Feasibility analysis and development of on-road charging solutions for future electric vehicles

Detailed LCA/LCCA assessment of environment and cost impact of E-Roads

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LIST OF ABBREVIATIONS

ABBREVIATION	DESCRIPTION
ARAN	Automatic Road Analyser
CAM	Cement Asphalt Mortar
CED	Cumulative Energy Demand
CRF	Centro Ricerche Fiat
CU	Charging Unit
CWD	Charge While Driving
DoW	Description of work
DWPT	Dynamic Wireless Power Transfer
eCo-FEV	efficient Cooperative infrastructure for Fully Electric Vehicles
EoL	End of Life
E-Roads	Electrified Roads
FU	Functional Unit
IPV	Induction Powered Vehicle
LCA	Life Cycle Analysis
LCCA	Life Cycle Costing
t-Roads	Traditional Roads
WPT	Wireless Power Transfer

REVISION CHART AND HISTORY LOG

REV	DATE	REASON
0^{st} revision	2017-08-04	First skeleton (KTH)
1	2017-9-6	Inclusion of LCA part (POLITO)
2	2017-11-20	Inclusion of LCCA part (QiE)
3	2017-12-21	Summary and compilation (KTH)
4	2018-01-14	Final compilation for review (KTH)
5	2018-03-07	Submission version after peer review

EXECUTIVE SUMMARY

This document is the final report within WP 5.3 Road Infrastructure Impact & Solutions. By focusing on the environmental and economic performances of the e-Road infrastructure (i.e. Task 5.3.6), D5.3.4 is one of the most important cornerstones within the project to determine the feasibility of the on-the-Road charging technology in the future.

In this deliverable, by employing the integrated LCA/LCCA analysis framework that had been developed in D5.3.1, a series of practical LCA and LCCA calculations were carried out, aiming to probe into the life cycle environmental and economic costs of the e-Road infrastructure in a quantitative way. In the detailed assessment, the assumptions in system boundaries, the chosen functional unit, as well as the case scenarios, are mainly based on D5.3.2 & D5.3.3 which contain specifications of e-Road construction, maintenance and operation. In order to obtain representative results for practical LCA/LCCA calculations of this deliverable, slight adjustments have been applied to system boundary conditions established in the beginning of WP5.3. The LCA/LCCA assessment results can be comprehended as follows:

- The environmental performance of e-Road infrastructure was firstly evaluated via the selected LCA tool, in which the potential energy usage, fuel usage and emissions during its long life cycle were calculated and analysed. Case studies over the POLITO and SAET solutions showed that the WPT components contribute significantly to the life cycle impacts of e-Road, while the two solutions didn’t show significant differences between each other. Further interesting discussions were conducted on impacts and consumptions during the individual life cycle stages (construction, maintenance and operations), as well as the potential solutions for reducing the impacts/consumptions.
- In LCCA of e-Road infrastructure, three representative scenarios were considered during assessment: i) *Motorways* with dual traffic of e-light vehicles, e-trucks and e-buses, ii) *Peri-urban scenario* with e-trucks and e-buses, and iii) *Urban scenario* with e-buses in cities. In the meanwhile, for each of the technological options (POLITO and SAET), two possible construction alternatives were considered in the calculation of the costs: i) re-construction of an existing

lane from a traditional road (e-Road), and ii) manufacture of a new separated dedicated lane (e-Corridor). The costs calculated for specific cases, considering two important market entry times, i.e. 2030 and 2050, have been well documented in this report.

As a last step, the results of this deliverable will be integrated into the final comprehensive assessment of the life cycle performances of the reviewed charging solutions at system-level, w.r.t not only the roads, but also the vehicles and electricity productions.

1 INTRODUCTION

The environmental and economic costs of using the Wireless Power Transfer (WPT) technologies must be affordable for administrations and the society as a whole. Provided that the e-Road is built based on upgrading the existing road infrastructure, the road pavement will be excavated and reconstructed. Likewise, regular operational maintenance actions will be performed throughout the use phase to ensure the good conditions of the e-Road. In these stages, new infrastructural materials, new on-site processes and extra waste disposals can be involved but the consequential impacts are unclear. Therefore, for the case of e-Road infrastructure, the impacts of the changed road construction and maintenance also need to be included in EV's total life cycle analysis. In other words, the benefits of the electrified road transportation should not be overshadowed by the added environmental burdens associated with the inclusion of IPT charging technology in the road infrastructure.

