.00 |
| Il Prato | 0 | 0 | 0 | 0 | 0 | 0 | 0.2 | 3 | 0.00 |
| Santa Lucia | 12.9 | 0 | 16.1 | 12.2 | 0 | 18 | 15.6 | 0 | 0.63 |
| Stazione Orti Oricellari | 45.5 | 55.6 | 50.7 | 30.1 | 97.2 | 88.2 | 37.8 | 15.5 | 1.00 |
| Stazione Via Panzani | 27.8 | 9.2 | 46.6 | 0 | 54.5 | 0.6 | 18.7 | 0 | 0.50 |
| Pecori | 28 | 9.4 | 20.1 | 15.1 | 17.3 | 15.1 | 19.1 | 19 | 0.88 |
| Roma | 17.4 | 9.6 | 0 | 13.7 | 23.1 | 12.9 | 10.8 | 14.3 | 0.75 |
| Orsanmichele | 24.7 | 5.7 | 24.3 | 13 | 35.3 | 33.2 | 18.1 | 20.3 | 0.88 |
| Canto alla Quarconia | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Ghibellina | 15.8 | 0 | 23.6 | 8.9 | 27.1 | 0 | 16.6 | 17.1 | 0.63 |
| Teatro Verdi | 21.3 | 0.5 | 18.4 | 11.2 | 0 | 0 | 17.5 | 20.3 | 0.63 |
| Malborghetto | 16.5 | 21.7 | 19 | 1.1 | 21.8 | 15.3 | 21.2 | 12.1 | 0.88 |
| Annigoni | 15.9 | 9.8 | 23.5 | 11.7 | 12.8 | 8.3 | 12.7 | 12.8 | 0.75 |
| Leopardi | 14.2 | 26.3 | 8.5 | 27.7 | 33.7 | 0 | 64.8 | 11.3 | 0.75 |
| Beccaria | 162.1 | 78.5 | 139.9 | 352.6 | 278.3 | 18.2 | 32.2 | 18.3 | 1.00 |
| Agnolo | 0 | 12.5 | 18.9 | 20.5 | 10.9 | 0 | 9.1 | 12.1 | 0.63 |
| Salvemini | 15.7 | 34.7 | 17.1 | 17.8 | 43.4 | 34.2 | 19.1 | 0.6 | 0.88 |
| Oriuolo | 8.2 | 11.8 | 12.7 | 14.6 | 0 | 20.8 | 9.1 | 10 | 0.50 |
| Proconsolo | 15.2 | 0 | 0 | 0 | 25 | 17 | 0 | 18.5 | 0.50 |
| Condotta | 0 | 17.8 | 0 | 0 | 0 | 20.8 | 28.5 | 7.8 | 0.38 |
| Porta Rossa | 0 | 1.4 | 0 | 0 | 0 | 0 | 4.9 | 6.8 | 0.00 |
| Repubblica | 17.5 | 17.3 | 15.2 | 19 | 0 | 27.8 | 42.5 | 10.2 | 0.88 |
| Olio | 0 | 14.8 | 15.2 | 7.2 | 0 | 0.4 | 14.4 | 18.8 | 0.50 |
| Stazione Piazza dell'Unita' | 10.7 | 21.2 | 26.5 | 18.8 | 16.1 | 21.4 | 35.9 | 95.4 | 1.00 |
| Stazione Scalette | 29.8 | 43.8 | 37.3 | 28.4 | 38.5 | 98.5 | 79.8 | 40 | 1.00 |
| Palazzuolo | 15.2 | 0.6 | 21.1 | 0 | 11.3 | 0 | 12.3 | 0 | 0.50 |
| Rotonda Barbetti | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 17.2 | 0.13 |
| Solferino | 0 | 7.9 | 0 | 0 | 0 | 11.8 | 10.9 | 0 | 0.25 |

Table 45 Stop times of line C3 [s]

| **Station name** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **Stop percentage** |
|---|---|---|---|---|---|---|---|---|---|
| Leopolda | 166.8 | | 104.4 | 327.3 | 170.2 | 196.9 | | 14.3 | 1.00 |
| Il Prato | 0 | | 0 | 5.1 | 0 | 0 | 0 | 0 | 0.00 |
| Curtatone | 8.7 | | | 10.5 | 0 | 0 | 0 | 15.3 | 0.33 |
| Ponte Vespucci | 0 | | | 0 | 0 | 0 | 0 | 0 | 0.00 |
| Sauro | 38.9 | | 19.3 | 46.1 | | 40.2 | 25.2 | 18.4 | 1.00 |
| Porta Romana | 16.4 | | 34.8 | 8.1 | | 108.5 | 5.2 | 21.6 | 0.67 |
| Pitti | 9.7 | | 31.5 | 13.5 | 7.6 | 15.1 | | 6.4 | 0.50 |
| Bardi | 16.9 | | 16.1 | 10.4 | 9.8 | 0 | | 33.8 | 0.67 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Mozzi | 0 | | 0 | 0 | 3.6 | 4 | 0 | 2.2 | 0.00 |
| Benci | 35.2 | | 29.7 | 56.5 | 27.1 | 44.9 | 52.6 | 0 | 0.86 |
| Verdi | 0 | | 0 | 30.3 | 28.9 | 32.7 | 7.9 | 43.6 | 0.57 |
| Teatro Verdi | 0 | | 0 | 0 | 18.3 | 0 | 6.8 | 2.9 | 0.14 |
| Malborghetto | 37.5 | | 22 | | 11.3 | 7.9 | 16.3 | 12.7 | 0.83 |
| Annigoni | 12.5 | | 18.3 | | 0.5 | 25.7 | 13.5 | 20.3 | 0.83 |
| Leopardi | 43.7 | | 36.2 | 9.9 | 0.6 | 72.9 | 0 | 0 | 0.43 |
| Beccaria | 31.7 | 5.2 | | 18.5 | | 8.5 | 22.9 | 23.5 | 0.67 |
| Agnolo | 25.5 | 26.6 | | 0 | | 9 | 23.4 | 25.8 | 0.67 |
| Pepi | 0 | 33.3 | 9 | 25.3 | 0 | 10.4 | 23.1 | 0.8 | 0.50 |
| Magliabechi | 1.9 | 39.1 | 6 | 20 | | 2.4 | 34.8 | 1.6 | 0.43 |
| Tintori | 0.4 | 52.4 | 15.4 | 7.4 | | 31.2 | 19.4 | 0 | 0.57 |
| Torrigiani | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0.00 |
| Ponte Vecchio | 0 | 28.7 | 6 | 5 | 11.1 | 23.3 | | 2 | 0.43 |
| Coverelli | 11 | 0 | 10.5 | 13.1 | 0 | 10.7 | 12.3 | 21.1 | 0.75 |
| Guicciardini | 12.2 | 0 | 12.3 | 26.9 | 36.9 | 11.5 | 40.2 | 48.6 | 0.88 |
| Ognissanti | 16.7 | 0 | 0 | 16.4 | 0 | 0 | 10.1 | 22.9 | 0.50 |
| Soderini | 9.6 | 11.1 | 7 | 0 | 12.2 | 11.3 | 17.3 | 16.1 | 0.63 |
| Fonderia | 0 | 0 | 8.8 | 0 | 1.8 | 0 | 0 | 16.3 | 0.13 |
| Santa Maria al Pignone | 0 | | 8.6 | 0 | 0 | 0 | 10.1 | 0 | 0.14 |
| Vittorio Veneto | 0 | | 0 | 11.4 | 0 | 0 | 0 | 0 | 0.14 |

In addition, also the travelled times of the busses have been determined by analyzing the recorded drive cycles. The relevant results are presented in Table 46, Table 47 and Table 48.

Table 46 - Travelled time per subparts of line C1 [s]

| **Sub part Name** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **Avg.** | **σ** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parterre - Ponte Rosso | 509.7 | 688 | 691.7 | 476.4 | | 605.3 | 706.2 | 766 | 625.2 | 727.9 | 644 | 98.7 |
| Ponte Rosso - Sant'Anna | 181.2 | 102 | 205.9 | 142.4 | 99.6 | 168.5 | 103.6 | 118.3 | 79.8 | 164.3 | 136.6 | 41.9 |
| Sant'Anna - Salvestrina | 56.1 | 45.3 | 26 | 30.7 | 50.5 | 26.9 | 54.4 | 32 | 52.3 | 59.2 | 43.3 | 13 |
| Salvestrina - Arazzieri | 54.6 | 50.5 | 89.4 | 55 | 43.3 | 72.7 | 33.4 | 34.1 | | 69.4 | 55.8 | 18.6 |
| Arazzieri - Cavour | 120.7 | 131.8 | 186.7 | 141.6 | 132.9 | 243.8 | 134.5 | 150.8 | | 156.2 | 155.4 | 38.3 |
| Cavour - San Lorenzo | 129.2 | 53 | 121.5 | 124 | 59 | | 45.1 | 34.6 | | 81.4 | 81 | 38.8 |
| San Lorenzo - Ginori | 60.3 | 67 | 60.5 | 61.7 | 51.7 | | 67.9 | 58.3 | | 62.6 | 61.3 | 5.1 |
| Ginori - Brunelleschi | 187.1 | 195.4 | 124.2 | 176.6 | 178.4 | | 169.7 | 193 | | 157.3 | 172.7 | 23.2 |
| Brunelleschi - Alfani | 56 | 46.7 | 42.6 | 26 | 36.5 | 40.4 | 29.2 | 53.7 | | 42.3 | 41.5 | 10 |
| Alfani - Pilastri | 52.5 | 49.5 | 58.3 | 57.3 | 50.5 | 49 | 49.9 | 43.5 | | | 51.3 | 4.8 |
| Pilastri - Agenzia del Territorio | 129.4 | 107 | 126.9 | 83.6 | 96.7 | | 101.8 | 71.3 | | | 102.4 | 21.2 |
| Agenzia del Territorio - Oriuolo | 152.4 | 101.7 | 137 | 151.5 | 130.6 | | 115.9 | 162.9 | | 98.8 | 131.3 | 24.1 |
| Oriuolo - Proconsolo | 38.1 | 31.1 | 57.1 | 28.1 | 46.7 | 29 | 33.4 | 43.2 | | 44.5 | 39 | 9.7 |
| Proconsolo - Galleria degli Uffizi | 77.7 | | 86.2 | 92.7 | 67.3 | 92.3 | 73.1 | 71.7 | | 93.4 | 81.8 | 10.6 |
| Galleria degli Uffizi - Diaz | 89.2 | | 91.7 | 90.1 | 81.2 | 74.2 | 84.3 | 65.8 | | 73.4 | 81.2 | 9.3 |
| Diaz - Benci | | 115.9 | | 99.2 | 509.3 | 231.7 | | 96.6 | 119.2 | 288.5 | 208.6 | 151.9 |
| Benci - Verdi | | 77.1 | 69.9 | 141.3 | 95.2 | 89.6 | | 65.7 | 65.8 | 67.3 | 84 | 25.7 |
| Verdi - Salvemini | | 90 | 69 | 72.1 | | 89 | | 73.9 | 78.1 | 69.7 | 77.4 | 8.8 |
| Salvemini - Sant'egidio | 79.8 | 46.8 | 71.8 | 73.6 | | | 55.4 | 75.9 | 77.4 | 76.3 | 69.6 | 11.9 |
| Sant'egidio - Santa Maria | 38 | 43.1 | 32.9 | 37.8 | 56.4 | | 52.7 | 77.5 | 39.6 | 37.4 | 46.2 | 14 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nuova | | | | | | | | | | | |
| Santa Maria Nuova - Pucci | 73.9 | 73.2 | 80.4 | 59.2 | 58 | 70.9 | 75 | 67.5 | 97.2 | 66.7 | 72.2 | 11.2 |
| Pucci - San Marco | 137.4 | 121.3 | 107.5 | 157.4 | 155.1 | 87.1 | 84.3 | 87.3 | 75.9 | 114.6 | 112.8 | 29.8 |
| San Marco - Venezia | 80.3 | 86.9 | 99.1 | 100 | 92.7 | 121.1 | 84 | 87.8 | 84.6 | 166.8 | 100.3 | 26.2 |
| Venezia - Liberta' | 76.7 | 87 | 66.6 | 142.9 | 119.7 | 138.5 | 69.5 | 43.3 | 69 | 89.5 | 90.3 | 33 |
| Liberta' - Parterre | 174.8 | 153.1 | 152.9 | 165.6 | 172.4 | 140 | 143.5 | 166 | 160.4 | 177 | 160.6 | 12.9 |

Table 47 - Travelled time per subparts of line C2 [s]

| **Sub part Name** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **Avg.** | **σ** |
|---|---|---|---|---|---|---|---|---|---|---|
| Leopolda - Il Prato | 552.2 | 451.6 | | | 158.5 | 157.8 | | 88.1 | 281.6 | 206.2 |
| Il Prato - Santa Lucia | 35.3 | 30.4 | 40.1 | 34.6 | 31.4 | 36.7 | 46.0 | 43.0 | 37.2 | 5.5 |
| Santa Lucia - Stazione Orti Oricellari | 75.1 | 57.3 | 132.8 | 66.6 | 51.6 | 83.1 | 98.4 | 108.9 | 84.2 | 27.7 |
| Stazione Orti Oricellari - Stazione Via Panzani | 164.5 | 327.9 | 181.7 | 178.6 | 347.4 | 307.4 | 491.9 | 505.9 | 313.2 | 135.2 |
| Stazione Via Panzani - Pecori | 146.2 | 127.1 | 194.9 | 109.9 | 177.7 | 121.3 | 139.9 | 97.8 | 139.3 | 33.1 |
| Pecori - Roma | 56.4 | 37.5 | 48.7 | 50.3 | 50.0 | 40.0 | 58.3 | 47.2 | 48.6 | 7.2 |
| Roma - Orsanmichele | 75.1 | 87.5 | 42.7 | 62.3 | 81.2 | 70.1 | 72.5 | 67.6 | 69.9 | 13.5 |
| Orsanmichele - Canto alla Quarconia | 110.9 | 82.3 | 114.8 | 83.0 | 111.3 | 123.0 | 100.9 | 95.1 | 102.7 | 15.0 |
| Canto alla Quarconia - Ghibellina | 49.0 | 51.6 | 46.7 | 50.6 | 42.0 | 72.3 | 53.4 | 55.1 | 52.6 | 8.9 |
| Ghibellina - Teatro Verdi | 97.8 | 100.3 | 85.4 | 90.7 | 164.9 | 42.3 | 120.5 | 76.0 | 97.2 | 35.4 |
| Teatro Verdi - Malborghetto | 82.7 | 53.2 | 110.7 | 66.0 | 46.4 | 40.8 | 74.3 | 67.5 | 67.7 | 22.4 |
| Malborghetto - Annigoni | 90.9 | 93.6 | 118.4 | 120.6 | 87.8 | 77.4 | 101.0 | 80.0 | 96.2 | 16.2 |
| Annigoni - Leopardi | 85.8 | 101.9 | 103.4 | 122.8 | 82.4 | 93.4 | 84.1 | 74.5 | 93.5 | 15.4 |
| Leopardi - Beccaria | 116.3 | 79.2 | 79.9 | 97.3 | 83.0 | 59.5 | 130.7 | 126.8 | 96.6 | 25.7 |
| Beccaria - Agnolo | 287.6 | 200.1 | 291.8 | 453.1 | 362.9 | 108.2 | 145.8 | 160.0 | 251.2 | 118.7 |
| Agnolo - Salvemini | 104.8 | 94.0 | 98.8 | 89.8 | 127.8 | 84.0 | 102.2 | 116.1 | 102.2 | 14.2 |
| Salvemini - Oriuolo | 79.2 | 106.2 | 115.4 | 116.3 | 121.8 | 104.6 | 125.4 | 72.0 | 105.1 | 19.6 |
| Oriuolo - Proconsolo | 46.6 | 47.3 | 51.3 | 55.7 | 32.8 | 51.9 | 42.8 | 47.1 | 46.9 | 6.9 |
| Proconsolo - Condotta | 127.6 | 95.5 | 98.3 | 132.5 | 148.6 | 135.3 | 110.7 | 140.0 | 123.6 | 19.7 |
| Condotta - Porta Rossa | 41.6 | 71.8 | 54.2 | 45.9 | 57.9 | 91.3 | 81.0 | 84.7 | 66.1 | 18.7 |
| Porta Rossa - Repubblica | 29.8 | 27.8 | 28.8 | 23.4 | 28.1 | 47.5 | 35.2 | 66.4 | 35.9 | 14.3 |
| Repubblica - Olio | 101.7 | 79.3 | 82.9 | 93.7 | 67.9 | 101.8 | 102.0 | 68.9 | 87.3 | 14.5 |
| Olio - Stazione Piazza dell'unita' | 99.0 | 120.4 | 150.0 | 132.5 | 116.0 | 114.9 | 114.5 | 130.7 | 122.2 | 15.3 |
| Stazione Piazza dell'unita' - Stazione Scalette | 80.4 | 75.7 | 80.9 | 162.5 | 72.1 | 324.5 | 348.4 | 228.7 | 171.7 | 115.6 |
| Stazione Scalette - Palazzuolo | 131.7 | 168.2 | 262.8 | 161.9 | 154.2 | 299.0 | 311.6 | 173.1 | 207.8 | 71.4 |
| Palazzuolo - Rotonda Barbetti | 114.9 | 111.3 | 139.5 | 116.6 | 130.2 | 85.9 | 111.7 | 116.1 | 115.8 | 15.6 |
| Rotonda Barbetti - Solferino | 70.8 | 72.7 | 79.1 | 73.8 | 68.1 | 67.1 | 78.5 | 128.8 | 79.9 | 20.2 |
| Solferino - Leopolda | 37.2 | 59.1 | 42.2 | 47.8 | 48.0 | 57.2 | 62.2 | 52.9 | 50.8 | 8.6 |

Table 48 - Travelled time per subparts of line C3 [s]

| Sub part Name | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Avg. | σ |
|---|---|---|---|---|---|---|---|---|---|---|
| Leopolda - Il Prato | 244.5 |  | 509.5 | 404.3 | 239.7 | 332.6 |  | 70.9 | 300.3 | 151.7 |
| Il Prato - Curtatone | 33.2 |  | 41.9 | 74.7 | 60.9 | 47.5 | 33.6 | 30.7 | 46.1 | 16.4 |
| Curtatone - Ponte Vespucci | 66.8 |  |  | 101.6 | 78.3 | 104.8 | 36.9 | 116.6 | 84.2 | 29.5 |
| Ponte Vespucci - Sauro | 181 |  |  | 209.7 | 276.2 | 201.7 | 221.3 | 215.2 | 217.5 | 32 |
| Sauro - Porta Romana | 264 |  | 199.8 | 248.4 |  | 201.4 | 189.1 | 161.6 | 210.7 | 38.3 |
| Porta Romana - Pitti | 178.1 |  | 202.7 | 179.1 |  |  | 157.9 | 141 | 171.8 | 23.4 |
| Pitti - Bardi | 98 |  | 155.5 | 92.4 | 82.5 | 127.3 |  | 85.5 | 106.9 | 28.7 |
| Bardi - Mozzi | 95.3 |  | 110.2 | 105.4 | 72.8 | 85 |  | 118.2 | 97.8 | 16.9 |
| Mozzi - Benci | 50.2 |  | 27.9 | 43.1 | 44.2 | 84.3 | 50.1 | 70.6 | 52.9 | 18.8 |
| Benci - Verdi | 124.2 |  | 149 | 114.8 | 102.3 | 107.5 | 138.5 | 52.7 | 112.7 | 31.2 |
| Verdi - Teatro Verdi | 22.2 |  | 35.1 | 79.8 | 58.9 | 58.7 | 49.7 | 92.9 | 56.8 | 24.4 |
| Teatro Verdi - Malborghetto | 69.3 |  | 50 | 57.9 | 70 | 80.1 | 64.2 | 83.1 | 67.8 | 11.7 |
| Malborghetto - Annigoni | 131.3 |  | 86.1 |  | 116.9 | 81.7 | 93.4 | 78.6 | 98 | 21.3 |
| Annigoni - Leopardi | 88.7 |  | 88 |  | 126.4 | 124.1 | 146.2 | 130.9 | 117.4 | 23.8 |
| Leopardi - Beccaria | 116.6 |  | 105.1 | 81.2 | 61.3 | 214.7 | 65.3 | 100.1 | 106.3 | 52 |
| Beccaria - Agnolo | 178.5 | 64.2 |  | 124.8 |  | 78.7 | 122 | 96.5 | 110.8 | 40.8 |
| Agnolo - Pepi | 79.6 | 68 |  | 59.4 |  | 75.1 | 84.5 | 86.7 | 75.6 | 10.4 |
| Pepi - Magliabechi | 72.8 | 95.3 | 62.1 | 75.9 | 22.1 | 51.8 | 74.4 | 41.7 | 62 | 22.9 |
| Magliabechi - Tintori | 101.3 | 72.3 | 72.3 | 92.8 |  | 77.9 | 109.3 | 67.8 | 84.8 | 16.3 |
| Tintori - Torrigiani | 38.2 | 89.7 | 47.5 | 52.5 |  | 95.9 | 54.9 | 29.9 | 58.4 | 25.1 |
| Torrigiani - Ponte Vecchio | 62.7 | 52.6 | 43.3 | 60.3 | 80 | 68.2 |  | 79 | 63.7 | 13.4 |
| Ponte Vecchio - Coverelli | 84.8 | 125.1 | 89.4 | 98.9 | 99.9 | 110.2 |  | 130.1 | 105.5 | 17.2 |
| Coverelli - Guicciardini | 48 | 46.3 | 29.7 | 42.9 | 27.2 | 38.1 | 39 | 98.1 | 46.2 | 22.2 |
| Guicciardini - Ognissanti | 107.7 | 102.8 | 90.8 | 104.7 | 141.8 | 139 | 126.2 | 119.7 | 116.6 | 18.2 |
| Ognissanti - Soderini | 83.6 | 76.3 | 101.4 | 172.7 | 64.3 | 63.8 | 87.6 | 129.2 | 97.4 | 37.1 |
| Soderini - Fonderia | 73 | 73.4 | 34.7 | 40.4 | 59.2 | 48.6 | 51.7 | 50 | 53.9 | 14 |
| Fonderia - Santa Maria al Pignone | 51.3 | 66.9 | 49.1 | 57.1 | 47.1 | 55.4 | 24.7 | 62.4 | 51.8 | 12.8 |
| Santa Maria al Pignone - Vittorio Veneto | 80.3 |  | 105.8 | 105.6 | 61.9 | 71.2 | 97.1 | 77.3 | 85.6 | 17.4 |
| Vittorio Veneto - Leopolda | 27.1 |  | 15.1 | 42.4 | 15.8 | 15.6 | 14.6 | 25.5 | 22.3 | 10.3 |

## 10.3 Vehicle's consumption model

Using the drive cycles it is possible to evaluate the power demand of the vehicles. To do this, it is necessary to build a model that takes into account all the forces that oppose the vehicle's motion:

- Inertia force during accelerations
- Aerodynamic resistance
- Rolling friction due to the not ideal contact between wheels and street surface

Generally speaking, also the altitudes variation could be considered in such kind of models, however Firenze's topography is substantially plan and so it has been omitted.

Mathematical formulations of the three forces are presented below:

- $F_{in} = m\ a\ [N]$ where *m* is the mass and *a* is the acceleration.
- $F_{aer} = \frac{1}{2}\ \rho\ C_d\ S\ v^2\ [N]$ where $C_d$ is the aerodynamic resistance coefficient, *S* is the frontal surface of the vehicle, *ρ* is the air density, and *v* is the vehicle's speed.

- $F_{rot} = \frac{2\,P\,\mathrm{a}}{D} = r_{rot}\,P\ \ [N]$ where *P* is the weight on the wheel, *a* is the shift of the pressure profile while the vehicle moves and *D* is the diameter of the wheel (Figure 29)

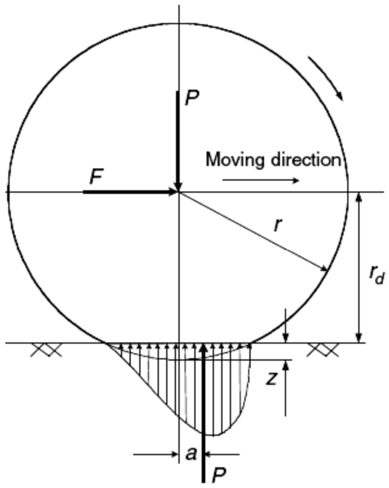


Figure 29 Rolling friction model

There is also to be taken into account the internal forces that oppose to the vehicle's motion. This forces could be represented in the "yield chain" within the vehicle itself.

The schematization of the vehicle is represented in Figure 30:

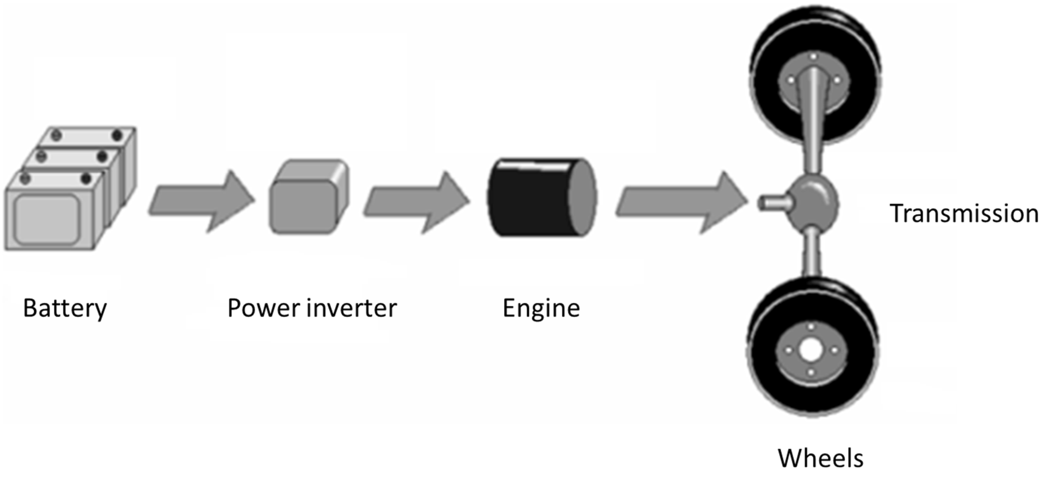


Figure 30 Yield chain within the vehicle

Parameters for the yields are 90% for battery discharging process, an average of 86% for the power inverter/engine group and 91% for the mechanical parts of the transmission/wheels group. The overall yield of the system will be (0):

2.

$$\eta_{tot} = \eta_{batt} * \eta_{inv} * \eta_{eng} * \eta_{trasm} \cong 0.7$$

Last aspect of the vehicle's absorption is the evaluation of the absorption of the auxiliary devices. The devices and their average power absorption have been obtained from the technical sheets of the vehicles themselves. They are reported in Table 49.

Table 49 Auxiliary devices' power absorption

| **Device** | **Power (W)** | **Utilization factor** |
|---|---|---|
| Compressors (x2) | 2x107 | 0.3 |
| Power steering pump | 1800 | 0.25 |
| External illumination | 140 | 1 |
| Internal illumination | 200 | 1 |
| Stop lights | 50 | 0.25 |
| On board instrumentation | 50 | 1 |

Auxiliary power absorption has been calculated as sum of the product between power of each device per utilization factor (0).

3. $$P_{aux} = \sum_i P_i * C_i \cong 920\, W$$

To keep the model as simple as possible, both yield and $P_{aux}$ has been considered constant during the driving.

The total absorption has been calculated as sum of the forces per speed obtained from the drive cycle (0).

4. $$P_{mec\ net} = (F_{in} + F_{aer} + F_{roll}) * speed$$

To have the total net Energy, it is necessary to calculate the integral along the time of the drive cycle between initial point and time “T” (0).

5 $$E_{mec\ net} = \int_0^T P_{mec\ net}(t)dt$$

To take into account also yields and auxiliary devices absorption, the equation is (0):

6. $$E_{tot} = \frac{E_{mec\ net}}{\eta_{tot}} + P_{aux} * t$$

Table 50, Table 51 and Table 52 report the lines’ net consumptions.

Table 50 Net consumptions for line C1 [Wh]

| Sub part Name | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Avg. | σ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parterre - Ponte Rosso | 105.18 | 146.10 | 119.91 | 100.75 | 109.28 | 128.11 | 125.34 | 138.00 | 180.06 | 98.29 | 125.1 | 25.0 |
| Ponte Rosso - Sant'anna | 217.64 | 189.52 | 194.28 | 197.77 | 165.16 | 164.87 | 144.33 | 168.99 | 162.44 | 190.11 | 179.5 | 21.8 |
| Sant'anna - Salvestrina | 120.50 | 128.66 | 118.88 | 75.89 | 147.32 | 89.82 | 109.43 | 86.49 | 107.70 | 132.51 | 111.7 | 22.4 |
| Salvestrina - Arazzieri | 123.91 | 147.92 | 113.03 | 148.27 | 115.95 | 145.88 | 85.20 | 84.80 |  | 69.98 | 115.0 | 29.7 |
| Arazzieri - Cavour | 174.34 | 193.52 | 176.20 | 140.96 | 125.68 | 256.41 | 173.34 | 172.87 |  | 176.12 | 176.6 | 36.3 |
| Cavour - San Lorenzo | 71.99 | 106.22 | 112.99 | 82.75 | 80.85 |  | 58.34 | 63.97 |  | 85.05 | 82.8 | 19.0 |
| San Lorenzo - Ginori | 60.62 | 55.08 | 52.55 | 60.18 | 39.24 |  | 52.33 | 47.91 |  | 50.68 | 52.3 | 6.9 |
| Ginori - Brunelleschi | 187.75 | 164.22 | 177.95 | 194.11 | 161.69 |  | 171.02 | 211.84 |  | 153.58 | 177.8 | 19.3 |
| Brunelleschi - Alfani | 85.95 | 68.73 | 64.34 | 69.69 | 74.01 | 78.47 | 57.02 | 47.78 |  | 64.26 | 67.8 | 11.3 |
| Alfani - Pilastri | 80.08 | 102.15 | 92.63 | 104.32 | 80.94 | 71.61 | 57.27 | 83.33 |  |  | 84.0 | 15.6 |
| Pilastri - Agenzia Del Territorio | 113.50 | 136.18 | 146.31 | 131.36 | 140.80 |  | 104.37 | 112.45 |  |  | 126.4 | 16.2 |
| Agenzia Del Territorio - Oriuolo | 174.43 | 213.75 | 211.81 | 211.47 | 173.69 |  | 230.70 | 232.78 |  | 232.89 | 210.2 | 24.1 |
| Oriuolo - Proconsolo | 82.66 | 65.04 | 59.69 | 66.03 | 64.19 | 75.74 | 51.99 | 67.46 |  | 84.33 | 68.6 | 10.6 |
| Proconsolo - Galleria Degli Uffizi | 148.23 |  | 134.95 | 173.71 | 156.37 | 145.35 | 152.39 | 147.34 |  | 192.94 | 156.4 | 18.4 |
| Galleria Degli Uffizi - Diaz | 122.48 |  | 138.91 | 123.39 | 121.85 | 93.43 | 106.92 | 112.83 |  | 120.38 | 117.5 | 13.4 |
| Diaz - Benci |  | 38.04 |  | 50.54 | 47.02 | 58.34 |  | 59.78 | 60.15 | 76.88 | 55.8 | 12.3 |
| Benci - Verdi |  | 122.84 | 130.73 | 102.78 | 121.93 | 112.50 |  | 113.22 | 107.47 | 126.89 | 117.3 | 9.8 |
| Verdi - Salvemini |  | 56.39 | 52.96 | 86.50 |  | 67.12 |  | 56.12 | 93.16 | 118.59 | 75.8 | 24.5 |
| Salvemini - Sant'egidio | 66.59 | 58.95 | 72.95 | 74.85 |  |  | 68.11 | 65.26 | 94.04 | 73.37 | 71.8 | 10.4 |
| Sant'egidio - Santa Maria Nuova | 59.03 | 70.15 | 65.69 | 63.40 | 47.40 |  | 56.03 | 63.69 | 45.91 | 86.59 | 62.0 | 12.3 |
| Santa Maria Nuova - Pucci | 89.25 | 106.11 | 101.59 | 102.63 | 86.87 | 96.57 | 111.68 | 98.14 | 88.16 | 120.87 | 100.2 | 10.9 |
| Pucci - San Marco | 187.84 | 179.50 | 189.76 | 188.79 | 157.85 | 177.49 | 177.69 | 160.37 | 196.32 | 219.59 | 183.5 | 17.7 |
| San Marco - Venezia | 210.37 | 226.13 | 209.11 | 203.83 | 209.86 | 232.21 | 228.31 | 186.08 | 205.64 | 246.18 | 215.8 | 17.3 |
| Venezia - Liberta' | 116.50 | 143.06 | 136.88 | 155.42 | 138.80 | 120.73 | 148.71 | 120.22 | 115.96 | 190.63 | 138.7 | 23.0 |
| Liberta' - Parterre | 216.62 | 265.44 | 269.08 | 250.25 | 268.79 | 268.90 | 303.00 | 335.33 | 276.59 | 226.92 | 268.1 | 34.1 |

Table 51 Net consumptions for line C2 [Wh]

| Sub part Name | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Avg. | σ |
|---|---|---|---|---|---|---|---|---|---|---|
| Leopolda - Il Prato | 137.4 | 142.5 |  |  | 160.8 | 145.8 |  | 155.6 | 148.4 | 9.6 |
| Il Prato - Santa Lucia | 68.2 | 61.5 | 64.2 | 70.4 | 70.8 | 70.7 | 81.7 | 89.0 | 72.1 | 9.1 |
| Santa Lucia - Stazione Orti Oricellari | 112.3 | 97.4 | 120.9 | 121.5 | 103.3 | 113.2 | 124.7 | 117.7 | 113.9 | 9.4 |
| Stazione Orti Oricellari - Stazione Via Panzani | 164.9 | 193.6 | 172.0 | 189.9 | 177.6 | 197.6 | 181.4 | 200.6 | 184.7 | 12.8 |
| Stazione Via Panzani - Pecori | 173.1 | 188.8 | 174.2 | 167.9 | 191.1 | 173.0 | 180.2 | 196.5 | 180.6 | 10.3 |
| Pecori - Roma | 52.7 | 55.7 | 54.1 | 52.4 | 47.5 | 58.5 | 43.1 | 59.8 | 53.0 | 5.5 |
| Roma - Orsanmichele | 62.1 | 59.5 | 50.7 | 57.2 | 56.8 | 52.0 | 49.7 | 71.6 | 57.5 | 7.2 |
| Orsanmichele - Canto Alla Quarconia | 68.6 | 79.1 | 72.5 | 72.6 | 62.5 | 64.0 | 76.5 | 75.2 | 71.4 | 5.9 |
| Canto Alla Quarconia - Ghibellina | 61.3 | 60.1 | 54.5 | 62.3 | 65.6 | 72.6 | 64.9 | 70.4 | 64.0 | 5.8 |
| Ghibellina - Teatro Verdi | 125.0 | 126.8 | 125.1 | 121.9 | 165.9 | 122.0 | 129.7 | 134.6 | 131.4 | 14.6 |
| Teatro Verdi - Malborghetto | 103.3 | 103.9 | 88.8 | 101.3 | 90.0 | 80.4 | 102.9 | 118.3 | 98.6 | 11.7 |
| Malborghetto - Annigoni | 95.3 | 97.9 | 92.0 | 88.7 | 126.3 | 110.2 | 119.1 | 123.0 | 106.6 | 14.9 |
| Annigoni - Leopardi | 137.7 | 168.0 | 150.4 | 140.2 | 154.2 | 163.9 | 172.6 | 156.9 | 155.5 | 12.6 |
| Leopardi - Beccaria | 103.5 | 103.4 | 108.1 | 95.1 | 121.4 | 112.1 | 114.1 | 137.3 | 111.9 | 13 |
| Beccaria - Agnolo | 170.2 | 180.8 | 205.7 | 198.7 | 199.8 | 229.5 | 206.3 | 200.7 | 198.9 | 17.7 |
| Agnolo - Salvemini | 143.3 | 139.4 | 123.3 | 139.0 | 168.2 | 182.8 | 137.8 | 151.3 | 148.1 | 19 |
| Salvemini - Oriuolo | 129.9 | 116.1 | 128.3 | 131.2 | 123.6 | 118.1 | 159.3 | 124.1 | 128.8 | 13.4 |
| Oriuolo - Proconsolo | 61.0 | 78.6 | 63.4 | 57.8 | 81.1 | 42.7 | 61.1 | 61.5 | 63.4 | 12.1 |
| Proconsolo - Condotta | 138.3 | 133.4 | 156.2 | 147.5 | 129.1 | 147.4 | 141.8 | 154.7 | 143.6 | 9.7 |
| Condotta - Porta Rossa | 44.1 | 53.3 | 58.3 | 44.2 | 44.0 | 49.0 | 45.2 | 42.7 | 47.6 | 5.5 |
| Porta Rossa - Repubblica | 44.3 | 42.7 | 42.5 | 36.5 | 27.1 | 34.9 | 47.5 | 45.6 | 40.1 | 6.8 |
| Repubblica - Olio | 83.4 | 84.7 | 74.8 | 87.7 | 68.1 | 59.6 | 84.1 | 96.7 | 79.9 | 11.8 |
| Olio - Stazione Piazza Dell'unita' | 146.0 | 152.7 | 156.8 | 153.0 | 169.2 | 140.1 | 139.6 | 148.4 | 150.7 | 9.6 |
| Stazione Piazza Dell'unita' - Stazione Scalette | 95.7 | 90.6 | 94.0 | 102.3 | 91.7 | 111.2 | 105.4 | 94.7 | 98.2 | 7.3 |
| Stazione Scalette - Palazzuolo | 158.8 | 150.4 | 154.3 | 147.2 | 185.6 | 198.8 | 190.3 | 162.4 | 168.5 | 20 |
| Palazzuolo - Rotonda Barbetti | 149.8 | 123.9 | 133.1 | 132.2 | 137.1 | 162.3 | 161.1 | 114.0 | 139.2 | 17.3 |
| Rotonda Barbetti - Solferino | 168.5 | 143.2 | 149.1 | 154.4 | 177.4 | 161.5 | 179.8 | 139.5 | 159.2 | 15.2 |

Table 52 Net consumptions for line C3 [Wh]

| Sub part Name | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Avg. | σ |
|---|---|---|---|---|---|---|---|---|---|---|
| Leopolda - Il Prato | 213.1 | | 269.7 | 173.0 | 180.3 | 194.0 | | 231.0 | 210.2 | 36.1 |
| Il Prato - Curtatone | 116.9 | | 108.3 | 103.2 | 130.1 | 126.4 | 120.4 | 119.9 | 117.9 | 9.5 |
| Curtatone - Ponte Vespucci | 156.2 | | | 131.9 | 191.4 | 181.4 | 179.7 | 239.2 | 180 | 36.1 |
| Ponte Vespucci - Sauro | 386.0 | | | 301.2 | 380.6 | 363.0 | 409.4 | 489.1 | 388.2 | 61.5 |
| Sauro - Porta Romana | 385.5 | | 407.4 | 394.1 | | 389.0 | 352.7 | 421.8 | 391.7 | 23.3 |
| Porta Romana - Pitti | 363.9 | | 336.9 | 313.2 | | 325.5 | 350.0 | 409.4 | 349.8 | 34.2 |
| Pitti - Bardi | 135.9 | | 150.1 | 129.7 | 206.4 | 148.8 | | 171.0 | 157 | 28.1 |
| Bardi - Mozzi | 139.8 | | 164.7 | 155.0 | 164.7 | 113.7 | | 119.8 | 143 | 22.3 |
| Mozzi - Benci | 126.2 | | 91.0 | 75.8 | 116.5 | 119.9 | 143.1 | 111.2 | 111.9 | 22.4 |
| Benci - Verdi | 121.9 | | 114.6 | 90.3 | 127.8 | 119.6 | 129.1 | 94.3 | 114 | 15.6 |
| Verdi - Teatro Verdi | 40.1 | | 54.4 | 46.0 | 61.5 | 43.1 | 32.9 | 31.5 | 44.2 | 10.9 |
| Teatro Verdi - Malborghetto | 67.8 | | 89.8 | 60.8 | 106.5 | 63.2 | 112.7 | 146.8 | 92.5 | 31.7 |
| Malborghetto - Annigoni | 87.8 | | 134.0 | | 84.6 | 73.4 | 87.3 | 64.1 | 88.5 | 24.1 |
| Annigoni - Leopardi | 191.6 | | 209.0 | | 205.2 | 150.5 | 157.8 | 187.4 | 183.6 | 24.3 |
| Leopardi - Beccaria | 120.5 | | 139.0 | 92.6 | 155.8 | 108.7 | 168.9 | 103.9 | 127 | 28.3 |
| Beccaria - Agnolo | 244.1 | 177.8 | | 184.7 | | 195.9 | 306.2 | 258.3 | 227.8 | 50.5 |
| Agnolo - Pepi | 136.8 | 135.4 | | 83.9 | | 111.9 | 114.1 | 126.5 | 118.1 | 19.7 |
| Pepi - Magliabechi | 81.7 | 103.7 | 114.2 | 66.4 | 79.5 | 77.0 | 85.0 | 92.9 | 87.6 | 15.4 |
| Magliabechi - Tintori | 144.0 | 58.7 | 180.8 | 61.1 | | 123.1 | 162.3 | 94.2 | 117.7 | 48.2 |
| Tintori – Torrigiani | 136.9 | 149.7 | 103.7 | 122.7 | | 133.2 | 117.5 | 126.4 | 127.2 | 14.7 |
| Torrigiani - Ponte Vecchio | 114.9 | 151.6 | 86.1 | 96.5 | 91.8 | 84.0 | | 116.4 | 105.9 | 24 |
| Ponte Vecchio - Coverelli | 157.0 | 259.6 | 231.5 | 141.1 | 269.0 | 178.6 | | 195.9 | 204.7 | 49.9 |
| Coverelli - Guicciardini | 66.7 | 128.5 | 120.8 | 78.8 | 45.2 | 95.7 | 92.8 | 82.8 | 88.9 | 27.2 |
| Guicciardini - Ognissanti | 182.6 | 255.7 | 238.4 | 156.4 | 250.2 | 220.7 | 223.9 | 220.7 | 218.6 | 33.7 |
| Ognissanti – Soderini | 149.7 | 163.0 | 215.6 | 148.4 | 199.4 | 175.1 | 214.6 | 193.5 | 182.4 | 27.3 |
| Soderini – Fonderia | 132.0 | 124.2 | 141.8 | 123.5 | 171.6 | 150.6 | 199.7 | 124.9 | 146 | 27.2 |
| Fonderia - Santa Maria Al Pignone | 128.4 | 156.4 | 146.6 | 82.4 | 195.8 | 147.1 | 62.8 | 163.4 | 135.4 | 43.5 |
| Santa Maria Al Pignone - Vittorio Veneto | 275.3 | | 322.9 | 191.7 | 321.9 | 339.4 | 311.1 | 302.7 | 295 | 49.8 |
| Vittorio Veneto - Leopolda | 33.0 | | 57.9 | 65.1 | 55.9 | 25.3 | 71.2 | 59.1 | 52.5 | 16.9 |

Table 53, Table 54 and Table 55 report the average data for the city center bus service and the overall average power consumption per trait:

Table 53 Summary for line C1

| Trait name | Stop % | Routing Time [s] | Net energy [Wh] | Yield | Auxiliary [W] | Total energy [Wh] |
|---|---|---|---|---|---|---|
| Parterre - Ponte Rosso | 1.00 | 644.0 | 125.1 | 0.7 | 920 | 343.3 |
| Ponte Rosso - Sant'anna | 0.80 | 136.6 | 179.5 | | | 291.3 |
| Sant'anna - Salvestrina | 0.40 | 43.3 | 111.7 | | | 170.6 |
| Salvestrina - Arazzieri | 0.44 | 55.8 | 115.0 | | | 178.5 |
| Arazzieri – Cavour | 1.00 | 155.4 | 166.6 | | | 277.7 |
| Cavour - San Lorenzo | 0.25 | 81.0 | 82.8 | | | 139.0 |
| San Lorenzo – Ginori | 1.00 | 61.3 | 52.3 | | | 90.4 |
| Ginori – Brunelleschi | 0.38 | 172.7 | 177.8 | | | 298.1 |
| Brunelleschi – Alfani | 0.44 | 41.5 | 67.8 | | | 107.5 |
| Alfani – Pilastri | 0.13 | 51.3 | 84.0 | | | 133.1 |
| Pilastri - Agenzia Del Territorio | 0.43 | 102.4 | 126.4 | | | 206.7 |
| Agenzia Del Territorio - Oriuolo | 0.75 | 131.3 | 210.2 | | | 333.8 |
| Oriuolo – Proconsolo | 0.33 | 39.0 | 68.6 | | | 108.0 |
| Proconsolo - Galleria Degli Uffizi | 0.25 | 81.8 | 156.4 | | | 244.3 |
| Galleria Degli Uffizi - Diaz | 0.38 | 81.2 | 117.5 | | | 188.6 |
| Diaz – Benci | 1.00 | 208.6 | 55.8 | | | 133.0 |
| Benci – Verdi | 0.89 | 84.0 | 117.3 | | | 189.0 |
| Verdi – Salvemini | 0.88 | 77.4 | 75.8 | | | 128.1 |
| Salvemini - Sant'egidio | 0.88 | 69.6 | 71.8 | | | 120.4 |
| Sant'egidio - Santa Maria Nuova | 0.22 | 46.2 | 62.0 | | | 100.4 |
| Santa Maria Nuova - Pucci | 0.80 | 72.2 | 100.2 | | | 161.6 |
| Pucci - San Marco | 1.00 | 112.8 | 183.5 | | | 291.0 |
| San Marco – Venezia | 1.00 | 100.3 | 215.8 | | | 333.9 |
| Venezia - Liberta' | 0.50 | 90.3 | 138.7 | | | 221.2 |
| Liberta' – Parterre | 1.00 | 160.6 | 268.1 | | | 424.0 |
| **Total** | | **2900.6** | **3130.7** | | | **5213.5** |

Table 54 Summary for line C2

| Trait name | Stop % | Routing Time [s] | Net energy [Wh] | Yield | Auxiliary [W] | Total energy [Wh] |
|---|---|---|---|---|---|---|
| Leopolda - Il Prato | 1.00 | 281.6 | 148.4 | 0.7 | 920 | 284.0 |
| Il Prato - Santa Lucia | 0.00 | 37.2 | 72.1 | | | 112.5 |
| Santa Lucia - Stazione Orti Oricellari | 0.63 | 84.2 | 113.9 | | | 184.2 |
| Stazione Orti Oricellari - Stazione Via Panzani | 1.00 | 313.2 | 184.7 | | | 343.9 |
| Stazione Via Panzani - Pecori | 0.50 | 139.3 | 180.6 | | | 293.6 |
| Pecori – Roma | 0.88 | 48.6 | 53.0 | | | 88.1 |
| Roma - Orsanmichele | 0.75 | 69.9 | 57.5 | | | 100.0 |
| Orsanmichele - Canto Alla Quarconia | 0.88 | 102.7 | 71.4 | | | 128.2 |
| Canto Alla Quarconia - Ghibellina | 0.00 | 52.6 | 64.0 | | | 104.9 |
| Ghibellina - Teatro Verdi | 0.63 | 97.2 | 131.4 | | | 212.6 |
| Teatro Verdi - Malborghetto | 0.63 | 67.7 | 98.6 | | | 158.2 |
| Malborghetto - Annigoni | 0.88 | 96.2 | 106.6 | | | 176.9 |
| Annigoni – Leopardi | 0.75 | 93.5 | 155.5 | | | 246.0 |
| Leopardi – Beccaria | 0.75 | 96.6 | 111.9 | | | 184.5 |
| Beccaria – Agnolo | 1.00 | 251.2 | 198.9 | | | 348.3 |
| Agnolo – Salvemini | 0.63 | 102.2 | 148.1 | | | 237.7 |
| Salvemini – Oriuolo | 0.88 | 105.1 | 128.8 | | | 210.9 |
| Oriuolo – Proconsolo | 0.50 | 46.9 | 63.4 | | | 102.6 |
| Proconsolo - Condotta | 0.50 | 123.6 | 143.6 | | | 236.7 |
| Condotta - Porta Rossa | 0.38 | 66.1 | 47.6 | | | 84.9 |
| Porta Rossa - Repubblica | 0.00 | 35.9 | 40.1 | | | 66.5 |
| Repubblica – Olio | 0.88 | 87.3 | 79.9 | | | 136.5 |
| Olio - Stazione Piazza Dell'unita' | 0.50 | 122.2 | 150.7 | | | 246.5 |
| Stazione Piazza Dell'unita' - Stazione Scalette | 1.00 | 171.7 | 98.2 | | | 184.2 |
| Stazione Scalette - Palazzuolo | 1.00 | 207.8 | 168.5 | | | 293.8 |
| Palazzuolo - Rotonda Barbetti | 0.50 | 115.8 | 139.2 | | | 228.5 |
| Rotonda Barbetti - Solferino | 0.13 | 79.9 | 159.2 | | | 247.8 |
| Solferino – Leopolda | 0.25 | 50.8 | 103.6 | | | 161.0 |
| **Total** | | **3147** | **3219.4** | | | **5403.5** |

Table 55 Summary for line C3

| Trait name | Stop % | Routing Time [s] | Net energy [Wh] | Yield | Auxiliary [W] | Total energy [Wh] |
|---|---|---|---|---|---|---|
| Leopolda - Il Prato | 1.00 | 300.3 | 210.2 | 0.7 | 920 | 377.0 |
| Il Prato - Curtatone | 0.00 | 46.1 | 117.9 | | | 180.2 |
| Curtatone - Ponte Vespucci | 0.33 | 84.2 | 180.0 | | | 278.7 |
| Ponte Vespucci - Sauro | 0.00 | 217.5 | 388.2 | | | 610.2 |
| Sauro - Porta Romana | 1.00 | 210.7 | 391.7 | | | 613.4 |
| Porta Romana - Pitti | 0.67 | 171.8 | 349.8 | | | 543.6 |
| Pitti - Bardi | 0.50 | 106.9 | 157.0 | | | 251.6 |
| Bardi - Mozzi | 0.67 | 97.8 | 143.0 | | | 229.3 |
| Mozzi - Benci | 0.00 | 52.9 | 111.9 | | | 173.4 |
| Benci - Verdi | 0.86 | 112.7 | 114.0 | | | 191.7 |
| Verdi - Teatro Verdi | 0.57 | 56.8 | 44.2 | | | 77.7 |
| Teatro Verdi - Malborghetto | 0.14 | 67.8 | 92.5 | | | 149.5 |
| Malborghetto - Annigoni | 0.83 | 98.0 | 88.5 | | | 151.5 |
| Annigoni - Leopardi | 0.83 | 117.4 | 183.6 | | | 292.3 |
| Leopardi - Beccaria | 0.43 | 106.3 | 127.0 | | | 208.6 |
| Beccaria - Agnolo | 0.67 | 110.8 | 227.8 | | | 353.7 |
| Agnolo - Pepi | 0.67 | 75.6 | 118.1 | | | 188.0 |
| Pepi - Magliabechi | 0.50 | 62.0 | 87.6 | | | 141.0 |
| Magliabechi - Tintori | 0.43 | 84.8 | 117.7 | | | 189.8 |
| Tintori - Torrigiani | 0.57 | 58.4 | 127.2 | | | 196.6 |
| Torrigiani - Ponte Vecchio | 0.00 | 63.7 | 105.9 | | | 167.6 |
| Ponte Vecchio - Coverelli | 0.43 | 105.5 | 204.7 | | | 319.4 |
| Coverelli - Guicciardini | 0.75 | 46.2 | 88.9 | | | 138.8 |
| Guicciardini - Ognissanti | 0.88 | 116.6 | 218.6 | | | 342.1 |
| Ognissanti - Soderini | 0.50 | 97.4 | 182.4 | | | 285.5 |
| Soderini - Fonderia | 0.63 | 53.9 | 146.0 | | | 222.3 |
| Fonderia – S. Maria Al Pignone | 0.13 | 51.8 | 135.4 | | | 206.7 |
| S. Maria Al Pignone - Vittorio Veneto | 0.14 | 85.6 | 295.0 | | | 443.3 |
| Vittorio Veneto - Leopolda | 0.14 | 22.3 | 52.5 | | | 80.7 |
| **Total** | | **2881.8** | **4807.3** | | | **7604.2** |

## 10.4 System simulation

Simulation analysis for processes is a tool that allows to evaluate different scenarios with different input variables values without any direct interactions with reality. This characteristic is very useful in situations where to provide experiments is very expensive or even not possible. This is a fit approach for wireless charging, where the infrastructure does not exist yet. Data about travel time and energy consumption reported in the previous chapters will be used as input data for the simulation model.