1.1 Backgrounds

The aim of WP53 is to implement a systematic evaluation over the life cycle performances of e-Road infrastructures (wireless charging of electric vehicles in motion), determining the environmental impact and the economic costs. The conclusions from these analyses shall provide important insight into where the impacts and costs are incurred into the whole e-Road life cycle, as well as helping on determining the strategies to reduce these impacts and costs. In this regard, this work would help decision-makers in industry organizations and administrations to adopt best options for e-Road design practices, contributing to improve sustainability of the road transport sector through the full electrification. This work package is organised in tasks and deliverables as follows:

- T531 Sustainability of the e-Road at system scale (LCA/LCCA component integration and development). Deliverable D5.3.1 assigned to T531 contains the bases for the elaboration of the LCCA and LCA.
- T532 Framework for long-term performance of the e-Roads, including effects of environmental and mechanical loading.

- T533 Construction of e-Roads. Deliverable D5.3.2 assigned to T5.3.2 and T5.3.3 collects the conclusions from the construction of e-Roads reports.
- T5.3.4 Long-term e-Road response predictions.
- T5.3.5 Monitoring, maintenance & operations of e-Roads. Deliverable D5.3.3 assigned to T5.3.4 and T5.3.5, gathers the information related to the operation, monitoring and maintenance activities.
- T5.3.6 Final assessment of e-Roads using LCA and LCCA. Deliverable D5.3.4 concludes with the final LCA and LCCA assessment.

T536 and the corresponding deliverable D5.3.4 are the subject of this report described as follows:

> *"Using the life cycle assessment and costs tools developed in Task 5.3.1, the long-life e-Road predictions from Task 5.3.4, the construction, maintenance and operations scenarios from Tasks 5.3.3 and 5.3.5, this task is evaluating the environmental and costs impacts of the developed e-Road solutions. The costs in terms of energy, time and money will be detailed from the LCCA analyses. The environmental impact will be expressed in energy usage, fuel usage and emissions. By performing an extensive parametric study, varying the crucial parameters, detailed recommendations will be made for each individual e-Road solution to minimize the environmental impact and costs as well as a general comparison between the solutions will be made".*

Figure 1 shows the location of D5.3.4 (in yellow colour) among the rest of tasks and deliverables, as well as the links that exist between the previous tasks necessary to complete and the subsequent tasks affected by the results of this crucial deliverable.