Within this study, a commercial software has been used to develop the model. The software is Rockwell Arena that is based on a “process iteration” approach, so a chronological representation of the system states along the time. The software allows to describe the process in a graphical way, activities with blocks, decisions with rhombus, fluxes with arrows etc., in order to make easy the schematization phase. The elements within a simulation model are:

1. Entities: the objects that cross the system and modify its status. Each single vehicle within the model will be an entity.
2. Attributes: characteristic of the specific entities.
3. Resource: tools used by the entities.
4. Variables: values that define the system state.

Rokwell Arena is a software based on the Montecarlo method to determine pseudo-casual values for the variables [5]. So it is necessary to find out the data statistical distribution for each of the values that have to be simulated. Within this study the used variables have been consumption, time to cross a trait and probability to stop.

The system has been schematized as reported in Figure 31, where as an example has been reported the Line C1 model.

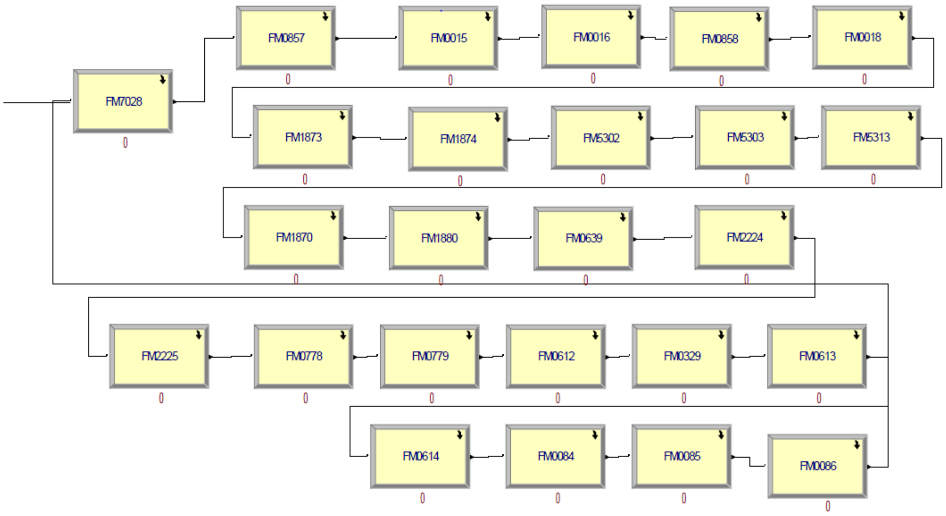


Figure 31 Schematization of line C1

Each box above represents one of the line stop and to allow an easier navigation within the model itself, the terminal stops have been reported on the extreme left of the diagram.

In addition it is important to mention that the simulation software will evaluate the system evolution whenever an entity will cross one box. This kind of modeling is defined “event driven” because the software evaluate the system evolution when something happens, and not for each time step. This kind of solution is used to reduce the calculation time for complex systems.

The simulation software evaluate the charge/discharge behavior of the battery basing on the balance equation reported below:

$$7. \quad SOC_{out} = SOC_{in} + PI_{capacity} * TIME_{stop} - DISCHARGE$$

Where:

- SOCout: the SOC at the end of a certain trait.
- SOCin: the state of charge (expressed in kWh) of the battery before to be charged by infrastructure or discharged by driving cycle. This value is the result of the previous behavior of the system.
- PIcapacity: parameter that express the power inverter capacity at each stop.
- TIMEstop: variable that determines the stop time at a certain stop.
- DISCHARGE: variable that expresses a certain discharge value for a single trait.

If the power inverter is installed in a certain stop, the battery can be recharged, otherwise only discharging is considered. The time to reach the next stop is also evaluate in order to understand if vehicles overlapping could be at the recharge stations .

To have a structured data log at the end of each simulation, the variables have been arranged as matrix, divided per line. Rows are the values recorded or evaluate and columns are the single vehicles of the line. Here below the general structure of each variable has been reported (Table 56).

Table 56 Simulation variable 1 structure

| Trait name | Bus 1 | Bus 2 | Bus 3 | Bus 4 | Bus n |
|---|---|---|---|---|---|
| Tnow | | | | | |
| SOC | | | | | |
| Position | | | | | |
| T_pre_ter | | | | | |
| T_post_ter | | | | | |
| T_pre_tr | | | | | |
| T_post_tr | | | | | |
| # Run | | | | | |
| | | | | | |

In the “tnow” row it is recorded the time of the day of the data; “SOC” is the actual state of charge of the battery; “Position” determine the stop where the record has been done; “T_pre_ter” is the time when the vehicle arrives at terminal stop, “T_post_ter” is the time when the vehicle leaves a terminal stop, the same for “T_pre_tr” and “T_post_tr”, but for normal stops. The differentiation of these variables is very useful for the analysis phase. At least, “#Run” records the number of run during the working day: for example, each time a vehicle reach the first terminal stop, this variable is increased of 1.

Another variable has been set to insert data about presence and power of power inverters (Table 57):

Table 57 Simulation variable 2 structure

| Trait name | Stop #1 | Stop #2 | Stop #3 | … | Stop #n |
|---|---|---|---|---|---|
| Length | | | | | |
| Static_PI | | | | | |
| | | | | | |

In “Length” it is possible to enter the trait length between two stops. Within the static en-route analysis this data is not significant, however it will be for the dynamic recharge analysis and so the model has already been set. “Static_PI” refers to the power of power inverter; if this value is not set and the relative cell is left blank, the power inverter is not introduced within the relative stop.

For what concern the data logging, in each sub-model the ending part after the simulation of vehicle behavior refers not to a physical process, but it fills a .txt file with all the data that has to be post-processed.

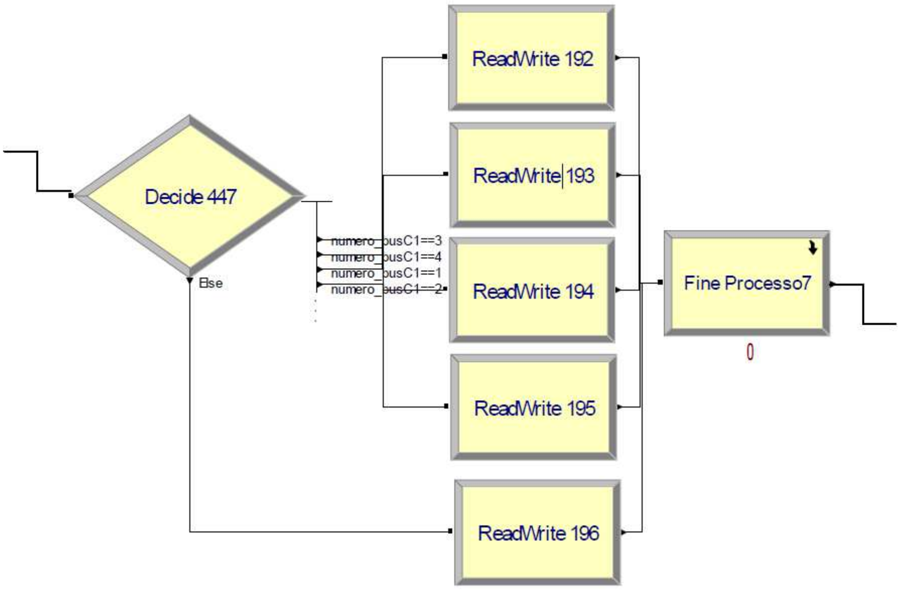


Figure 32 Data logger structure

The example reported in Figure 32 refers to a generic stop. The blocks refers to:

- Decide: this block switches the entity depending on the number of the vehicle.
- Read/Write: these blocks fill the relative vehicle .txt file of data log. In general, the Read/Write block allows the Arena software to communicate with other analysis software.
- Fine Processo: this is the final block that close the relative variable and makes it ready for next write.

Before to start the simulation, the model has to be validated. The model validation procedure, in general, includes the modeling of the "as-is" situation and the calculation of some "fitness index" both for reality and simulated case. When these index coincide, the model could be considered validated and the experimental phase could start. However, wireless recharge is not available at the moment and so it is necessary to provide an indirect validation procedure. It has been conducted in two aspects, by considering the stop time in terminal stops and the "total battery discharge" time in the situation of no recharge during the day. Real and simulated data has been compared with t-student hypothesis test on the average values for what concern the stop times and graphically for what concern the discharge time. T-student method gives about 80% of positive results and graphical method results of simulation accord with reality time of battery discharge, as it is possible to see in the below figure.

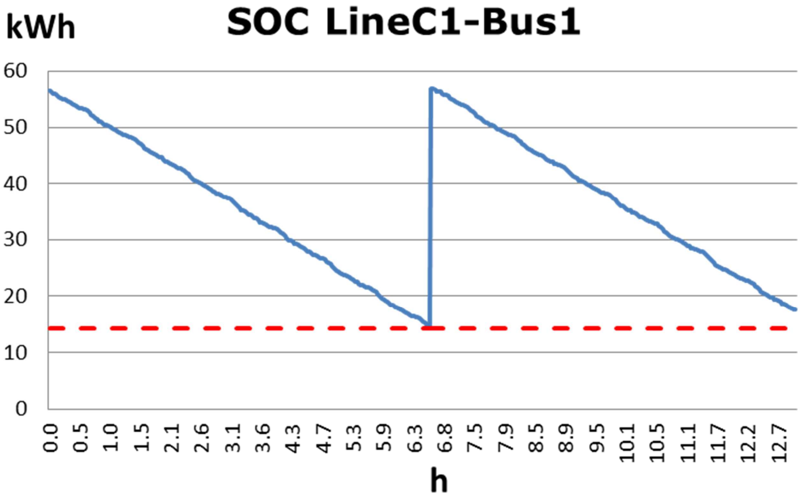


Figure 33 SOC trend for line C1 bus 1 in as-is scenario

Figure 33 reports an example of the as is simulated situation: in accord with reality, at about half of the working day, bus' battery fells under the protection limit and has to be replaced with a fully recharged one.

Before to start the simulations, a cost function has been defined in order to evaluate different scenarios:

$$8. \quad Total\ Cost = \sum_{j=1}^{n}(Battery\ cost_j +\ Battery\ Substitution\ Cost_j) + \sum_{i=1}^{m} Infrastructure\ Cost_i$$

In equation 8, j represents the total batteries used in the control time period and i represents the recharge points developed.

The simulations have been carried out considering a 50 kW power inverter. No overlapping issues has been found and so the total number of charging stations locations for C1 C2 and C3 lines are 4.

After the validation phase, first simulation has been made with an on board battery of 3.75 kWh (protection limits 3.1 – 1.5 kWh) and a power inverter of 50 kW at each of terminal stop (Figure 34).

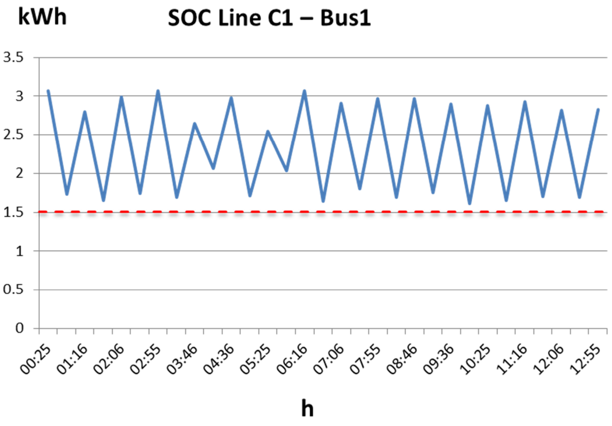


Figure 34 Example of SOC trend for line C1 bus 1 in 4 kWh scenario

This scenario is the one with the less possible battery dimension that does not allow the SOC to fall down the lower protection limit during the simulated period. The workload is all up to the infrastructure and the battery pack is only needed as a kind of energy buffer to reach the next recharge station.

Another scenario provided, instead, is the opposite. In fact, the battery size is wider and the workload is distributed between battery and infrastructure; the bus starts the service in the morning with a full charged battery and finishes with SOC very close to the lower limit, always without any stop during the daytime. Battery limits are 24 – 9.6 kWh (Figure 35)

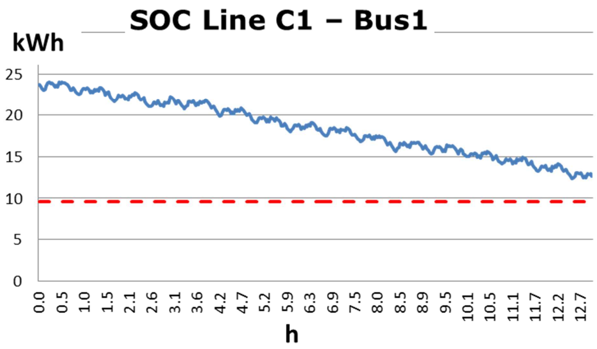


Figure 35 Example of SOC trend for line C1 bus 1 in 24 kWh scenario

To choose which between the proposed scenarios could be considered the best, total cost of ownership of each proposal has been determined with the above presented cost function. The considered amortization period has been set in 20 years.

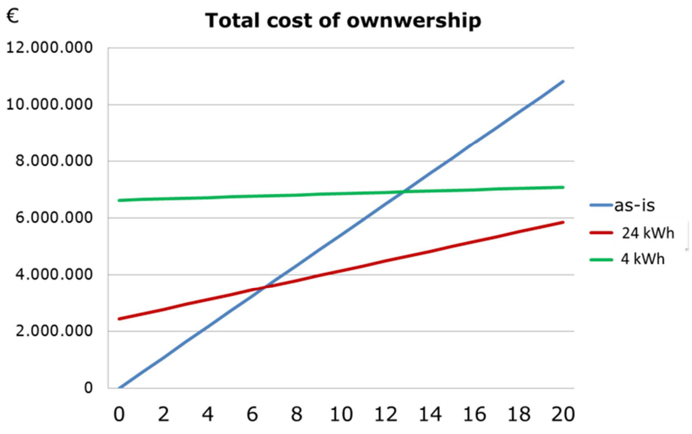


Figure 36 Scenarios' total cost of ownership benchmark

As it is possible to see in the graph (Figure 36), the as-is situation is the lowly cost effective within the 20 years considered. Instead, the most cost effective situation is the one that equips on board a 24 kWh battery.

# 11 Annex IV – List of the taxi available parking slots in Firenze

This Annex reports the list of the parking slots available for taxi service for each stations, located in Firenze.

Table 58 Firenze's parking spaces

| **Taxi stations** | **Parking spaces** |
|---|---|
| Stazione FS Santa Maria Novella | 27 |
| Aeroporto Amerigo Vespucci | 20 |
| Piazza della Repubblica | 16 |
| Piazza San Marco | 12 |
| San Giovanni - Via dei Pecori | 9 |
| Stazione FS Campo di Marte | 9 |
| Piazzale Donatello | 8 |
| Piazza Francia | 8 |
| Piazza Santa Maria Novella | 8 |
| Piazza Beccaria | 7 |
| Regione Toscana - Via di Novoli | 7 |
| Piazzale di Porta Romana | 7 |
| Piazza del Duomo | 7 |
| Ospedale di Careggi - Largo Brambilla | 6 |
| Palazzo di Giustizia - Viale Guidoni | 6 |
| Parterre - Via Mafalda di Savoia | 6 |
| Piazza Indipendenza | 5 |
| Piazza Ognissanti | 5 |
| Piazza Santa Croce | 5 |
| Piazza del Terzolle | 5 |
| Piazza Alberti | 4 |
| Viale Calatafimi | 4 |
| Piazza Ferrucci | 4 |
| Viale Segni | 4 |
| Viale Strozzi | 4 |
| Viale Guidoni | 4 |
| Stazione FS Rifredi | 4 |
| Piazza dell'Unità Italiana | 4 |
| Via Pio Fedi | 3 |
| Borgo San Jacopo | 3 |

| | |
|---|---|
| Piazza delle Cure | 3 |
| Piazza Giorgini | 3 |
| Stazione Leopolda | 3 |
| Piazza della Libertà | 3 |
| Piazzale Michelangelo | 3 |
| Via del Cavallaccio | 3 |
| Ponte Vecchio - Lungarno degli Acciaiuoli | 3 |
| Via Pratese | 3 |
| Piazza Puccini | 3 |
| RAI - Largo De Gasperi | 3 |
| Piazza di San Jacopino | 3 |
| Piazza Starnina | 3 |
| Ospedale di Torregalli | 3 |
| Fortezza da Basso - Piazza Bambini di Beslan | 3 |
| Viale Verga | 3 |
| Via del Prato | 3 |
| Piazza Acciaiuoli | 2 |
| Via Bolognese - Località La Lastra | 2 |
| Piazza dè Mozzi | 2 |
| Piazza Pier Vettori | 2 |
| Stazione FS Castello | 2 |

# 12 Annex V – List of the charging stations in Firenze Downtown (Use case public mobility)

This Annex reports the list of the charging stations in Firenze Downtown for the public mobility service used as input of the economical analysis.

| Station name | Longitude | Latitude | No stations | Zone (C=City center) |
|---|---|---|---|---|
| Boito | 11,21882250 | 43,78809090 | 3 | C |
| Kennedy | 11,21862920 | 43,78108610 | 2 | C |
| Via della dogana | 11,2597491 | 43,7791710 | 6 | C |
| La Pira | 11,25965770 | 43,77824970 | 3 | C |
| Stazione via Alamanni | 11,24544240 | 43,77806660 | 6 | C |
| Cascine | 11,23117850 | 43,77793640 | 1 | C |
| Stazione palazzo dei congressi | 11,24911500 | 43,77746030 | 8 | C |
| Stazione deposito bagagli | 11,24856330 | 43,77705220 | 5 | C |
| Stazione galleria | 11,24868710 | 43,77616150 | 1 | C |
| Stazione parcheggio | 11,24955500 | 43,77602890 | 3 | C |
| Stazione Mercato centrale | 11,25067100 | 43,77506040 | 3 | C |
| Santa Maria Maggiore | 11,25278540 | 43,77304210 | 1 | C |
| Ferrucci | 11,27193190 | 43,76396010 | 3 | C |
| Pia.le Michelangelo | 11,26521930 | 43,76244720 | 3 | C |
| San Giusto della Calza | 11,24215720 | 43,76134640 | 2 | C |
| Fermi | 11,24935000 | 43,75031100 | 1 | C |

| | |
|---|---|
| Total | 51 |
| Power required [kW] | 2550 |

Table 59 list of Firenze’s downtown charging stations

# 13 Annex VI – List of all charging stations in Firenze (Use case public mobility)

This Annex reports the list of all charging stations in Firenze area for a total public mobility service used as input of the economical analysis.

| Station name | Longitude | Latitude | No Charging stations | Zone (C=City Center, NC=No City Center) |
|---|---|---|---|---|
| Legri | 11,22411930 | 43,91406600 | 1 | NC |
| Calenzano centro | 11,16688970 | 43,86361280 | 2 | NC |
| Cimitero Calenzano | 11,16171410 | 43,86156300 | 2 | NC |
| Calenzano | 11,16090070 | 43,86106570 | 3 | NC |
| il rosi | 11,14014290 | 43,85725190 | 1 | NC |
| Caponnetto | 11,16213410 | 43,84866720 | 1 | NC |
| Caduti di Radio Cora | 11,26236570 | 43,84510680 | 1 | NC |
| GKN | 11,14139400 | 43,84477100 | 1 | NC |
| Manetti | 11,16917260 | 43,84387690 | 1 | NC |
| Officine Galileo | 11,14937430 | 43,84241920 | 1 | NC |
| La Querciola | 11,31963030 | 43,84134140 | 3 | NC |
| Campi Bisenzio Galilei | 11,12928080 | 43,83935800 | 2 | NC |
| Caldine Nuove | 11,30849240 | 43,83911280 | 1 | NC |
| Volpaia | 11,17763860 | 43,83855000 | 2 | NC |
| Togliatti | 11,18234670 | 43,83701510 | 1 | NC |
| Biblioteca di doccia | 11,21446580 | 43,83655740 | 1 | NC |
| Piazza Togliatti | 11,13150890 | 43,83440090 | 2 | NC |
| Sesto Fiorentino Vittorio Veneto | 11,19952320 | 43,83191380 | 2 | NC |
| Pian di San Bartolo | 11,28696330 | 43,83174070 | 2 | NC |
| Sesto Fiorentino mille | 11,20702780 | 43,82863140 | 2 | NC |
| Serpiolle | 11,25641410 | 43,82336880 | 1 | NC |
| Campi di Bisenzio Verdi | 11,14115030 | 43,82148490 | 1 | NC |
| Schiff | 11,19375810 | 43,82070280 | 1 | NC |
| Careggi | 11,25105100 | 43,81299270 | 4 | NC |
| Motorizzazione Civile | 11,16533900 | 43,81229120 | 1 | NC |
| Sant'Angelo a Lecore | 11,08332650 | 43,81191400 | 1 | NC |
| Ticino | 11,17842200 | 43,81083920 | 1 | NC |
| Adige | 11,17618640 | 43,80886630 | 2 | NC |
| Niccolo' da Tolentino | 11,24351110 | 43,80785650 | 3 | NC |
| Piazza Marconi | 11,18482900 | 43,80768390 | 1 | NC |
| Caruso | 11,23892210 | 43,80748280 | 4 | NC |
| Fiesole - Vinandro Osteria | 11,29219310 | 43,80708340 | 4 | NC |
| Villa Cancelli | 11,26116860 | 43,80703980 | 1 | NC |
| La Lastra | 11,27439680 | 43,80656600 | 1 | NC |
| Nuovo pignone | 11,22580230 | 43,80595390 | 5 | NC |

| | | | | |
|---|---|---|---|---|
| Patologia1 | 11,24563480 | 43,80310920 | 5 | NC |
| Incontri | 11,25407170 | 43,80267420 | 1 | NC |
| Patologia | 11,24549450 | 43,80247430 | 1 | NC |
| Michelacci | 11,18967210 | 43,80191900 | 2 | NC |
| Deposito peretola | 11,19064670 | 43,80118330 | 1 | NC |
| Rifredi - Vasco de Gama | 11,23576940 | 43,79999970 | 5 | NC |
| Salviati FS | 11,27518020 | 43,79937140 | 1 | NC |
| Barsanti | 11,22551610 | 43,79673520 | 1 | NC |
| Dalmazia | 11,24029900 | 43,79655270 | 3 | NC |
| Lippi e Macia | 11,21774420 | 43,79565570 | 3 | NC |
| San Donnino | 11,15062150 | 43,79543100 | 1 | NC |
| Boccaccio | 11,27407640 | 43,79350200 | 1 | NC |
| Piagge FS | 11,17233050 | 43,79012690 | 4 | NC |
| Boito | 11,21882250 | 43,78809090 | 3 | C |
| Cure | 11,2690160 | 43,7866800 | 1 | NC |
| Salviatino | 11,29402020 | 43,78488860 | 2 | NC |
| Mulino biondi | 11,27309460 | 43,78452890 | 2 | NC |
| Sosta del rosellino | 11,32160000 | 43,78299070 | 2 | NC |
| Piovano Arlotto | 11,16801320 | 43,78222280 | 1 | NC |
| Kennedy | 11,21862920 | 43,78108610 | 2 | C |
| Badia a settimo | 11,14612320 | 43,78044830 | 3 | NC |
| Via della dogana | 11,2597491 | 43,7791710 | 6 | C |
| Porto di Mezzo | 11,07951760 | 43,77901030 | 2 | NC |
| Verga | 11,29795800 | 43,77862180 | 4 | NC |
| La Pira | 11,25965770 | 43,77824970 | 3 | C |
| San Colombano | 11,13606740 | 43,77810670 | 2 | NC |
| Stazione via alamanni | 11,24544240 | 43,77806660 | 6 | C |
| Cascine | 11,23117850 | 43,77793640 | 1 | C |
| Stazione palazzo dei congressi | 11,24911500 | 43,77746030 | 8 | C |
| Stazione deposito bagagli | 11,24856330 | 43,77705220 | 5 | C |
| Stazione galleria | 11,24868710 | 43,77616150 | 1 | C |
| Stazione parcheggio | 11,24955500 | 43,77602890 | 3 | C |
| Il roseto | 11,36314430 | 43,77547620 | 1 | NC |
| Novelli | 11,29446520 | 43,77543580 | 6 | NC |
| Stazione Mercato centrale | 11,25067100 | 43,77506040 | 3 | C |
| Santa Maria Maggiore | 11,25278540 | 43,77304210 | 1 | C |
| La casella | 11,19055600 | 43,77219050 | 1 | NC |
| di sotto | 11,10552750 | 43,77188050 | 1 | NC |
| Foggini | 11,21220060 | 43,77174190 | 1 | NC |
| Pier della Francesca | 11,21220220 | 43,77072610 | 2 | NC |
| Comparetti | 11,30118160 | 43,76994880 | 3 | NC |
| Il Girone | 11,34019690 | 43,76975810 | 3 | NC |
| Cadorna | 11,10670010 | 43,76949550 | 3 | NC |
| Ripa | 11,30924170 | 43,76756310 | 4 | NC |
| Spontini | 11,17360100 | 43,76593570 | 2 | NC |
| Via del filarete | 11,21396640 | 43,76572040 | 3 | NC |

| | | | | |
|---|---|---|---|---|
| Ferrucci | 11,27193190 | 43,76396010 | 3 | C |
| San Lorenzo a Greve | 11,19783610 | 43,76276140 | 1 | NC |
| Pia.le Michelangelo | 11,26521930 | 43,76244720 | 3 | C |
| Cimitero di Soffiano | 11,21676150 | 43,76190910 | 1 | NC |
| Villamagna | 11,38248920 | 43,76175440 | 1 | NC |
| Nave a Rovezzano | 11,30688540 | 43,76156340 | 4 | NC |
| San Giusto della Calza | 11,24215720 | 43,76134640 | 2 | C |
| Scuola magistrati | 11,13906170 | 43,76089000 | 2 | NC |
| 68esimo reggimento | 11,18134560 | 43,75944680 | 5 | NC |
| Ospedale torri galli | 11,20248530 | 43,75873500 | 9 | NC |
| Bagnese | 11,19739160 | 43,75617410 | 1 | NC |
| De Andrè | 11,17868060 | 43,75424050 | 2 | NC |
| Sorgane Piazza Rodolico | 11,30610140 | 43,75417380 | 2 | NC |
| Scuola Rodari | 11,17906070 | 43,75404320 | 1 | NC |
| Scuola Russell | 11,17977200 | 43,75370550 | 2 | NC |
| I ponti | 11,31732850 | 43,75276700 | 2 | NC |
| Sorgane | 11,30512630 | 43,75154650 | 6 | NC |
| Scandicci | 11,17740630 | 43,75072760 | 1 | NC |
| Fermi | 11,24935000 | 43,75031100 | 1 | C |
| Marignolle | 11,21655700 | 43,74992750 | 1 | NC |
| Malavolta | 11,23526230 | 43,74913860 | 2 | NC |
| Pian dei Giullari | 11,25791360 | 43,74736640 | 1 | NC |
| Vingone | 11,18071890 | 43,74609470 | 2 | NC |
| Pietriboni | 11,22688920 | 43,73640130 | 2 | NC |
| Osteria Nuova | 11,34663700 | 43,72994800 | 1 | NC |
| Antella | 11,32203210 | 43,72649020 | 2 | NC |
| Grassina | 11,29319890 | 43,72399150 | 4 | NC |
| Slargo Lippi | 11,29272080 | 43,71782580 | 1 | NC |
| Tavarnuzze primo maggio | 11,2126062 | 43,7087201 | 2 | NC |
| Artigiani | 11,08460410 | 43,70542610 | 2 | NC |
| San Vincenzo a Torri | 11,09625110 | 43,70019800 | 3 | NC |
| San Polo | 11,35994150 | 43,67089780 | 1 | NC |

| | |
|---|---|
| N stazioni totali | 256 |
| Potenza totale [kW] | 12800 |

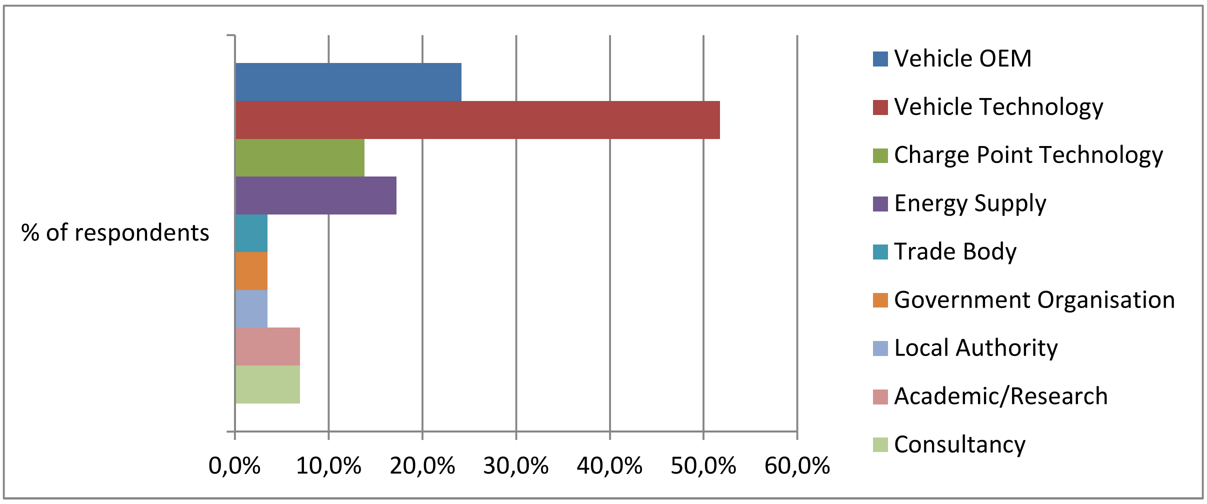
Table 60 list of all charging stations for public mobility service

# 14 Annex VII – Survey results

This Annex reports the questions and results of the survey performed to evaluate the effect of inductive charging stations in the urban environment.

## 14.1 Question 1

What activity does your business undertake within, or in partnership with, the automotive industry?



| Industry Sector | % of respondents |
|---|---|
| Vehicle OEM | 24.1% |
| Vehicle Technology | 51.7% |
| Charge Point Technology | 13.8% |
| Energy Supply | 17.2% |
| Trade Body | 3.5% |
| Government Organisation | 3.5% |
| Local Authority | 3.5% |
| Academic/Research | 6.9% |
| Consultancy | 6.9% |

## 14.2 Question 2

What do you think are the advantages of inductive charging technology for vehicles?

| Comment | % of respondents |
|---|---|
| Convenience/ease of use/less onus on user | 52.5% |
| Infrastructure more robust/tamper proof | 11.8% |
| Opportunity charging/quick top-up | 23.5% |
| Better aesthetics/less visually invasive | 17.6% |
| Reduced emissions/Improved zero emissions performance | 23.5% |
| Suited to public transport/vehicles with predictable paterns of use | 23.5% |

## 14.3 Question 3

What do you perceive as potential barriers to the uptake of inductive charging for vehicles?

| Comment | % of respondents |
|---|---|
| Infrastructure costs | 66.6% |
| Lack of standardisation | 38.9% |
| Technological reliability | 16.7% |
| Safety concerns | 23.5% |
| Energy transmission efficiency | 23.5% |
| Placement of infrastructure | 16.7% |
| Other | 11.8% |

## 14.4 Question 4

Are there any further concerns you have regarding inductive charging for vehicles? For example, infrastructural, health & safety, etc.

| Comment | % of respondents |
|---|---|
| EMF/safety concerns | 44.4% |
| Government stimuli/investment to develop public infrastructure | 11.1% |
| No | 16.7% |
| Other | 33.3% |

Among those responses coded ‘Other’ the following comments were made:

*“Members of the public may misunderstand the health & safety aspects of the technology as they did when mobile phones first started to become mass-market consumer items (EM radiation risk misunderstood).”*

*“More confusion in the market place for drivers. Commercial prospects for inductive charging - how to make it pay.”*

*“Needs well judged and successful pilot trials without being too ambitious.”*

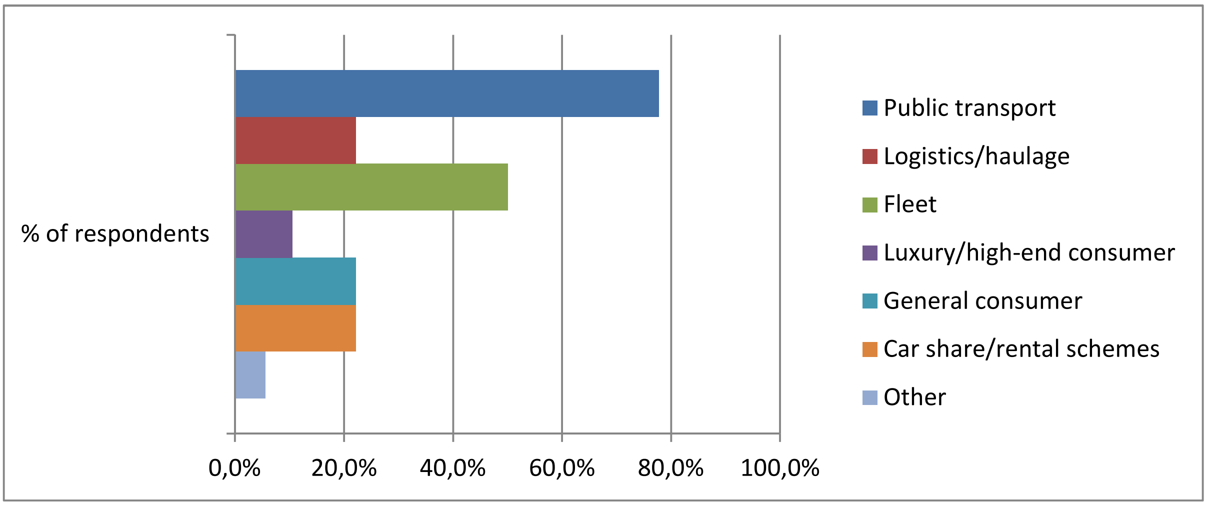
## 14.5 Question 5

How do you see inductive charging technologies integrating with current charge point infrastructure? E.g. standardisation, etc.

| Comment | % of respondents |
|---|---|
| Development of dual wireless and plug-in charge point infrastructure | 33.3% |
| Wireless charging will be for public transport/heavy commercial vehicle sectors | 16.7% |
| Standardisation of 'handshake' required | 11.1% |
| Short burst wireless charging to compliment plug in charging | 22.2% |
| Integration required | 11.1% |
| Other | 16.7% |

## 14.6 Question 6

Which area of the automotive market do you see inductive charging having the most impact?



| Market Area | % of respondents |
|---|---|
| Public transport | 77.8% |
| Logistics/haulage | 22.2% |
| Fleet | 50.0% |
| Luxury/high-end consumer | 10.5% |
| General consumer | 22.2% |
| Car share/rental schemes | 22.2% |
| Other | 5.6% |

## 14.7 Question 7

When do you envisage the first production vehicles featuring inductive charging technology becoming widely available?

| Comment | % of respondents |
|---|---|
| 2014-2016 | 33.3% |
| 2017-2020 | 50.0% |
| 2021 and beyond | 5.5% |
| Don't know | 5.5% |
| Other | 16.7% |

## 14.8 Question 8

Does your organisation currently have an agenda/road map/strategy regarding induction charging for vehicles?

| Comment | % of respondents |
|---|---|
| Yes | 72.2% |
| No | 22.2% |
| Other | 11.1% |

Among those responses coded ‘Other’ the following comments were made:

**“***We perceive the infrastructure barriers as being un-assailable without stimulus / intervention.”*

*“We are actively engaged in joint research or trials with external universities and private companies.”*

## 14.9 Question 9

What other issues/possibilities do you see as being specific to induction charging technology for vehicles?

In addition to considerations already covered by responses to earlier questions in this survey, here is a selection of pertinent comments made here:

*“As usual this is chicken-egg situation. Widespread take-up needs convenient infrastructure. Infrastructure investment needs widespread take-up. Take automotive LPG as an example. Battery technology at present (ability to accept charge quickly) is a limiting factor in usability”*

*“I believe conductive charging is simple, cheaper and will be more reliable in use so had greater chance of wide adoption”*

*“The whole agenda is open to investigation however there has to be a separation between large capacity i.e buses and passenger cars. Industry can use trickle charging or large downloads with super capacitors.”*

*“USP for EVs that offer it as a package. Infrastructure roll out might be promoted by authorities seeing themselves as eco-towns, or in new developments, where vehicles and charging are supplied to users as a package.”*

*“Infrastructure investment is the primary barrier. It will take partnership with local and central government, public transport service providers, utilities and equipment manufacturers.”*

*“Smart phone apps to notify users if charging has been interrupted due to foreign object detection. Opportunity for cross over into EV on-street rental schemes.”*

*“Combination of inductive charging with standard plug in points (once power supply is established, use can be made of the facility when the inductive charger is not in use)”*

# 15 Annex VIII – Socio – economic analysis

## 15.1 Wireless bus environmental and socio-economic impact modelling

### 15.1.1 Purpose

The purpose of this Annex is to provide a high level assessment of socio-economic and environmental impacts of inductive charging for buses for a particular case of end-of-route static charging of buses in London. The results described in this document are anticipated to form part of a TfL contribution to UNPLUGGED Task 3.2.6.

The results presented in this document are not intended to be treated as definitive calculations for possible or expected socio-economic and environmental impacts of inductive charging for buses. TRL took care to ensure that the results presented are as representative as possible and are based on the most up-to-date information, however, due to the nature of such high level analysis, a large number of required assumptions and uncertainties surrounding key technology specification and performance parameters, these results should only be considered indicative.

A more detailed and thorough assessment of the impacts will be undertaken by TRL as part of UNPLUGGED Task 3.4.

### 15.1.2 Scope and key assumptions

The scope is limited to buses in London, using static, end of route charging. The following key assumptions were made while undertaking the analysis:

- Diesel bus baseline is taken to be Euro III and Euro V
- Energy consumption of plug-in charging and inductive charging enabled vehicles is the same
- Data for Electric double decker buses is based on a range extended hybrid bus which is assumed to operate in an electric-only mode
- UNPLUGGED vehicles are assumed to have additional costs due to secondary coils, power electronics and additional control equipment compared with electric plug-in vehicles but also have batteries which are 40% smaller
- Fleet average calculations are weighted by the proportion of single and double decker buses in the fleet
- Fleet size does not increase or change composition over the term covered by the analysis
- Depreciation is assumed to be linear and spread over 5 and 7 years respectively for vehicles and charging infrastructure
- Annual discount for benefits and costs is assumed to be 3.5%
- Price of fuel and value of emissions are assumed to be fixed over the term covered by the analysis
- All data pertaining to the vehicle and fleet specific characteristics was provided by TfL
- Accident data is taken into account when calculating societal costs but accident likelihood and severity is assumed to be the same across all vehicle types to lack of any data to suggest otherwise.

Additional assumptions relevant to specific cases are stated in the relevant areas of the document.

### 15.1.3 Socio-economic impact assessment

The assessment is designed to get a high level understanding of the relative costs, benefits and societal / environmental impacts of inductively charged buses in London. The following are considered in this analysis:

- Capital costs of vehicles and infrastructure
- Operating costs (fuel and maintenance)
- Environmental impacts ($CO_2$, $NO_x$, PM and noise)
- Accident likelihood and severity
- Three main vehicle types are considered:
    - Diesel (Euro III and V)
    - Electric (plug-in)
    - Electric (unplugged).

#### 15.1.3.1 Bus level

This assessment is based on a comparison between the three main vehicle types in order to understand the socio-economic impacts for each. In this particular case, the following combination of vehicles was assessed and socio-economic impacts per bus identified for each:

| 1) Diesel | | 2) Electric | | 3) Electric UNPLUGGED | |
|---|---|---|---|---|---|
| 4) SD | 5) DD | 6) SD | 7) DD | 8) SD | 9) DD |
| 10) 10 | 11) 10 | 12) 10 | 13) 10 | 14) 10 | 15) 10 |

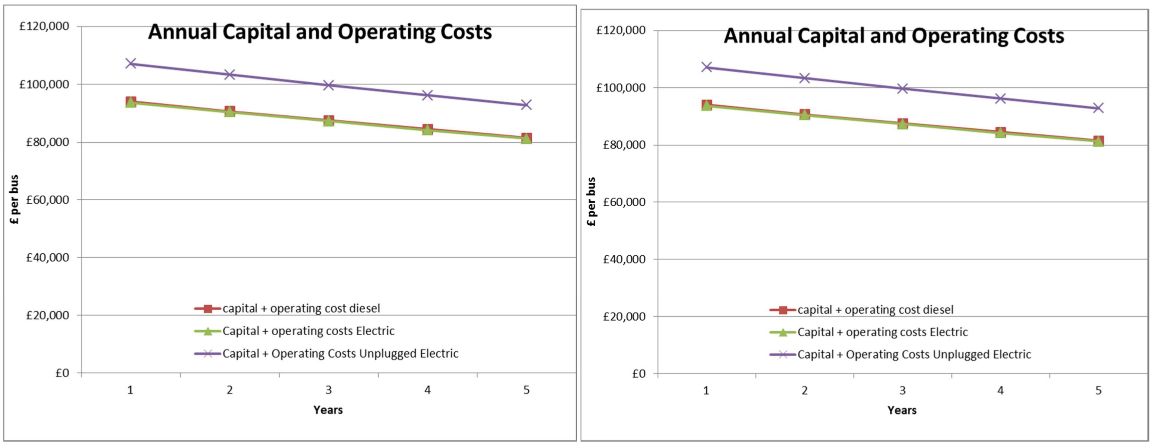
This type of analysis is useful for understanding the relative cost-benefit of each bus technology compared with others on per bus level which, cannot be easily understood from the fleet level cost-benefit analysis, as this will be highly dependent on the nature of the specific fleet composition. In order to determine the respective cost-benefit for each bus technology at an individual bus level, a “mock-up” fleet was created that contained 10 of each type of bus in each technology group, thereby, creating a balanced fleet that allows comparison between each technology. Ten of each bus type were selected in order to allow consideration of the infrastructure related costs, which in the case of UNPLUGGED buses are not on a one-to-one ration with the buses as a number of buses can use the same inductive charger.

Once costs and benefits are calculated for each technology type for 10 buses, they are averaged out between SD and DD buses and calculated on per bus level.

##### 15.1.3.1.1 Capital and operating costs

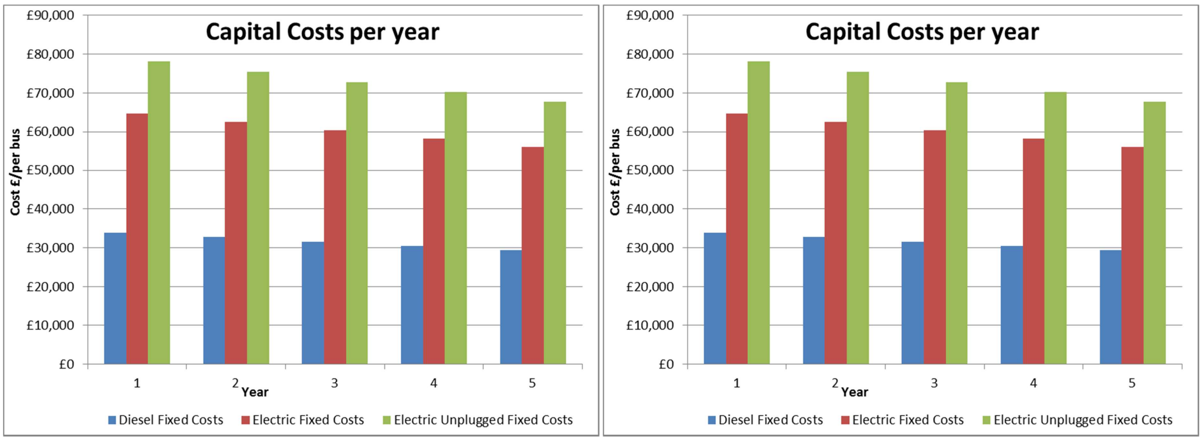
###### 15.1.3.1.1.1 Operating and Capital Costs for 5 years

Capital and operating costs per annum for Euro III and Euro V buses are first considered over a 5 year period and are shown in Figure 37 a) and b) respectively. All costs are distributed linearly over the 5 year period.  The analysis shows that diesel bus and electric bus annual combined costs (capital and operating) are almost the same over the 5 year period whereas annual costs for unplugged buses are approximately £13,000 per year higher than diesel Euro III and V.  It should be noted that in terms of running costs the difference between Euro III and Euro V buses is negligible. Breakdown between capital costs and operating costs for each bus category is shown in Figure 20 and Figure 21 respectively. Electric and UNPLUGGED buses are considered to have very similar running costs and are typically approximately £30,000 per year lower than diesel. However, the increased capital costs required for UNPLUGGED buses cannot be compensated by lower operating costs over the 5 year period and therefore, the result is a higher total cost for UNPLUGGED buses than electric or diesel. Euro V buses can generate a saving of approximately £600 per bus, per year when compared to Euro diesel III. This is due to the reduced emissions. Fuel use is averaged over the entire fleet so no difference in fuel use can be detected between different diesel buses.



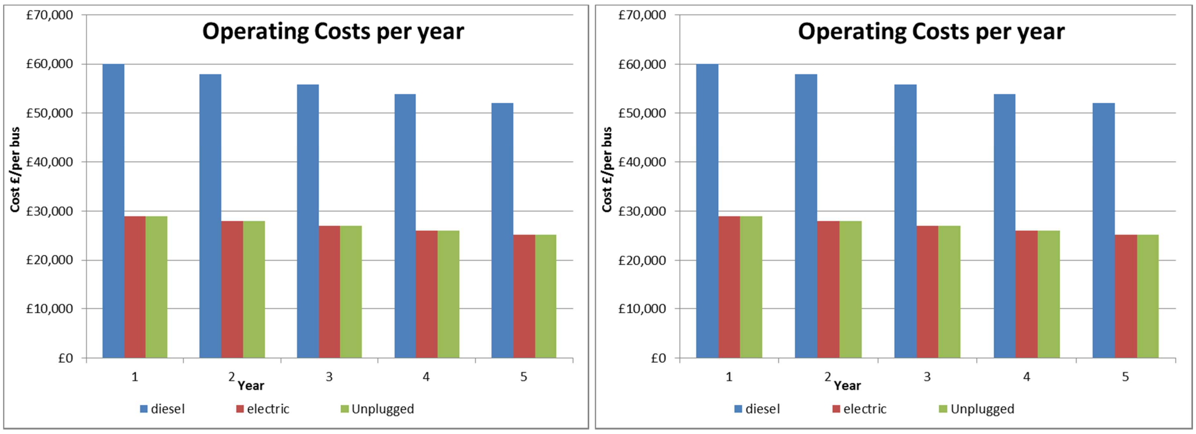
(a) (b)

Figure 37 Capital and operating costs (a) Euro III bus (b) Euro V bus



(a) (b)

Figure 38 Capital costs (a) Euro III bus (b) Euro V bus



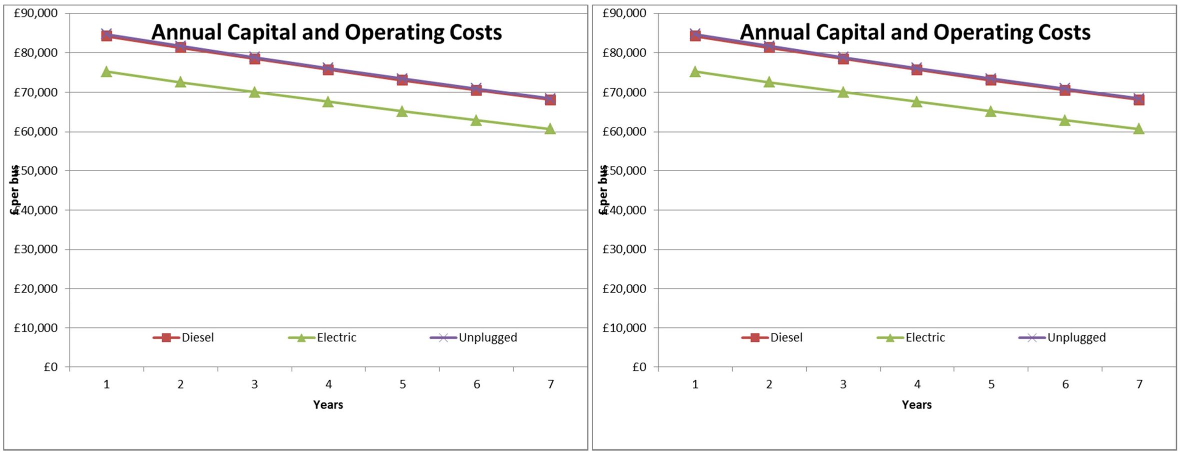
(a) (b)

Figure 39 Operating costs (a) Euro III bus (b) Euro V bus

### 15.1.3.1.1.2 Capital and operating costs for 7 year Period.

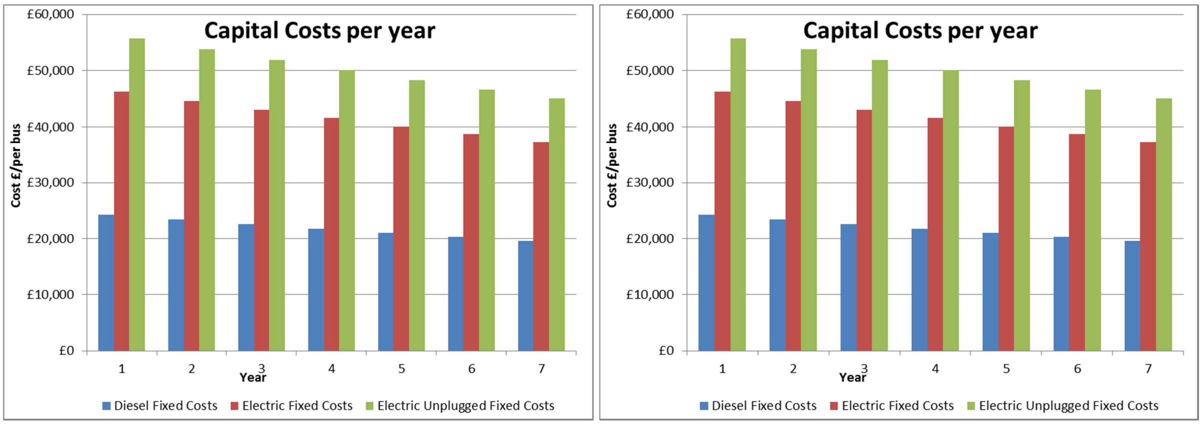
When comparing capital and operating costs over a 7 year time frame, as shown in Figure 40, it can be seen that electric bus annual costs become lower than those of diesel and electric due to a longer depreciation period, and therefore lower annual cost, and lower running cost over a longer period. Annual capital and operating costs of electric buses are approximately £9,000 per year lower than for diesel or UNPLUGGED buses. It should also be noted that over a 7 year period, annual costs of UNPLUGGED buses can be the same as those for diesel, primarily due to lower running costs and an ability to spread the higher capital costs over longer period. This essentially suggests that UNPLUGGED buses can reach cost parity with diesel buses over a 7 year timeframe.

Capital costs for electric and UNPLUGGED buses are considerably higher than those for diesel buses, as can be seen in Figure 41, approximately £25,000 and £32,000 per year higher those for electric and UNPLUGGED respectively. However, the reduced running costs for electric and UNPLUGGED buses result in the overall annual costs being around £9,000 less for electric and reaching cost parity with diesel for UNPLUGGED respectively, see Figure 42.



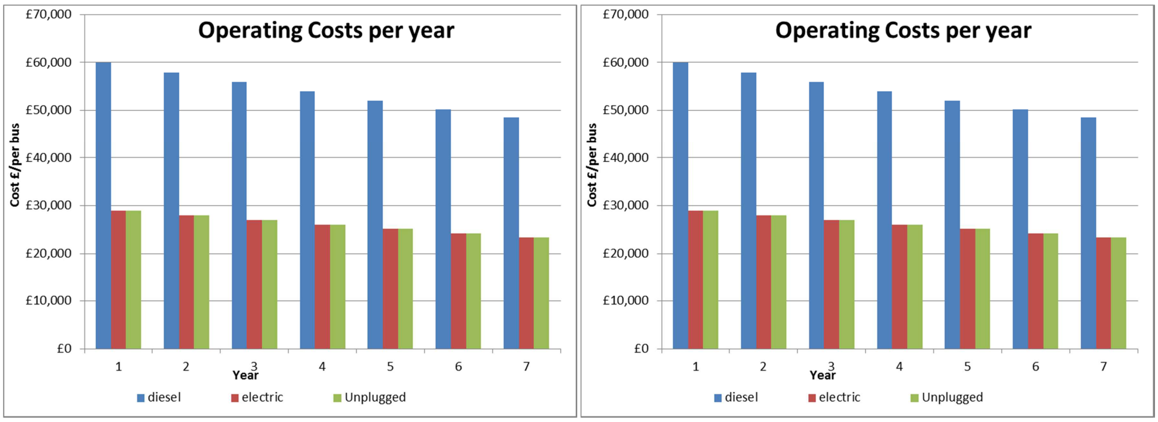
(a) (b)

Figure 40 Capital and operating costs for seven year period. (a) Euro Diesel III (b) Euro Diesel V



(a) (b)

Figure 41 Capital costs for seven years (a) Euro III (b) Euro V



(a) (b)

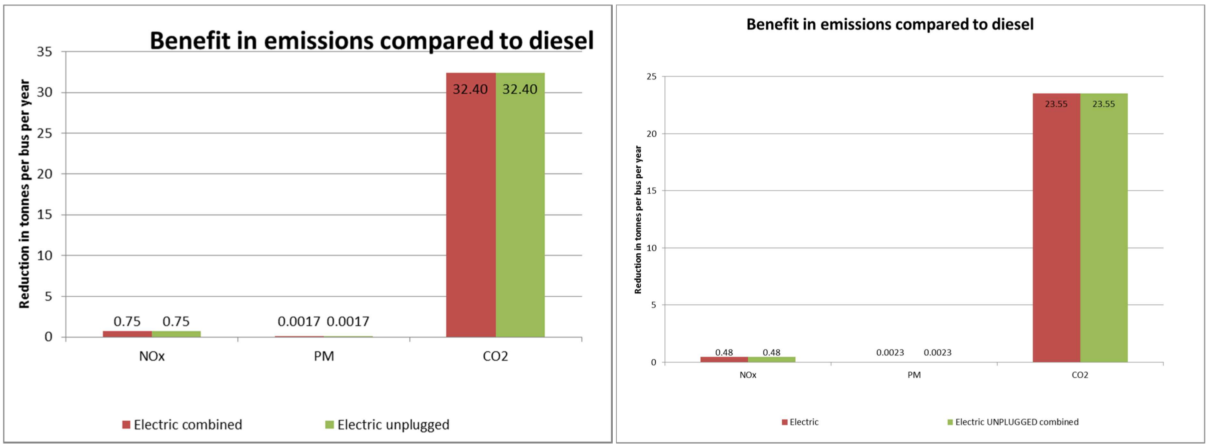
Figure 42 Operating costs for seven years (a) euro III (b) euro V

### 15.1.3.1.2 Societal impacts

#### 15.1.3.1.2.1 Assessment over a 5 year period

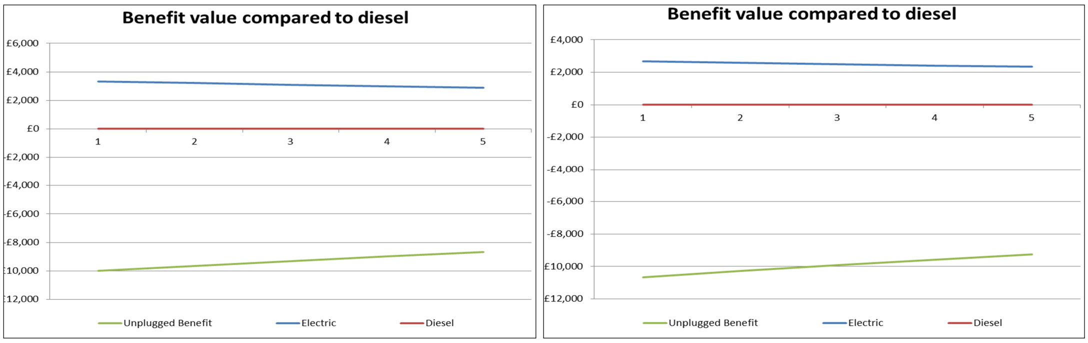
When considering environmental impacts of UNPLUGGED and electric buses, it can be seen from Figure 43 that whether Euro III or Euro V diesel buses are used as a benchmark is important due to their respective emissions. The analysis shows that the $CO_2$ emission reductions for electric and electric UNPLUGGED buses when compared with diesel Euro III and diesel Euro V are 32.4 tonnes/year and 23.5 tonne/year respectively. Lower emission of Euro V buses result in a slightly reduced cost-benefit of UNPLUGGED and electric buses. The analysis shows that if societal costs are included in the assessment then electric buses cost £3,300 per year less than Euro III diesel. Electric UNPLUGGED buses cost approximately £10,000 per year more, as shown in Figure 44.

Comparing with diesel V, electric buses cost £2,600 less and UNPLUGGED £10,600 more. The graphs show that the adaptation of electric drive train buses can create around £3,000 of societal benefits and $CO_2$ reduction of approximately 30 tonne per year per bus. NOx emissions can be reduced by 0.75 tonne/year when compared with Euro III buses and 0.48 tonne/year when compared with Euro V, as shown in Figure 43 and Figure 44.



(a) (b)

Figure 43 Emission Benefits for electric (a) euro III (b) euro V



(a) (b)

Figure 44 Total Benefit compared to Diesel (a) euro III (b)

Figure 45 shows the cumulative cost for each category of bus and includes capital, operating and societal costs. Although societal costs include emissions and accidents in the analysis, the accident costs are assumed to be the same across all vehicle types in this analysis. Figure 45 shows that the cumulative costs of diesel Euro III bus over 5 years are approximately £516,000, whereas the cumulative costs for electric and UNPLUGGED are £500,000 and £562,000 respectively. The cost of diesel Euro V bus is £505,000. The results show that electric bus reaches parity with diesel over this timeframe, whereas UNPLUGGED bus results in an additional cost of £46,000 per bus over 5 years.

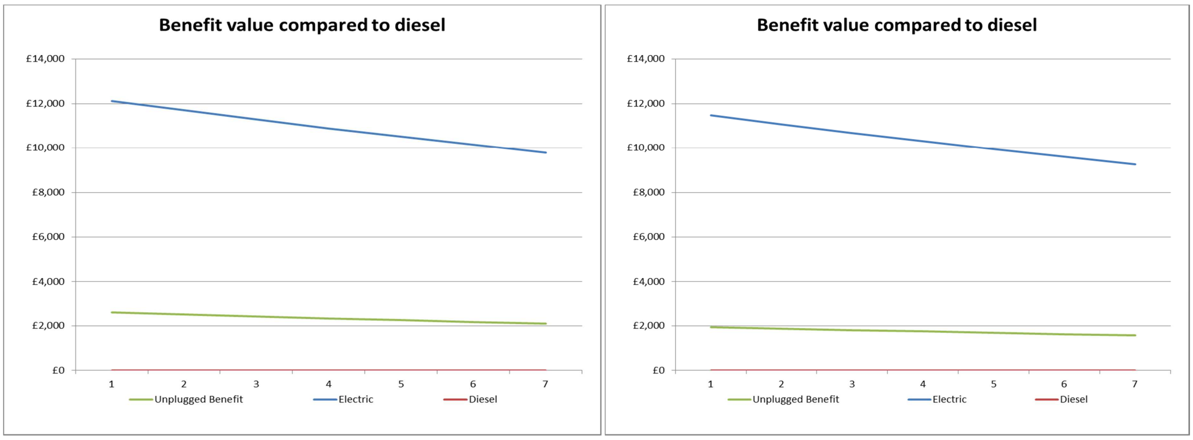
(a) (b)

Figure 45 Cumulative total annual costs over 5 years (a) Euro III (b) Euro V

### 15.1.3.1.2.2 Assessment over a 7 year period

Analysis of combined economic and environmental benefits over 7 years shows that the total benefits of electric buses, when compared with diesel buses, are between £12,000 and £10,000 per year, including a discount value rate of 3.5% over seven years; this benefit is mostly due to reduced fuel costs and societal benefits from emissions reduction. The benefits for UNPLUGGED buses over this timeframe are approximately £2,100 (approx. £1950 for diesel V) per year, see Figure 46. This result suggests that unplugged buses are economically feasible over a seven year period and show a better cost/befit ratio than diesel buses when taking into account societal benefits.

Figure 47 shows the cumulative costs of a bus over a seven year period, where total costs include capital and operating costs and societal impacts due to emissions. The total cost for diesel Euro III bus is around £636,000, the costs for electric and UNPLUGGED are £560,000 and £620,000 respectively over this timeframe. Total costs for Euro V buses stand at £632,000. The combination of capital and operating costs shown in Figure 40 indicates that the cost of diesel and UNPLUGGED buses is almost at parity over a 7 year timeframe. If societal costs due to emissions are taken into account for both buses then UNPLUGGED buses become a more feasible option.



(a) (b)

Figure 46 Total benefits compare to diesel (a) euro III (b) euro V

(a) (b)

Figure 47 Cumulative costs (a) Euro III (b) euro V

### 15.1.4 Fleet Level

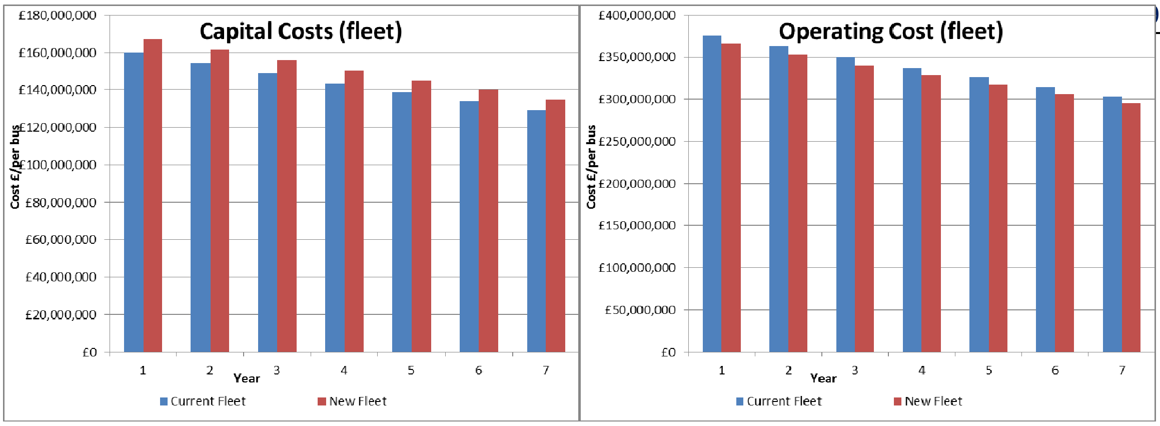
In this section the comparison undertaken in Section 15.1.3.1 is applied to a particular case study – TfL's London fleet of buses. Only Euro III and Euro V diesel buses were considered as a benchmark diesel fleet. All analysis is performed over a 7 year timeframe to reflect TfL's typical bus lifespan.

#### 15.1.4.1 Replacing 5% of TFL diesel bus fleet

This assessment considers the impact on the overall costs and emissions of the TfL fleet of Euro III and Euro V diesel buses if 5% are replaced with either electric or UNPLUGGED buses.

##### 15.1.4.1.1 5% Electric

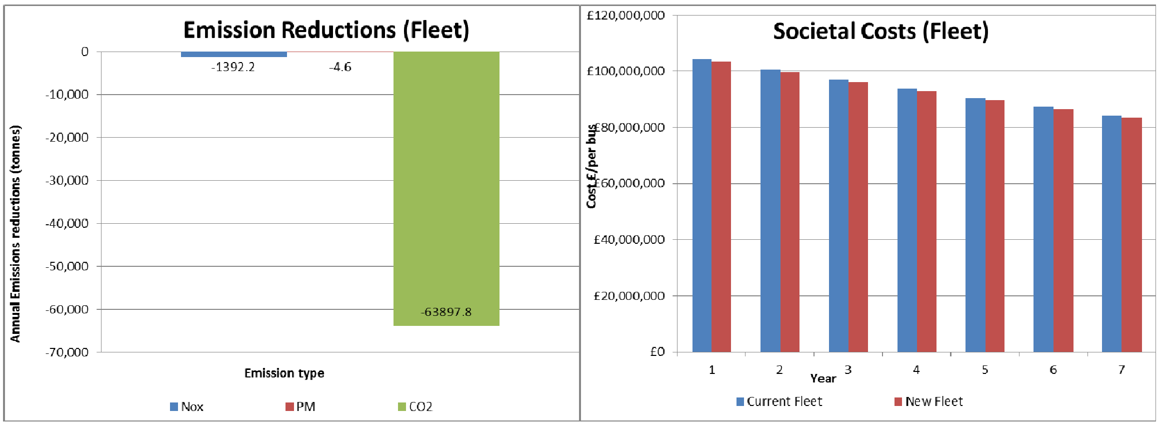
If 5% of TfL fleet was replaced with electric buses then the analysis suggests that although capital costs for electric buses are higher, around £7.3 million higher per year over the 7 year timeframe, running costs are sufficiently lower, around £9.9 million per year lower, to result in an overall slight reduction in annul costs for the new fleet composition, see Figure 48. However, the introduction of electric buses into the fleet also results in an overall societal benefit due to reduced emissions, as shown in Figure 49.



(a) (b)

Figure 48 Fleet impact on capital (a) and operating costs (b): 5% electric

Replacing 5% of the fleet with EVs can result in emission reductions of 1,392, 4.6 and 63,898 tonnes for NOx, PM and $CO_2$ respectively. These reductions can result in societal costs due to emissions being reduced by approximately £800,000 per year. The overall annual cost of the revised fleet, including societal benefits, is around £3 million less than current fleet, see Figure 50.



(a) (b)

Figure 49 Reduced emissions (a) and resulting societal cost reductions (b)

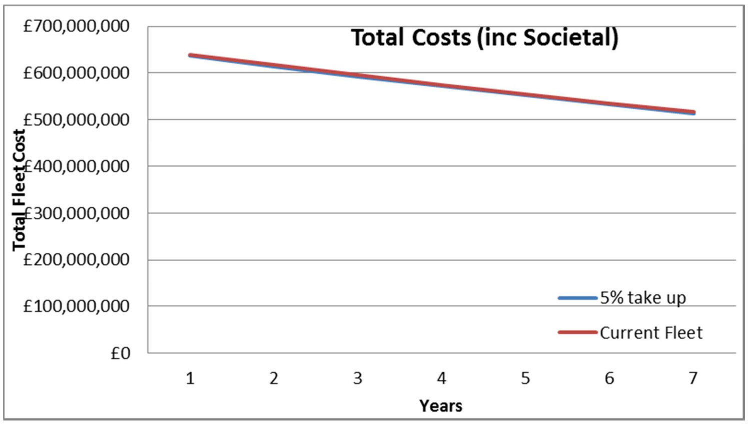
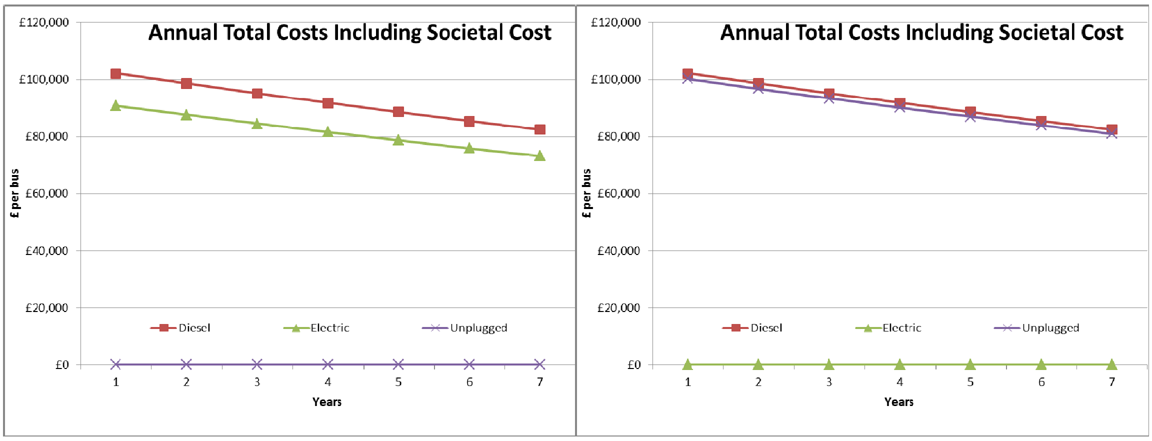


Figure 50 Total costs of revised fleet

### 15.1.4.1.2 5% UNPLUGGED

Results for replacing 5% of TfL diesel bus fleet with UNPLUGGED vehicles can be considered to be broadly similar to the results presented in Section 15.1.4.1.1 for electric buses, with the exception of capital costs, which are higher for UNPLUGGED vehicles due to infrastructure costs. This therefore, slightly reduces the overall cost-benefit of UNPLUGGED buses compared with electric, as can be seen in Figure 51. For each bus, the cost reduction for switching to electric from diesel is around £10,000 per bus per year whereas it is £1,700 per bus per year for UNPLUGGED, over a 7 year payback timeframe.



(a) (b)

Figure 51 Total costs per bus per year for electric (a) and UNPLUGGED (b)

The analysis suggest that total costs for a TfL fleet with 5% of diesel buses being replaced with UNPLUGGED buses is around £1million lower than the for the original diesel fleet, as can be seen in Figure 52. This includes the societal cost reductions due to reduced emissions as shown in Figure 49 (a).

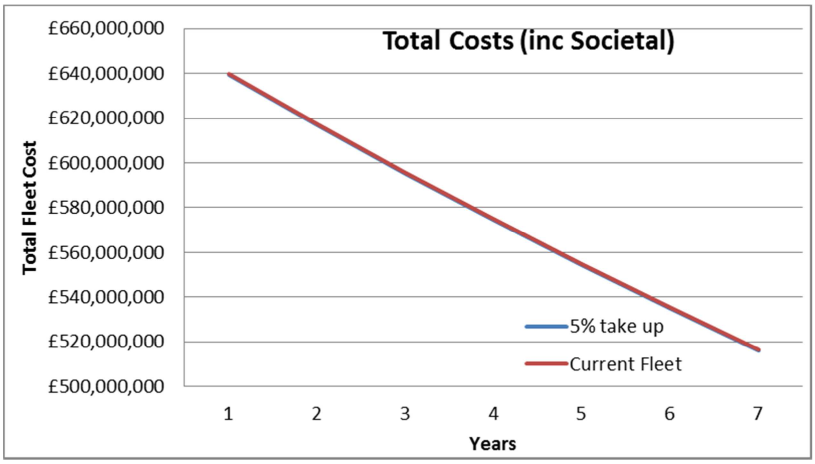


Figure 52 Total costs for 5% of fleet replaced with UNPLUGGED vehicles

Capital costs for the revised fleet are around 9.3 million higher, while operating costs are around 9.6 million lower, resulting in total net saving of around £300,000 per year before societal impacts are taken into account.

It should be noted that the key difference represented in this analysis between electric and UNPLUGGED vehicles is due to capital costs being higher for UNPLUGGED vehicles and with benefits being the same when compared with diesel. Therefore, electric buses appear to be more economically viable. Although this does seem to be the case due to lower infrastructure capital for electric than for UNPLUGGED, this outcome is based on the assumption that electric buses will be able to complete the same routes and drive/duty cycles and generate the same annual mileage as diesel buses at present. However, this is unlikely to be the case due to the range constraints of pure electric buses, especially for double-deckers. UNPLUGGED vehicles on the other hand are able to opportunistically charge throughout the day and are therefore not constrained by the battery range. What this means in practice is that electric buses are likely to be suitable for only a small number of selected routes and duty cycles, which could constrain their wider adoption, while UNPLUGGED buses could more directly replace diesel buses. Figure 53 below illustrates this point by showing modelling outputs for an electric bus and an inductively charged (IPT) electric bus along a real route in the UK over the daily drive cycle. It can be clearly seen that while the electric bus (represented by the orange line) was able to complete approximately 120 km during the day before the battery SoC was reduced to zero, the IPT-enabled bus that was able to charge at bus stops throughout the day continued to operate until the end of the day (represented by the sharp drop to 0% SoC) without dropping below 50% SoC throughout the day.

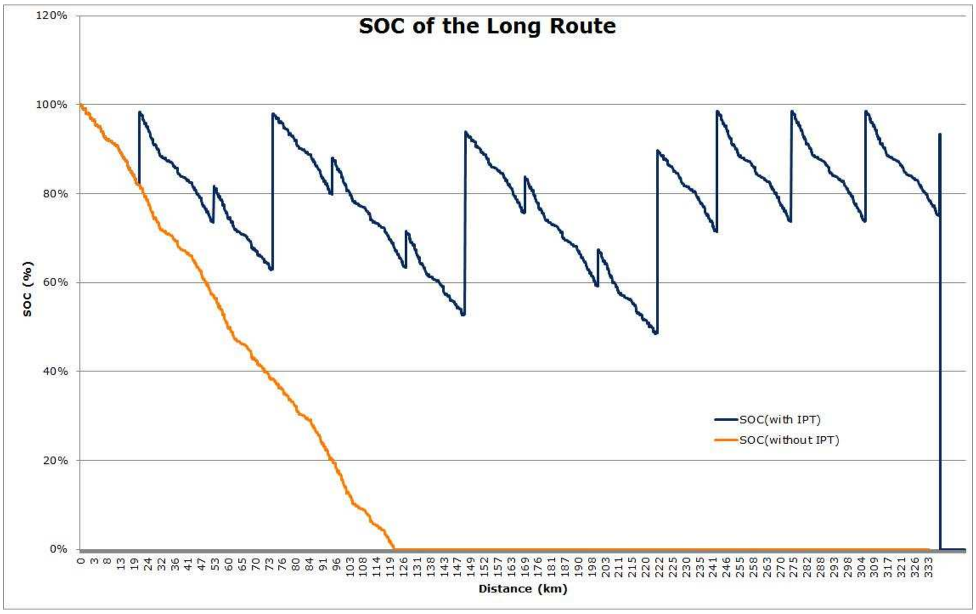


Figure 53 Example of bus SoC modelling along a route with and without IPT

#### 15.1.4.1.3 10% Electric

If 10% of TfL fleet is replaced with electric buses capital costs will increase by around £13 million per year over the 7 year timeframe; however, running costs will be around £20 million per year lower, which results in an overall reduction in annual costs for the new fleet composition of around £7million, see Figure 54. In addition to the reduced total costs, the introduction of electric buses into the fleet also results in an overall societal benefit due to reduced emissions, as shown in Figure 55.

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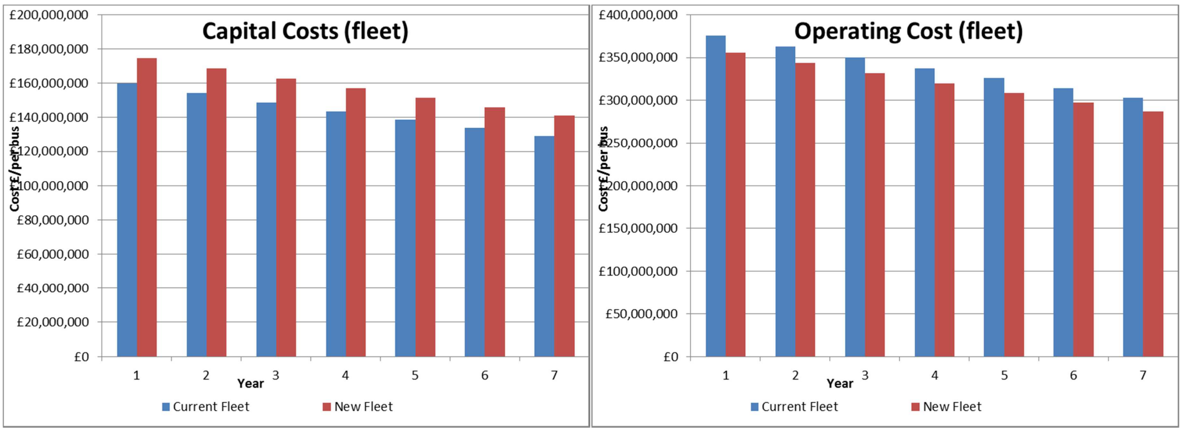
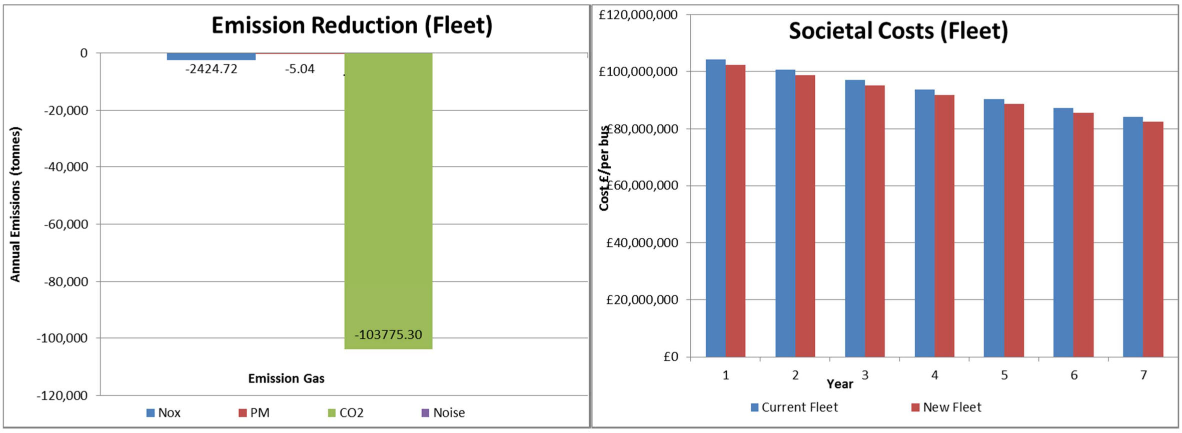


(a) (b)

Figure 54 10% Electric take-up (a) capital costs (b) operating costs

Replacing 10% of the fleet with electric buses can result in emission reductions of 2424, 5 and 103775 tonnes for NOx, PM and CO2 respectively. These reductions can result in societal cost reductions which can be attributed to the buses of approximately £2million per year. Overall annual cost of the revised fleet, including societal benefits, is around £7 million less than the current fleet of Euro III and Euro V diesel buses, see Figure 56.



(a) (b)

Figure 55 10% electric bus take-up (a) emission reduction in seven years (b) annual societal costs

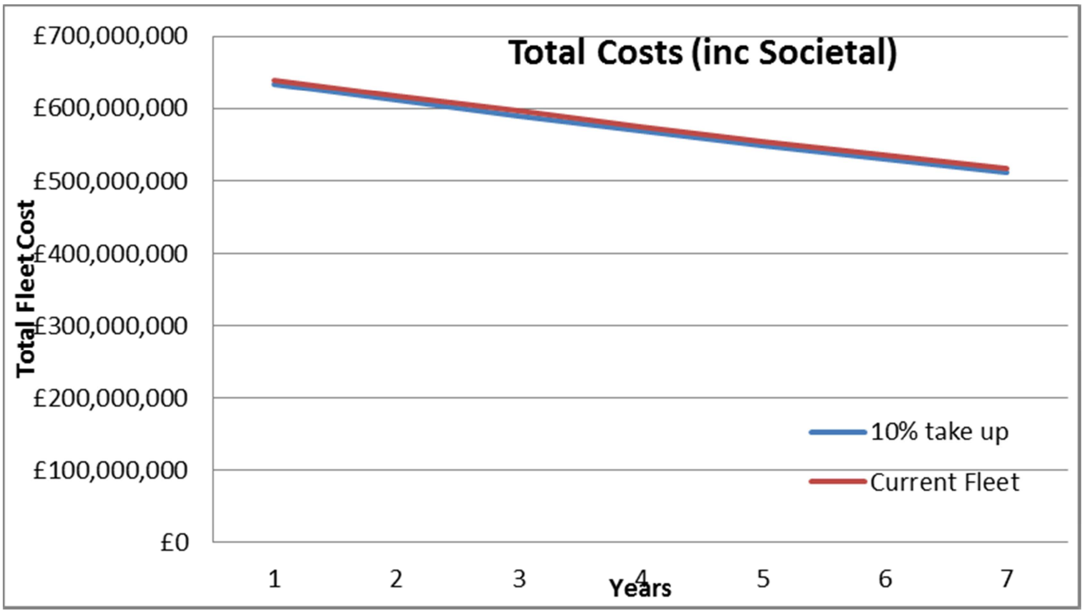
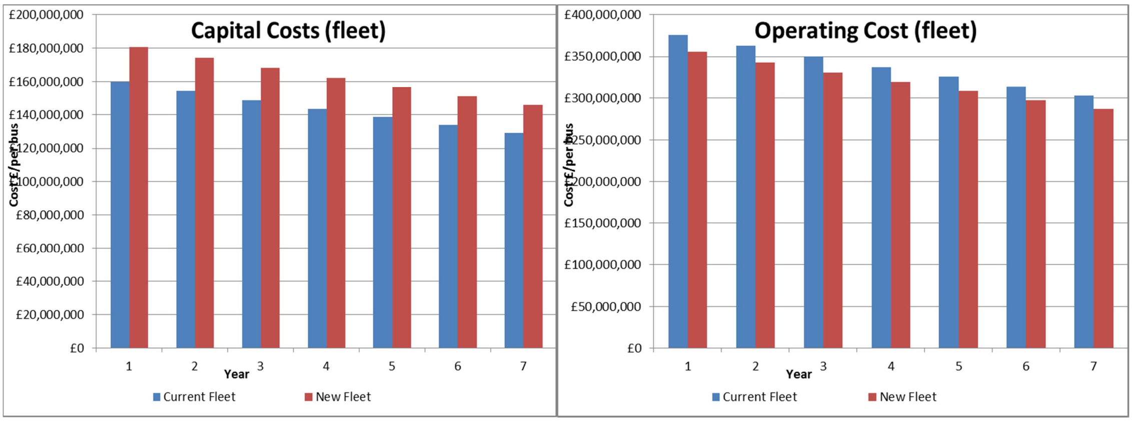


Figure 56 Overall annual cost over seven year time frame

#### 15.1.4.1.4 10% Unplugged

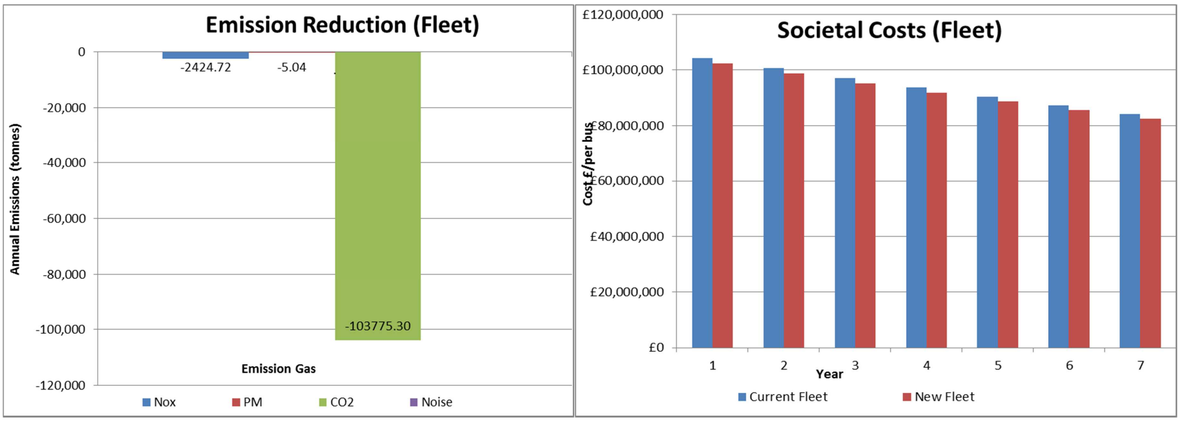
In this analysis 10% of the Euro III and Euro V diesel buses are replaced with UNPLUGGED buses. As shown in Figure 57, capital costs of the fleet with UNPLUGGED buses are £21m higher; however, operating costs are £20m lower. The results indicate that in terms of capital and operating costs the revised fleet with 10% UNPLUGGED buses will cost £1m more per year when compared with the existing fleet.



(a) (b)

Figure 57 10% Unplugged (a) capital costs (b) Operating costs

Replacing 10% of the fleet with UNPLUGGED buses can result in emission reductions of 2424, 5 and 103775 tonnes for NOx, PM and $CO_2$ respectively, as shown in Figure 58. These reductions can result in societal benefit in a way of a cost reduction that could be attributed to the buses of approximately £2million per year, see Figure 58b. The overall annual cost of the revised fleet, including societal benefits, is around £1 million less than current fleet, see Figure 59.



(a) (b)

Figure 58 10% UNPLUGGED bus take-up (a) emission reduction in seven years (b) annual societal costs

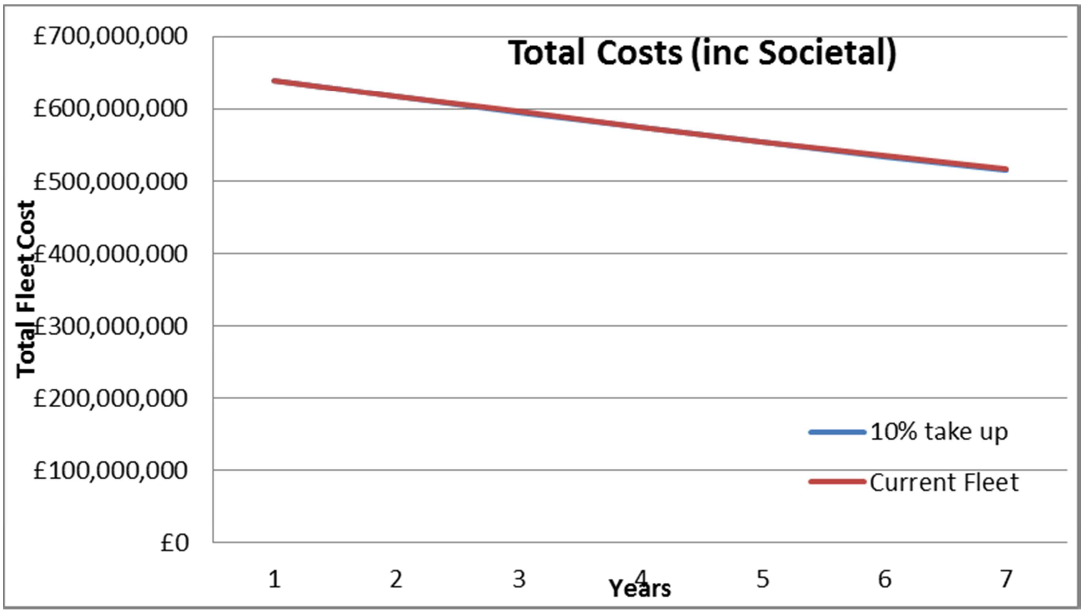
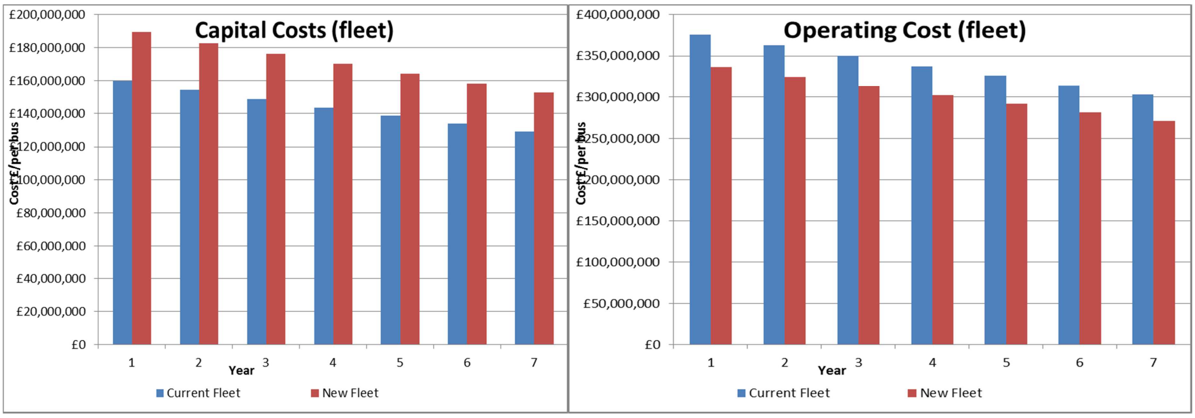


Figure 59 Total annual costs for fleet including societal costs

### 15.1.4.1.5 20% Electric

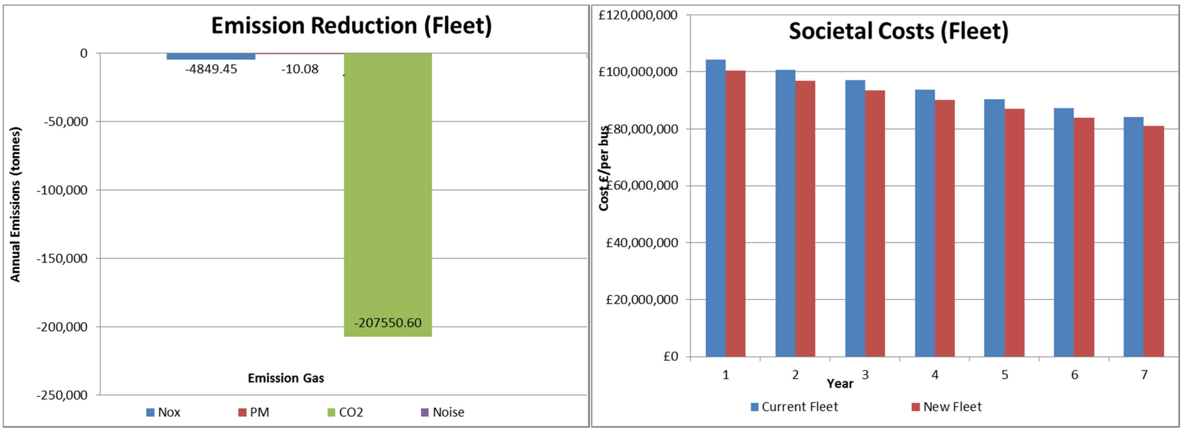
Replacing 20% of TfL fleet with electric buses results in £30 million higher capital costs per year over the 7 year timeframe; operating costs are significantly lower, by around £40 million per year, see Figure 60. Savings on operating costs result in an overall reduction of £10m in annual costs for the new fleet composition. However, the introduction of electric buses into the fleet also results in an overall societal benefit due to reduced emissions, as shown in Figure 61.



(a) (b)

Figure 60 20% electric take-up (a) Capital cost (b) Operating cost

Replacing 20% of the fleet with electric buses can result in emission reductions of 4,849, 10 and 207,550 tonnes for NOx, PM and $CO_2$ respectively. These reductions can result in societal benefits due to emissions reductions of approximately £4m per year. The overall annual cost of the revised fleet, including societal benefits, is around £14 million less than current fleet, see Figure 62.



(a) (b)

Figure 61 (a) emission reduction (b) Societal cost

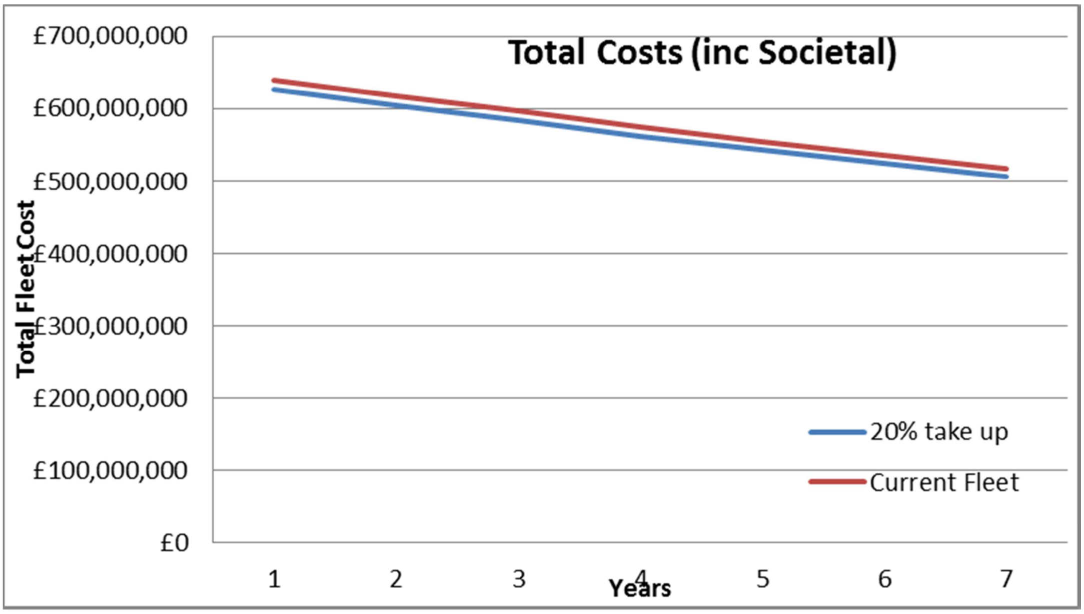
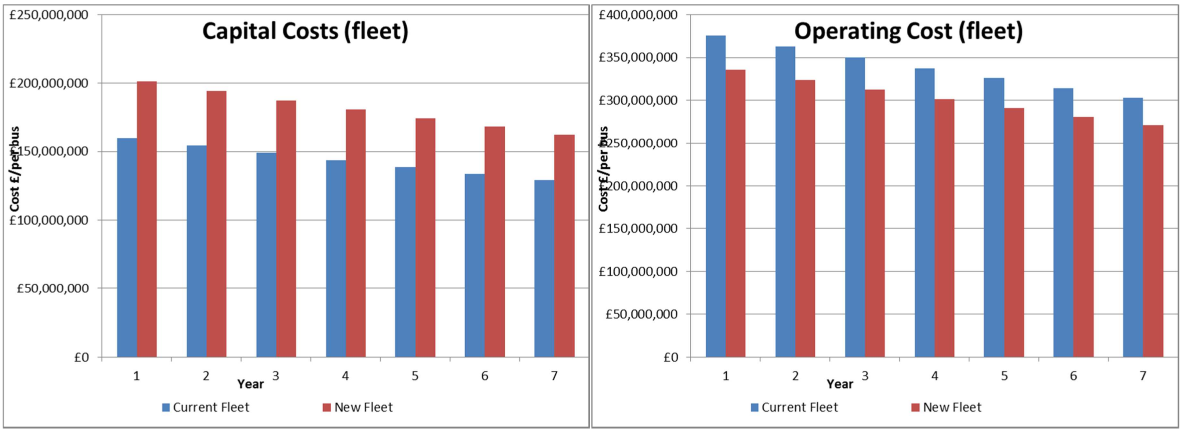


Figure 62 Total fleet cost per year

### 15.1.4.1.6 20% UNPLUGGED

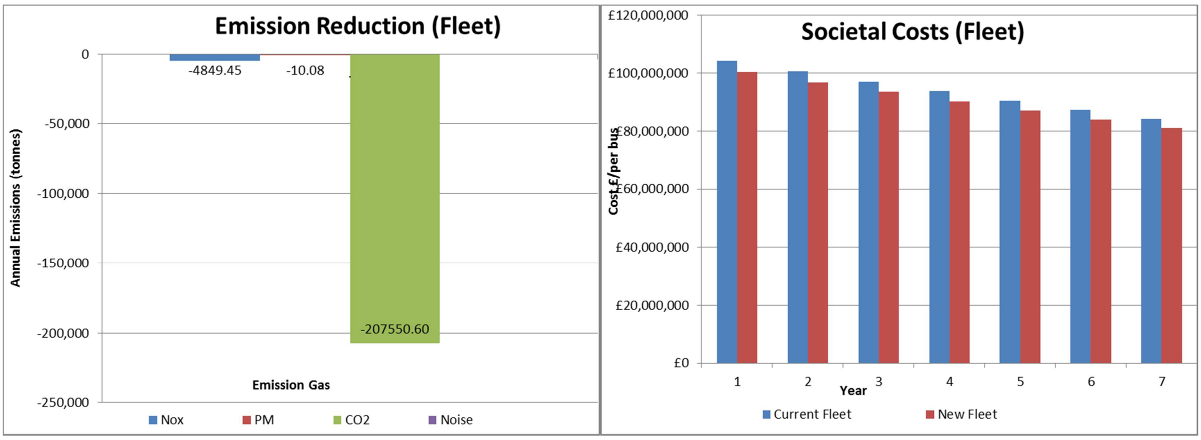
In this analysis 20% diesel buses are replaced with UNPLUGGED buses. As shown in Figure 63, capital costs of the revised fleet with 20% UNPLUGGED buses are £41m higher; however, operating costs are £40m lower. The results indicate that in terms of capital and operating costs UNPLUGGED fleet will cost £1m more per year when compared to existing fleet in terms of capital and operating costs.



(a) (b)

Figure 63 20% UNPLUGGED take-up (a) Capital cost (b) Operating cost

Replacing 20% of the fleet with UNPLUGGED buses can result in emission reductions of 4849, 10 and 207550 tonnes for NOx, PM and $CO_2$ respectively over a 7 year time frame. These reductions can result in a societal benefit due to emissions being reduced by approximately £3.5million per year, see Figure 64. The overall annual cost of the revised fleet, including societal benefits, is around £2.5 million less than current fleet, see Figure 65.



(a) (b)

Figure 64 (a) emission reduction (b) Societal cost

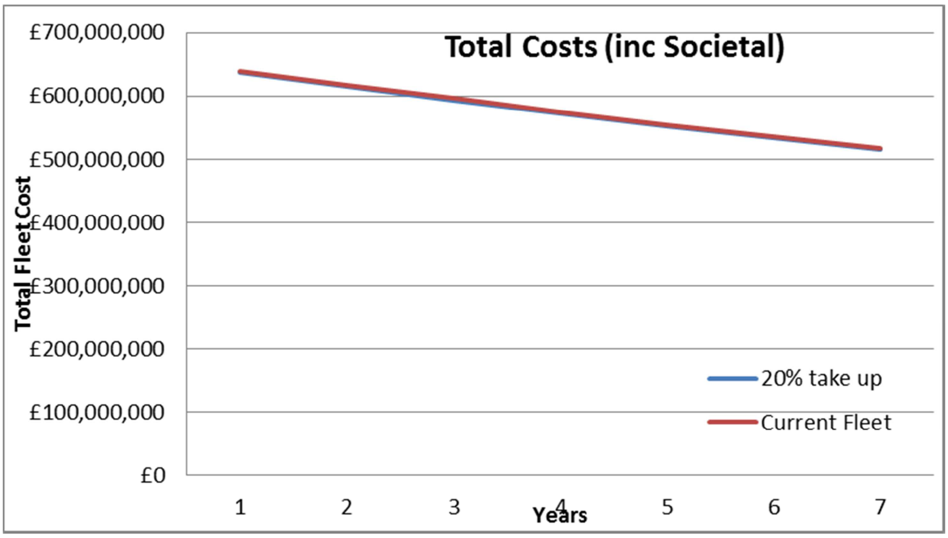


Figure 65 Total fleet cost per year

### 15.1.5 Summary

This high level analysis of possible costs and benefits along with societal impacts of the introduction of varying percentages of UNPLUGGED buses into the TfL bus fleet shows that over 10% of the fleet would need to be converted to UNPLUGGED before the large increase in capital costs is offset by savings from reduced operating costs. However, if societal benefits due to emission reductions are taken into account then a fleet that contains 20% UNPLUGGED buses can result in overall savings of £2.5million per year, over a 7 year timeframe, when compared with diesel, see

Table 61 for summary of results.

It should also be noted that in all cases, the operation of electric buses in the fleet will always be more cost effective. However, the calculated socio-economic impacts for electric buses are purely theoretical and are unlikely to be attained in practice due to the constraints of the possible range of the vehicles. Therefore, the use of inductive charging, or other means of rapid opportunistic charging, is required to materialise the operating and environmental benefits of electric buses.

Table 61 Summary table - Cost benefits compared to diesel £ millions (over 7 years)

| **% of vehicles in fleet** | **Capital Cost** | | **Operating Cost (saving)** | | **Societal Cost (saving)** | | **Total** |
|---|---|---|---|---|---|---|---|
| | electric | UNPLUGGED | electric | UNPLUGGED | electric | UNPLUGGED | |
| **5** | £7.3 | £9.3 | -£9.9 | -£9.6 | -£0.8 | -£0.8 | -£3, -£1.1 |
| **10** | £13 | £21 | -£20 | -£20 | -£2 | -£2 | -£7, -£1 |
| **20** | £30 | £41 | -£40 | -£40 | -£4 | -£4 | -£14, -£2.5 |

## 15.2 Noise impact

In order to fully understand the socio-economic impacts of the introduction of UNPLUGGED buses into the TfL bus fleet, noise emissions should also be taken into account. However, noise emissions are particularly difficult to calculate at a high level due to the complexity with which noise levels are measured and how their impact is monetised. Therefore, in this report noise emissions are considered in the way of a case study for a particular route in London in order to determine possible noise reduction due to the introduction of UNPLUGGED buses.

In order to undertake the analysis the following assumptions had to be made:

- Lmax levels at 30 km/h and 7.5 m estimated from testing and Harmonoise calculations on an HRA surface
- Cost figure based on an average on values for typical noise levels in London
- Assumed that the noise benefit is fully realised for households (in practice it would not be because the noise on other roads nearby is unchanged)
- A representative route length in London was considered to be 9 kilometers
- The number of households within an area of 30m radius was considered to be 6
- Manufacturer provided noise data for electric buses was used to determine the difference in drive-by noise levels from diesel buses
- Ambient noise and traffic levels data was based on data previously gathered and measure by TRL for TfL.

Considering actual bus flows along a particular route, different percentages of UNPLUGGED buses were considered to make up the overall bus flow rates. The results are summarised in Figure 66 .

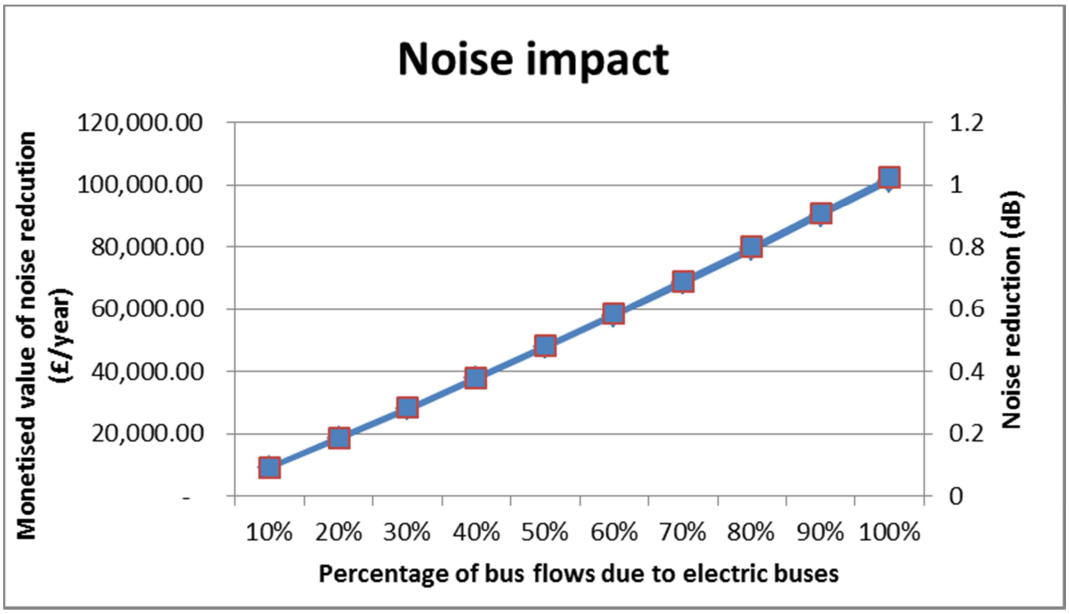


Figure 66 Noise impact of UNPLUGGED along a London bus route

Results shown in Figure 66 indicate that even if all of the buses on along the considered route were replaced with UNPLUGGED buses, the overall noise reduction is around 1dB. This is likely to be an overestimation as in this case the noise reduction is assumed to be fully realised and benefits the exposed households, in practice the noise originating from other nearby streets is likely to remain the same, thereby reducing the overall impact of this reduction.

For majority of cases for when less than 100% of the bus flows can be attributed to UNPLUGGED buses, overall noise reduction is likely to be less than 1dB. The maximum annual benefit that could be achieved in this scenario is around £100,000. It is not possible to directly scale this reduction to the number of buses in London overall as noise reductions are calculated based on flows and exposed households for each route, rather than numbers of vehicles. Therefore, a more thorough modelling approach will be required which can model individual routes across London and then determine the combined impact of a bus fleet containing UNPLUGGED buses. However, the anticipated impact of noise reductions is comparatively small and typically, noise reductions of less than 1dB can be considered as negligible. It should be noted that if night-time routes were considered in isolation then this impact may increase.

## 15.3 Sensitivity analysis

There are a large number of assumptions required to derive the analysis presented in Section 15.1.3 above. It is therefore recognised that many of these assumptions can vary in practice and over time. In order to understand the potential implications of these possible changes a sensitivity analysis was undertaken. Output from Section 15.1.4 is used as a baseline (5% of diesel buses converted to UNPLUGGED buses, over a 7-year timeframe) and the following key parameters are changed:

a) Price of diesel increases 10%

b) Price of diesel and electricity increases 10%

c) Charging infrastructure costs reduced by 30% (to reflect economies of scale and technology development).

d) Unplugged vehicle costs reduced by 30%

Each of these scenarios is described below.

### 15.3.1 Price of diesel increases 10%

The impact of increasing price of diesel by 10% is that operating costs for diesel buses increase, resulting in a bigger differential between UNPLUGGED operating costs and diesel operating costs, see Figure 67 (a). The overall difference in costs between diesel and UNPLUGGED is increased to approximately £1,500,000 per year.

(a) (b)

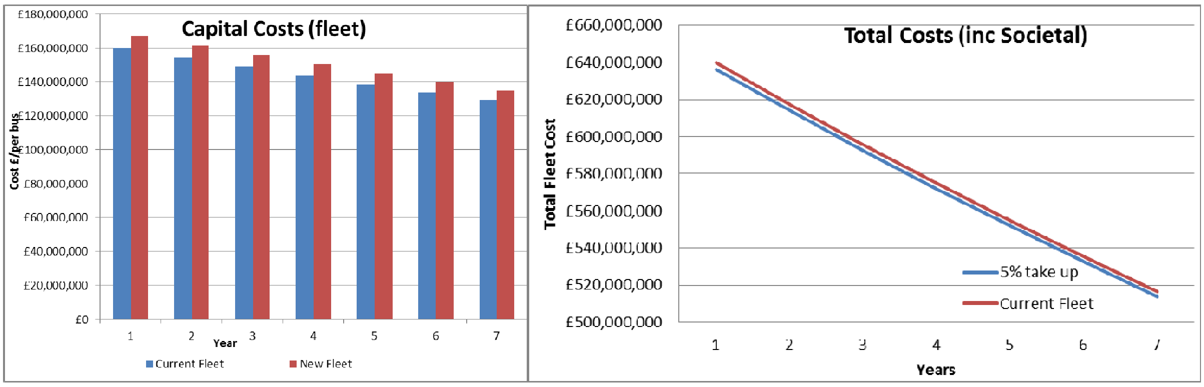
Figure 67 Impact of 10% increase in price of diesel on operating cost (a) and Total costs (b)

### 15.3.2 Price of diesel and electricity increases 10%

Increase in the price of electricity as well as diesel reduces the gap between UNPLUGGED operational costs and diesel bus operation costs. However, because the value of electricity is so much lower than diesel to begin with (£0.1 versus £1.3) this reduction is small, from around £1,500,000 per bus to £1,250,000 per bus when both fuel prices are increased by 10%.

### 15.3.3 Charging infrastructure costs reduced by 30%

Reducing the cost of charging infrastructure by 30% results in a reduction in the capital cost variation of electric from diesel from £7.3 million (see Figure 68 a) to £6.6 million higher than diesel.



(a) (b)

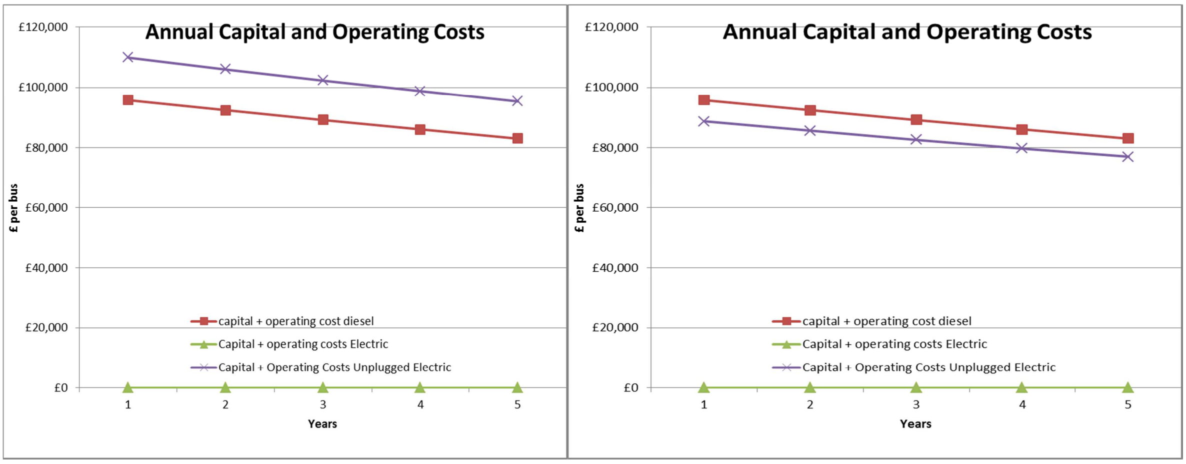
Figure 68 Reduction in infrastructure costs by 30%: capital costs (a) and Total costs (b)

Figure 68 shows how such reductions in infrastructure costs for UNPLUGGED could result in UNPLUGGED buses being more economically viable than diesel, over a 7 year ownership period.

### 15.3.4 UNPLUGGED vehicle costs reduced by 30%

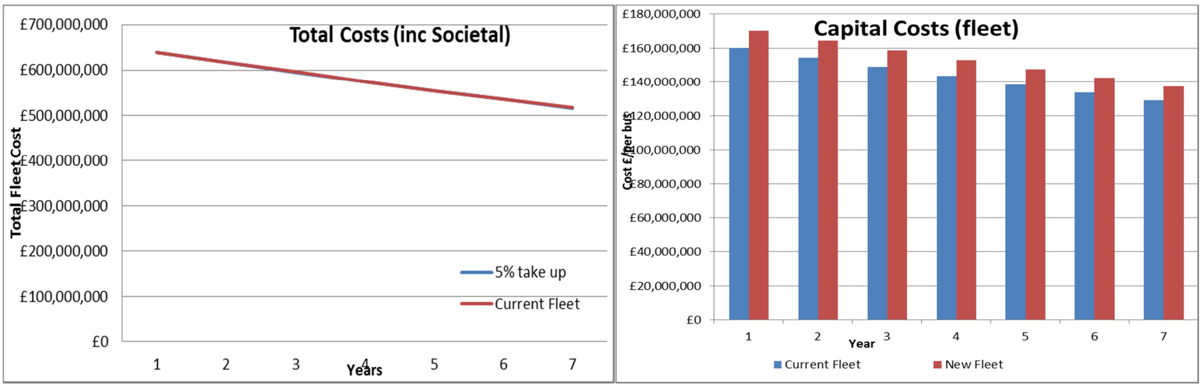
A reduction of 30% in UNPLUGGED vehicle costs results in annual costs of these buses falling below their diesel equivalent. As shown in Figure 69(a)
(b)

Figure 69, annual capital and operating costs for Unplugged are reduced by £21,000 per bus per year in a five year time frame. The capital cost of the fleet is reduced by £6.2m per year when compared to the non-reduced UNPLUGGED bus price model, as shown in Figure 70 and Figure 71.



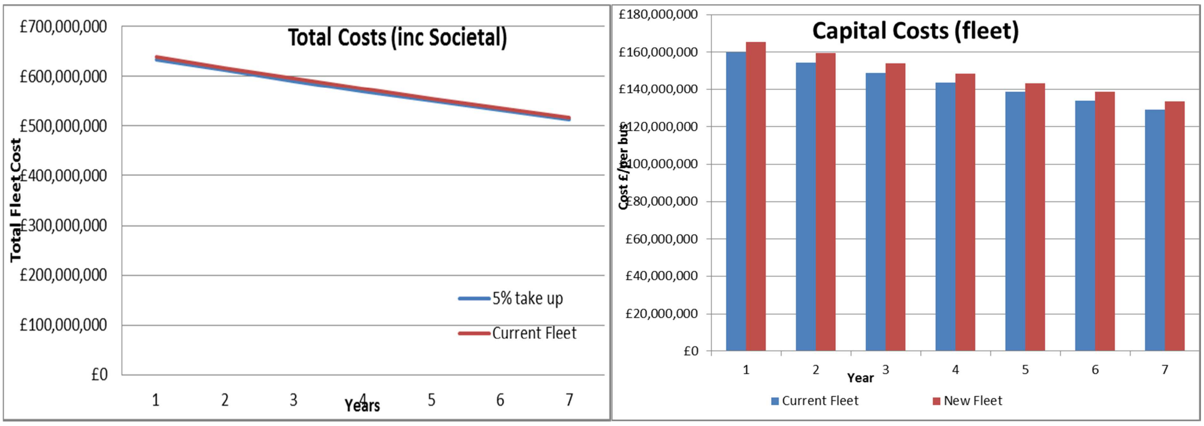
(a) (b)

Figure 69 Annual capital and operating cost per bus (a) 100% bus cost (b) 70% reduction.



(a) (b)

Figure 70 Costs for 100% of vehicle price



(a) (b)

Figure 71 Cost of vehicle reduced by 70%

# 16 Annex IX – Analysis for Volvo 7900 bus

During the 2nd Unplugged General Meeting held in Aachen in March 2014, there are discussed the first feedbacks done by Unplugged Project Officer.

One of these comments was "why didn't Volvo consider the 7900 bus instead of 7700 bus?" since Volvo 7900 bus was already present in the market.

For this reason, VUB and ENEL performed again the whole analysis and a comparison with the results to Volvo 7700 ones.

As done for the Volvo 7700 bus, the analysis is focused on the impact to the grid for the introduction of the charging stations to guarantee a full public service in Firenze with the Volvo 7900 bus.

First of all, it has been calculated the power consumption for different driving cycles, the number of charging stations to be located in each bus stations, and the cost analysis for the grid.

## 16.1 Power consumption analysis – Volvo 7900 bus

As a first point, the power consumption has been calculated for the same driving cycles considered for Volvo 7700 bus analysis, standard SORT and MLTB driving cycles.

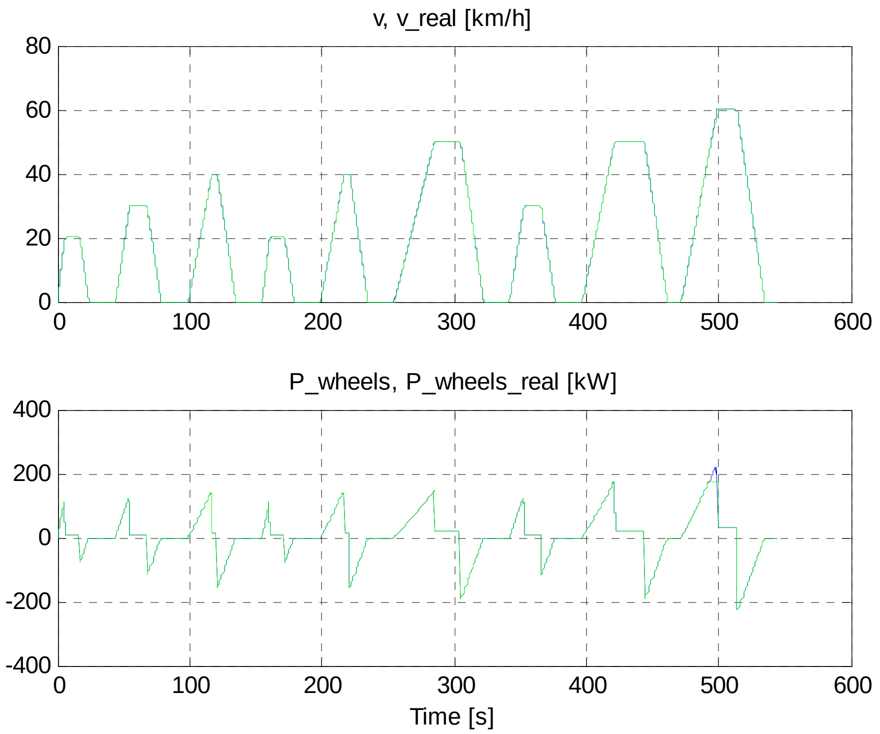
The Volvo 7900 parameters are detailed in Table 62

| | | |
|---|---|---|
| $M$ | Vehicle mass ($kg$) | 19000 |
| $f_r$ | Rolling Resistance Coefficient | 0.0056 |
| $C_D$ | Aerodynamic Drag Coefficient ($C_D$) | 0.55 |
| $A_f$ | Front Area ($m^2$) | 7.68 |
| $r_w$ | Radius of the wheel (m) | 0.452 |

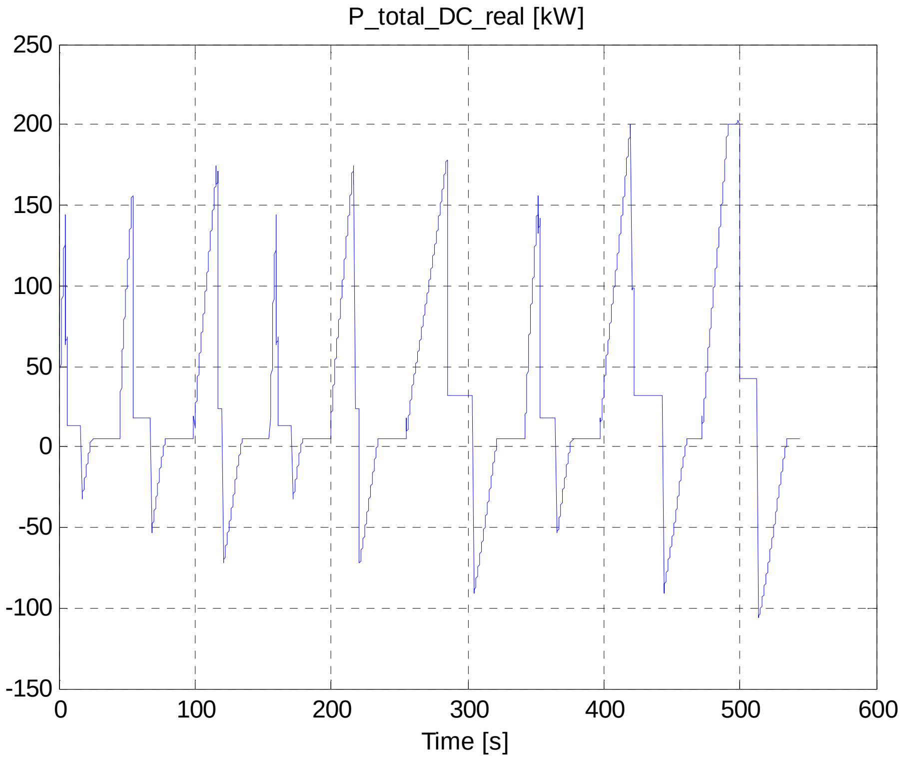
Table 62 Volvo 7900 Parameters

### 16.1.1 Power consumption during SORT Cycle

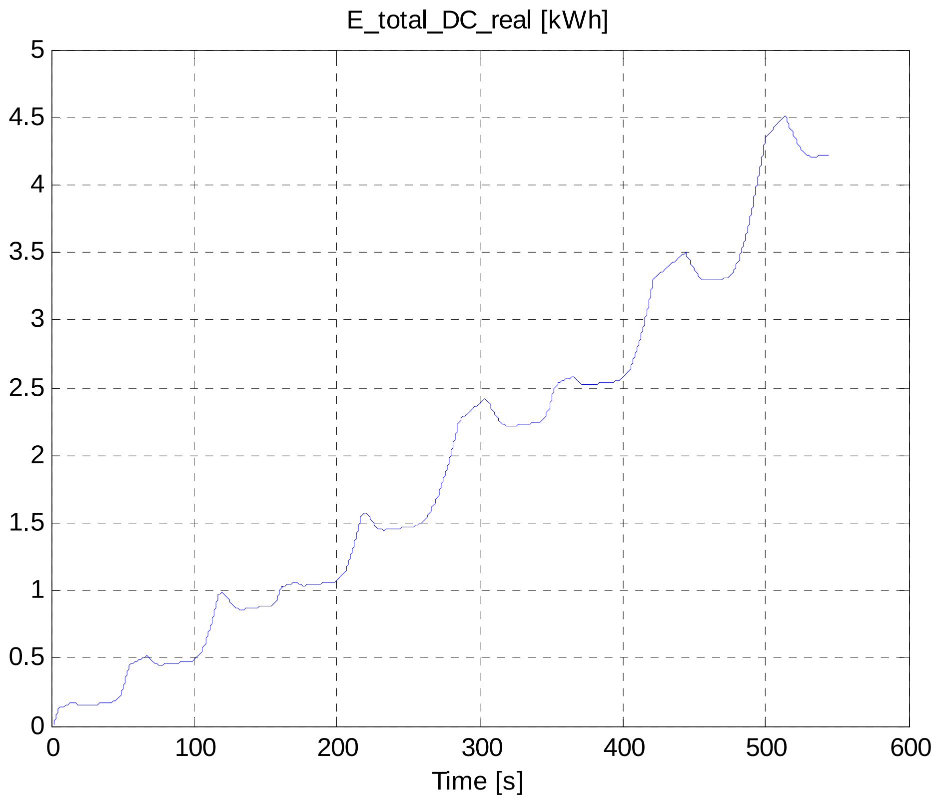
Figure 73 presents the wheels power consumption, the total DC power, total distance and energy consumption of the bus during SORT driving cycle.



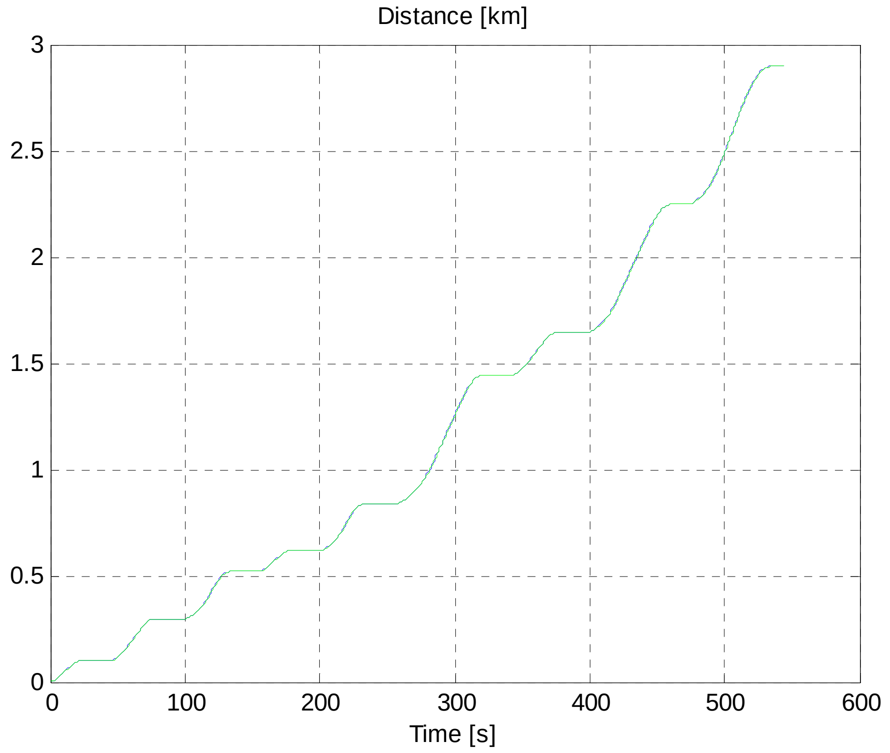
(b) The wheels power consumption (kW)



(b) The total DC power (kW)



(c) The total DC energy (kWh)

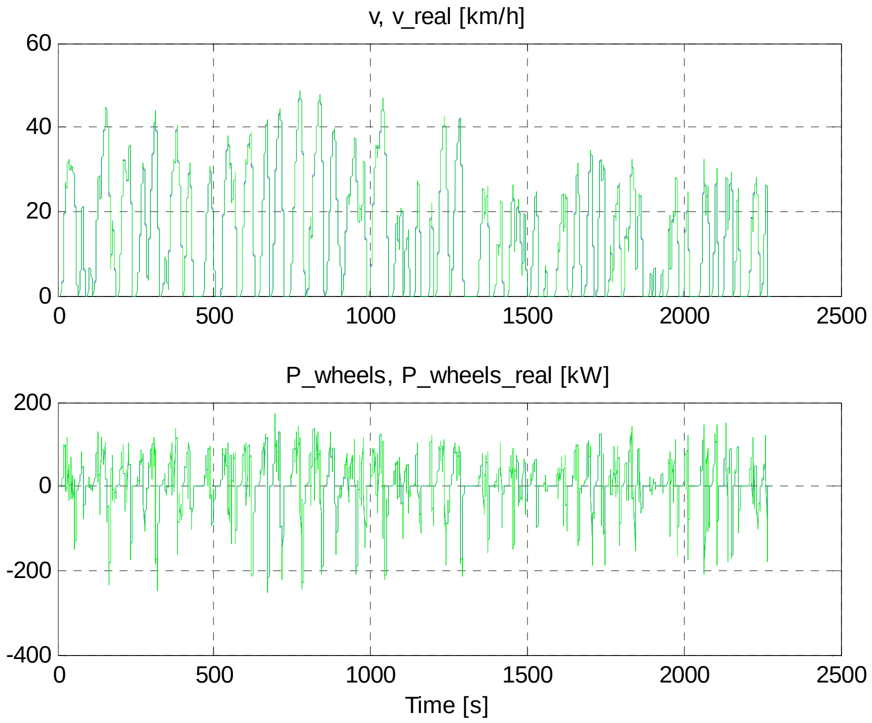


(e) The total distance (km)

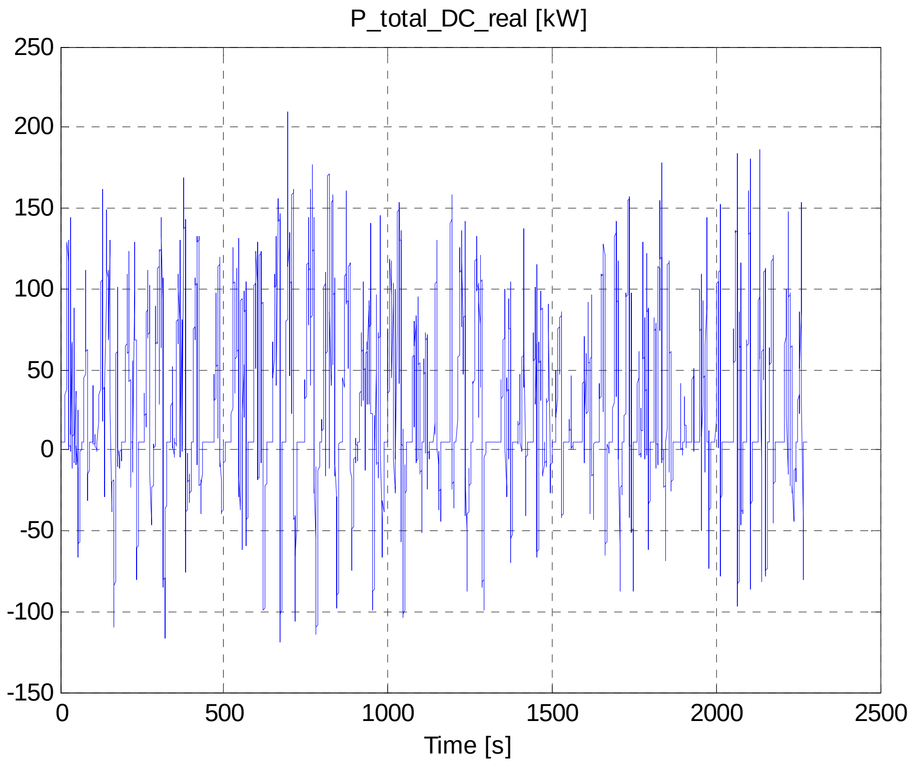
Figure 72 The performance of 7900 Volvo bus during SORT driving cycle

### 16.1.2 Power consumption during MLTB Cycle

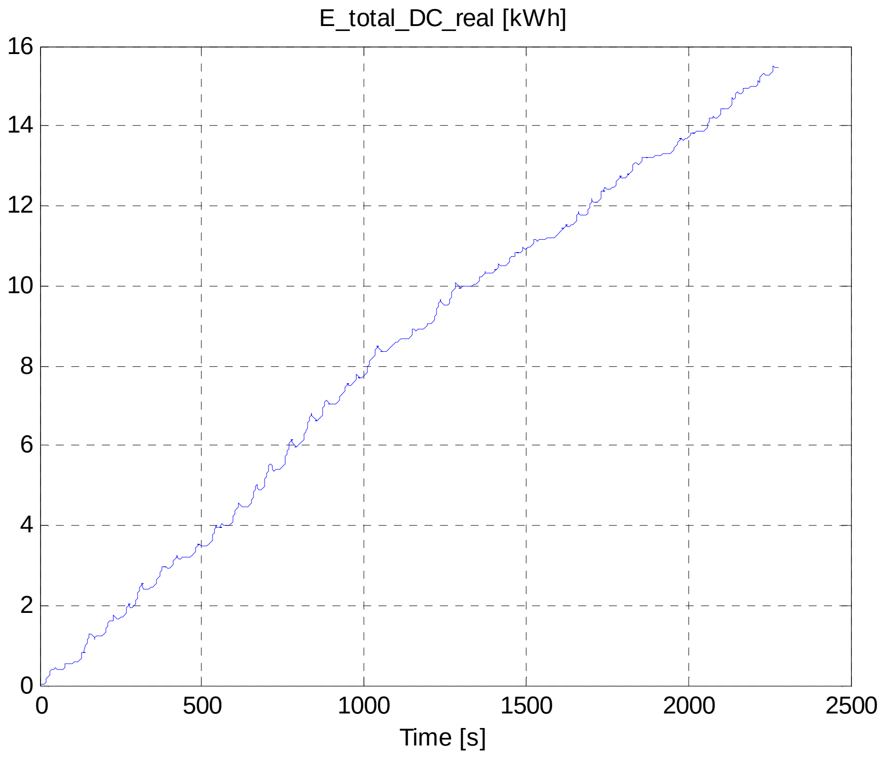
Figure 73 presents the wheels power consumption, the total DC power, total distance and energy consumption of the vehicle during MTLB driving cycle.



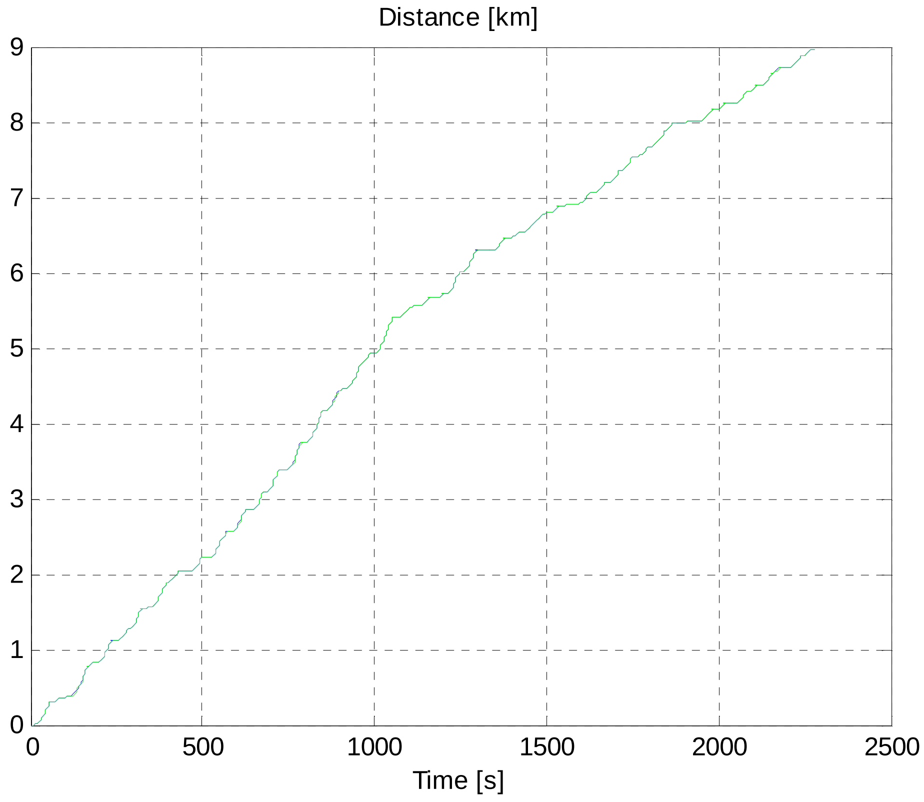
The wheels power consumption (Kw)



(b) The total DC power (kW)



(c) The total DC energy (kWh)



(d) The total distance (km)

Figure 73 The performance of 7900 Volvo bus during MTLB driving cycle

## 16.2 Comparison between Volvo 7700 bus and Volvo 7900 bus

Table 63 provides a comparison for the energy consumption in function of Volvo 7700 bus and Volvo 7900 bus.

| | 7700 Bus (Volvo) | | 7900 Bus (Volvo) | |
|---|---|---|---|---|
| | SORT Driving Cycle | MLTB Driving Cycle | SORT Driving Cycle | MLTB Driving Cycle |
| **Energy Consumption (kWh)** | **5.6** | **19** | **4.22** | **15.47** |
| **Distance (km)** | **2.9** | **9** | **2.90** | **9** |
| **Mass (kg)** | **18900** | **18900** | **19000** | **19000** |
| **Energy per km (kWh/km)** | **1.931** | **2.1** | **1.455** | **1.72** |

Table 63 Comparative Study of energy consumption

Comparing the power consumption results for the Volvo 7700 bus and Volvo 7900 bus, those are different. This gap can be pinpointed to the value for the front area used for Volvo 7700: while for the Volvo 7900 bus the front area value is the real value (“as is” the bus), for the Volvo 7700 bus the front area value is the simulated value and not the real one.
For the rest of analysis the value 1.455 kWh/km has been considered in calculating the number of charging stations and cost analysis.

## 16.3 Calculation for the number of charging stations

As a second step of the analysis, the calculation to determine the optimal number of charging stations has been accomplished based on the same algorithm explained in para 3.1.
The main hypotheses are kept, and they are:

1. At each terminal stop the battery is charged. The terminal stops have been considered as the locations in which the battery can be restored to a 100% of its capacity, since buses usually spend the maximum time of their life in bus stop and this time should be established.
2. A power consumption value of 1,455 kWh/km, as results from the previous analysis to be valid for the Volvo Bus (type 7900) in the SORT driving cycle. This is the only difference between the 2 analysis for Volvo Buses.
3. The charging stations are equipped with a power inverter of 50 kW while no hypothesis on batteries capacity has been done for the buses.
4. Only the buses during the daytime (6:00 am to 8:00 pm) have been considered and not during the night service, in which the bus service is similar to that during the daytime with a reduced frequency. So this analysis is also valid for the night service, even if not directly studied and evaluated.

5. The service level of the busses has been maintained at the actual level: no bus has been delayed respect to the actual schedule in order to have a longer recharge time.

Processing the data with the same algorithm of the previous one (para 3.1), the numbers of charging stations are reported in Table 64 comparing with the Volvo 7700 bus ones.

| | **Volvo 7700 Bus** | **Volvo 7900 Bus** |
|---|---|---|
| **Cases** | **Number of stations** | **Number of stations** |
| Standard | 291 | 249 |
| Option 1 | 256 | 204 |
| Option 2 | 252 | 213 |

Table 64 Comparison number of charging stations

For the evaluation of the impact to the grid, the value for Option 1 has been considered for the number of charging stations. Comparing the results for the 2 Volvo buses, in case of Volvo 7700 bus there are required 51 charging stations more than the Volvo 7900 bus case.

Surely this is caused to the different value of power consumption due to different value of front area.

The list of all charging stations for each terminal stop is reported in Table 65.

| | | | | No of charging stations | | |
|---|---|---|---|---|---|---|
| id | Place | Latitude | Longitude | Standard | Option 1 | Option 2 |
| 1 | Legri | 43,91406600 | 11,22411930 | 1 | 1 | 1 |
| 2 | Calenzano centro | 43,86361280 | 11,16688970 | 2 | 2 | 2 |
| 3 | Cimitero Calenzano | 43,86156300 | 11,16171410 | 2 | 2 | 2 |
| 4 | Calenzano | 43,86106570 | 11,16090070 | 3 | 2 | 2 |
| 5 | il rosi | 43,85725190 | 11,14014290 | 1 | 1 | 1 |
| 6 | Caponnetto | 43,84866720 | 11,16213410 | 1 | 1 | 1 |
| 7 | Caduti di Radio Cora | 43,84510680 | 11,26236570 | 1 | 1 | 1 |
| 8 | GKN | 43,84477100 | 11,14139400 | 1 | 1 | 1 |
| 9 | Manetti | 43,84387690 | 11,16917260 | 1 | 1 | 1 |
| 10 | Officine Galileo | 43,84241920 | 11,14937430 | 1 | 1 | 1 |
| 11 | La Querciola | 43,84134140 | 11,31963030 | 3 | 3 | 3 |
| 12 | Campi Bisenzio Galilei | 43,83935800 | 11,12928080 | 2 | 1 | 2 |
| 13 | Caldine Nuove | 43,83911280 | 11,30849240 | 1 | 1 | 1 |
| 14 | Volpaia | 43,83855000 | 11,17763860 | 2 | 1 | 2 |
| 15 | Biblioteca di doccia | 43,83655740 | 11,21446580 | 1 | 1 | 1 |
| 16 | Togliatti | 43,83701510 | 11,18234670 | 1 | 1 | 1 |
| 17 | Piazza Togliatti | 43,83440090 | 11,13150890 | 2 | 1 | 2 |
| 18 | Sesto Fiorentino Vittorio Veneto | 43,83191380 | 11,19952320 | 2 | 2 | 2 |
| 19 | Pian di San Bartolo | 43,83174070 | 11,28696330 | 2 | 2 | 2 |
| 20 | Sesto Fiorentino mille | 43,82863140 | 11,20702780 | 2 | 1 | 1 |
| 21 | Serpiolle | 43,82336880 | 11,25641410 | 1 | 1 | 1 |
| 22 | Campi di Bisenzio Verdi | 43,82148490 | 11,14115030 | 1 | 1 | 1 |
| 23 | Schiff | 43,82070280 | 11,19375810 | 1 | 1 | 1 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 24 | Careggi | 43,81299270 | 11,25105100 | 3 | 3 | 2 |
| 25 | Motorizzazione Civile | 43,81229120 | 11,16533900 | 1 | 1 | 1 |
| 26 | Sant'Angelo a Lecore | 43,81191400 | 11,08332650 | 1 | 1 | 1 |
| 27 | Ticino | 43,81083920 | 11,17842200 | 1 | 1 | 1 |
| 28 | Adige | 43,80886630 | 11,17618640 | 2 | 2 | 2 |
| 29 | Niccolo' da Tolentino | 43,80785650 | 11,24351110 | 3 | 2 | 2 |
| 30 | Piazza Marconi | 43,80768390 | 11,18482900 | 1 | 1 | 1 |
| 31 | Caruso | 43,80748280 | 11,23892210 | 4 | 3 | 2 |
| 32 | Fiesole - Vinandro Osteria | 43,80708340 | 11,29219310 | 4 | 3 | 3 |
| 33 | Villa Cancelli | 43,80703980 | 11,26116860 | 1 | 1 | 1 |
| 34 | La Lastra | 43,80656600 | 11,27439680 | 1 | 1 | 1 |
| 35 | Nuovo pignone | 43,80595390 | 11,22580230 | 5 | 4 | 4 |
| 36 | Patologia1 | 43,80310920 | 11,24563480 | 4 | 4 | 4 |
| 37 | Incontri | 43,80267420 | 11,25407170 | 1 | 1 | 1 |
| 38 | Patologia | 43,80247430 | 11,24549450 | 1 | 1 | 1 |
| 39 | Michelacci | 43,80191900 | 11,18967210 | 2 | 2 | 2 |
| 40 | Deposito peretola | 43,80118330 | 11,19064670 | 1 | 1 | 1 |
| 41 | Rifredi - Vasco de Gama | 43,79999970 | 11,23576940 | 5 | 3 | 3 |
| 42 | Salviati FS | 43,79937140 | 11,27518020 | 2 | 1 | 1 |
| 43 | Barsanti | 43,79673520 | 11,22551610 | 1 | 1 | 1 |
| 44 | Dalmazia | 43,79655270 | 11,24029900 | 3 | 3 | 3 |
| 45 | Lippi e Macia | 43,79565570 | 11,21774420 | 3 | 2 | 3 |
| 46 | San Donnino | 43,79543100 | 11,15062150 | 1 | 1 | 1 |
| 47 | Boccaccio | 43,79350200 | 11,27407640 | 1 | 1 | 1 |
| 48 | Piagge FS | 43,79012690 | 11,17233050 | 4 | 3 | 3 |
| 49 | Boito | 43,78809090 | 11,21882250 | 3 | 2 | 2 |
| 50 | Cure | 43,7866800 | 11,2690160 | 1 | 1 | 1 |
| 51 | Salviatino | 43,78488860 | 11,29402020 | 2 | 2 | 2 |
| 52 | Mulino biondi | 43,78452890 | 11,27309460 | 2 | 2 | 2 |
| 53 | Sosta del rosellino | 43,78299070 | 11,32160000 | 2 | 1 | 1 |
| 54 | Piovano Arlotto | 43,78222280 | 11,16801320 | 1 | 1 | 1 |
| 55 | Kennedy | 43,78108610 | 11,21862920 | 2 | 2 | 2 |
| 56 | Badia a settimo | 43,78044830 | 11,14612320 | 3 | 2 | 2 |
| 57 | Via della dogana | 43,7791710 | 11,2597491 | 5 | 5 | 4 |
| 58 | Porto di Mezzo | 43,77901030 | 11,07951760 | 1 | 1 | 1 |
| 59 | Verga | 43,77862180 | 11,29795800 | 4 | 3 | 3 |
| 60 | La Pira | 43,77824970 | 11,25965770 | 3 | 2 | 2 |
| 61 | San Colombano | 43,77810670 | 11,13606740 | 2 | 1 | 1 |
| 62 | Stazione via alamanni | 43,77806660 | 11,24544240 | 5 | 4 | 4 |
| 63 | Cascine | 43,77793640 | 11,23117850 | 2 | 1 | 1 |
| 64 | Stazione palazzo dei congressi | 43,77746030 | 11,24911500 | 7 | 6 | 6 |
| 65 | Stazione deposito bagagli | 43,77705220 | 11,24856330 | 5 | 3 | 3 |
| 66 | Stazione galleria | 43,77616150 | 11,24868710 | 2 | 1 | 1 |
| 67 | Stazione parcheggio | 43,77602890 | 11,24955500 | 3 | 2 | 3 |
| 68 | Il roseto | 43,77547620 | 11,36314430 | 1 | 1 | 1 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 69 | Novelli | 43,77543580 | 11,29446520 | 5 | 4 | 4 |
| 70 | Stazione Mercato centrale | 43,77506040 | 11,25067100 | 3 | 2 | 2 |
| 71 | Santa Maria Maggiore | 43,77304210 | 11,25278540 | 2 | 1 | 2 |
| 72 | La casella | 43,77219050 | 11,19055600 | 1 | 1 | 1 |
| 73 | di sotto | 43,77188050 | 11,10552750 | 2 | 1 | 1 |
| 74 | Foggini | 43,77174190 | 11,21220060 | 1 | 1 | 1 |
| 75 | Pier della Francesca | 43,77072610 | 11,21220220 | 2 | 2 | 2 |
| 76 | Comparetti | 43,76994880 | 11,30118160 | 3 | 3 | 3 |
| 77 | Il Girone | 43,76975810 | 11,34019690 | 3 | 3 | 3 |
| 78 | Cadorna | 43,76949550 | 11,10670010 | 3 | 3 | 3 |
| 79 | Ripa | 43,76756310 | 11,30924170 | 3 | 3 | 3 |
| 80 | Spontini | 43,76593570 | 11,17360100 | 2 | 2 | 2 |
| 81 | Via del filarete | 43,76572040 | 11,21396640 | 2 | 2 | 2 |
| 82 | Ferrucci | 43,76396010 | 11,27193190 | 3 | 1 | 3 |
| 83 | San Lorenzo a Greve | 43,76276140 | 11,19783610 | 1 | 1 | 1 |
| 84 | Pia.le Michelangelo | 43,76244720 | 11,26521930 | 3 | 1 | 2 |
| 85 | Cimitero di Soffiano | 43,76190910 | 11,21676150 | 1 | 1 | 1 |
| 86 | Villamagna | 43,76175440 | 11,38248920 | 1 | 1 | 1 |
| 87 | Nave a Rovezzano | 43,76156340 | 11,30688540 | 3 | 3 | 2 |
| 88 | San Giusto della Calza | 43,76134640 | 11,24215720 | 2 | 1 | 1 |
| 89 | Scuola magistrati | 43,76089000 | 11,13906170 | 2 | 1 | 2 |
| 90 | 68esimo reggimento | 43,75944680 | 11,18134560 | 5 | 4 | 5 |
| 91 | Ospedale torri galli | 43,75873500 | 11,20248530 | 8 | 6 | 7 |
| 92 | Bagnese | 43,75617410 | 11,19739160 | 1 | 1 | 1 |
| 93 | De Andrè | 43,75424050 | 11,17868060 | 1 | 1 | 1 |
| 94 | Sorgane Piazza Rodolico | 43,75417380 | 11,30610140 | 2 | 2 | 2 |
| 95 | Scuola Russell | 43,75370550 | 11,17977200 | 2 | 1 | 2 |
| 96 | I ponti | 43,75276700 | 11,31732850 | 2 | 2 | 2 |
| 97 | Sorgane | 43,75154650 | 11,30512630 | 6 | 5 | 4 |
| 98 | Scandicci | 43,75072760 | 11,17740630 | 1 | 1 | 1 |
| 99 | Scuola Rodari | 43,75404320 | 11,17906070 | 1 | 1 | 1 |
| 100 | Fermi | 43,75031100 | 11,24935000 | 1 | 1 | 1 |
| 101 | Marignolle | 43,74992750 | 11,21655700 | 1 | 1 | 1 |
| 102 | Malavolta | 43,74913860 | 11,23526230 | 2 | 2 | 2 |
| 103 | Pian dei Giullari | 43,74736640 | 11,25791360 | 1 | 1 | 1 |
| 104 | Vingone | 43,74609470 | 11,18071890 | 2 | 1 | 2 |
| 105 | Pietriboni | 43,73640130 | 11,22688920 | 2 | 2 | 1 |
| 106 | Osteria Nuova | 43,72994800 | 11,34663700 | 1 | 1 | 1 |
| 107 | Antella | 43,72649020 | 11,32203210 | 2 | 1 | 2 |
| 108 | Grassina | 43,72399150 | 11,29319890 | 4 | 4 | 4 |
| 109 | Slargo Lippi | 43,71782580 | 11,29272080 | 1 | 1 | 1 |
| 110 | Tavarnuzze primo maggio | 43,7087201 | 11,2126062 | 2 | 1 | 1 |
| 111 | Artigiani | 43,70542610 | 11,08460410 | 2 | 2 | 2 |
| 112 | San Vincenzo a Torri | 43,70019800 | 11,09625110 | 3 | 3 | 3 |
| 113 | San Polo | 43,67089780 | 11,35994150 | 1 | 1 | 1 |

| | | | |
|---|---|---|---|
| Total | 249 | 204 | 213 |
| Power required [kW] | 12450 | 10200 | 10650 |

Table 65 List of the charging stations for each terminal stop

Focusing on the differences for the number of the charging stations, table below reports the terminal stops where the number of the needed charging stations is different.

| Station name | N° charging stations (Volvo 7700) | N° charging stations (Volvo 7900) |
|---|---|---|
| Calenzano | 3 | 2 |
| Campi Bisenzio Galilei | 2 | 1 |
| Volpaia | 2 | 1 |
| Piazza Togliatti | 2 | 1 |
| Sesto Fiorentino mille | 2 | 1 |
| Careggi | 4 | 3 |
| Niccolo' da Tolentino | 3 | 2 |
| Caruso | 4 | 3 |
| Fiesole - Vinandro Osteria | 4 | 3 |
| Nuovo pignone | 5 | 4 |
| Patologia1 | 5 | 4 |
| Rifredi - Vasco de Gama | 5 | 3 |
| Lippi e Macia | 3 | 2 |
| Piagge FS | 4 | 3 |
| Boito | 3 | 2 |
| Sosta del rosellino | 2 | 1 |
| Badia a settimo | 3 | 2 |
| Via della dogana | 6 | 5 |
| Porto di Mezzo | 2 | 1 |
| Verga | 4 | 3 |
| La Pira | 3 | 2 |
| San Colombano | 2 | 1 |
| Stazione via alamanni | 6 | 4 |
| Stazione palazzo dei congressi | 8 | 6 |
| Stazione deposito bagagli | 5 | 3 |
| Stazione parcheggio | 3 | 2 |

| | | |
|---|---|---|
| Novelli | 6 | 4 |
| Stazione Mercato centrale | 3 | 2 |
| Ripa | 4 | 3 |
| Via del filarete | 3 | 2 |
| Ferrucci | 3 | 1 |
| Pia.le Michelangelo | 3 | 1 |
| Nave a Rovezzano | 4 | 3 |
| San Giusto della Calza | 2 | 1 |
| Scuola magistrati | 2 | 1 |
| 68esimo reggimento | 5 | 4 |
| Ospedale torri galli | 9 | 6 |
| De Andrè | 2 | 1 |
| Sorgane | 6 | 5 |
| Vingone | 2 | 1 |
| Antella | 2 | 1 |
| Tavarnuzze primo maggio | 2 | 1 |

Table 66 Comparison of the number for charging stations for the 2 Volvo buses

## 16.4 Impact to the grid

As a last point for the analysis, based on the number of charging stations needed for the Volvo 7900 bus, the impact to the grid in Firenze has been evaluated with Atlante. To have a compared analysis and so the possibility to compare the results, the hypotheses have been kept the same of the Volvo 7700 bus analysis, in detail:

- Power for each charging station is set at 50 kW as passive users
- The charging profile is considered to be steady during all day with a power fixed at 50 kW
- For each terminal stop up to 3 charging stations the connection is directly on LV grid with a new line, while in case of more than 3 stations a new secondary substation is needed to be built due to high power to be connected (more than 150 kW).

Based on the 2nd hypothesis, it results an analysis enough conservative since it does not reflect the real load charging profiles because Atlante always evaluates the worst case for the network.

Summarizing what said in para 4.2.1 regarding the cost, Atlante provides the cost for the infrastructure from the secondary substation to Point of Delivery, where a meter could be installed. It doesn't consider the typology of the load to connect, it is independent if a conductive charging station or inductive charging station is installed (the effect and impact of the inductive charging will be evaluated in task 2,4), and it does not consider any additional costs, specified for a single area.

In addition to these costs, based on the Italian regulation, the companies requiring the installation have to contribute some money to a part of the entire costs for the new LV connection for the permanent installation of stations. This cost is called the TIC cost and it is function of the power require and the distance to the secondary substation.

Analyzing the results gathered with Atlante the total cost for the 2 cases are really similar, since where a new secondary substation was forecast in the analysis for Volvo 7700 bus, it had to be maintain also for this for this case, due to overstocked of the secondary substation.

Even thought the power for the existing transformer has been increased to fulfill the power required, the difference cost for the 2 transformers is not significant.

In conclusion, this first typology of the cost resulting from Atlante shows no differences between the 2 cases.

Considering the TIC cost, the total amount to be paid by who requires the installation, shows differences in the cost, since the power required is different whereas the distance to the secondary substation remains constant.

Table below reports the main results for the 2 analysis:

| | Volvo 7700 bus | Volvo 7900 bus |
|---|---|---|
| Power consumption [kWh/km] | 1,931 | 1,455 |
| Charging stations | 256 | 204 |
| Power [MW] | 12,8 | 10,2 |
| Cost for Atlante [k€] | 1350 | 1350 |
| Cost for TIC [k€] | 910 | 730 |

Table 67 Comparison of the relevant results for the 2 analysis

All costs in the table do not consider the additional costs for the civil works in Firenze, which influence the whole costs from 22% for urban area to 37% for downtown area.
Reading the results, from the grid point of view, it is not significant to install 256 or 204 charging stations.
Surely these results really depend on the initial hypotheses and the analysis is enough conservative.