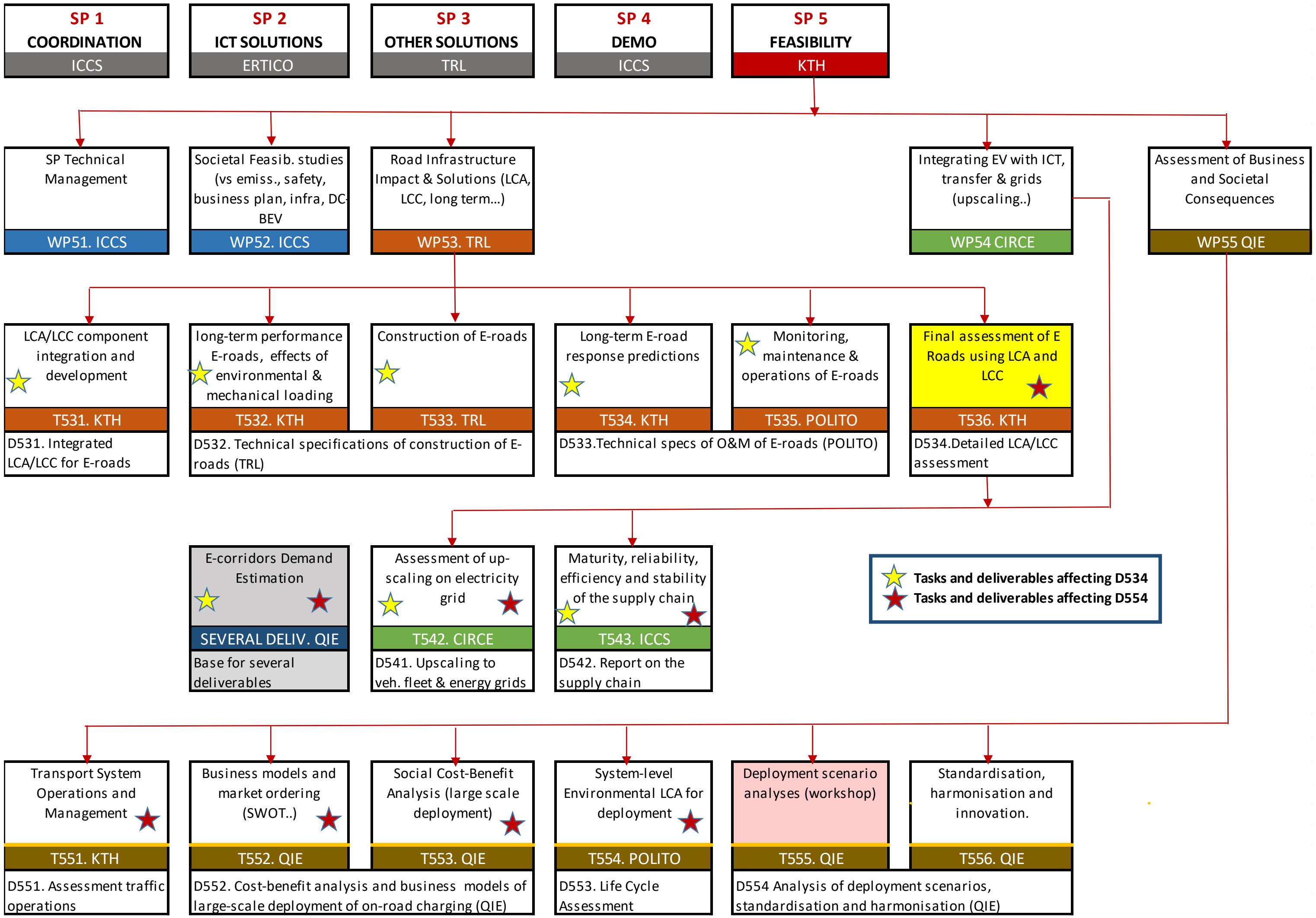


Figure 1 Deliverable D5.3.4 and its inter-connection with other WP deliverables

1.2 Organization of the deliverable D5.3.4

In previous D5.3.1, a common LCA/LCCA framework had been developed as a methodological base to coordinate the detailed life cycle performance analyses of e-Roads. The major work include essentially the goal and scope definition, where the phases over the lifetime, the analysis period, the functional unit (FU), the pavement alternatives and the scheduled activity timing are stated. In addition to these, the specific system boundaries for the integrated LCA and LCCA are further detailed.

As a follow-up, In this deliverable D5.3.4 the actual environmental and economic performances of the e-Road infrastructure are analysed and summarized, using specific LCA/LCCA tools and boundary inputs gathered from D5.3.2 & D5.3.3 on specifications of e-Road construction, maintenance and operations. To proceed, the rest of the deliverable is organized as follows::

- Section 2 presents the LCA results and analyses of the e-Roads.
- Section 3 presents the LCCA results and analyses of the e-Roads.
- Section 4 summarizes the main findings of the report.

2 LCA OF E-ROAD INFRASTRUCTURE

This section of the deliverable presents the environmental analysis of the e-Road infrastructure using the LCA tool, as defined in the DoW. This part is the result of the Task 5.3.6 Final assessment of E Roads using LCA and LCCA.

2.1 Introduction

This LCA aims at evaluating the long-life e-Road predictions defined in Tasks 5.3.3 and 5.3.5, and in terms of energy usage, fuel usage and emissions (Task 5.3.4). The model should be a parametric one, so to find an optimum solution in the construction of e-Roads, varying the significant inputs parameter.

2.1.1 WPT layout

The main WPT technology providers have been:

- Polytechnic University of Turin (**POLITO**).
- SAET Industrial Automation Systems (**SAET**).
- Qualcomm in alliance with the French research group VEDECOM.

SAET and POLITO have provided sufficiently disaggregated information of the their respective IPT technologies, which served as the basis for a detailed analysis of the costs and the environmental impact.

In an on-road power transfer solution, the grid provides three phases 400 V AC to a number of rectifiers and inverters, which converts AC to DC voltage and in a second step to high frequency AC. Converters and control electronics are located at the roadside (see Figure 2). The in-road equipment consists of coils that are connected to a roadside cabinet, sensors and switches; when the technology is enabled, one or more coils per segment can be switched on at the same time, depending on the solution design, power rating of the inverters and supply from the grid.

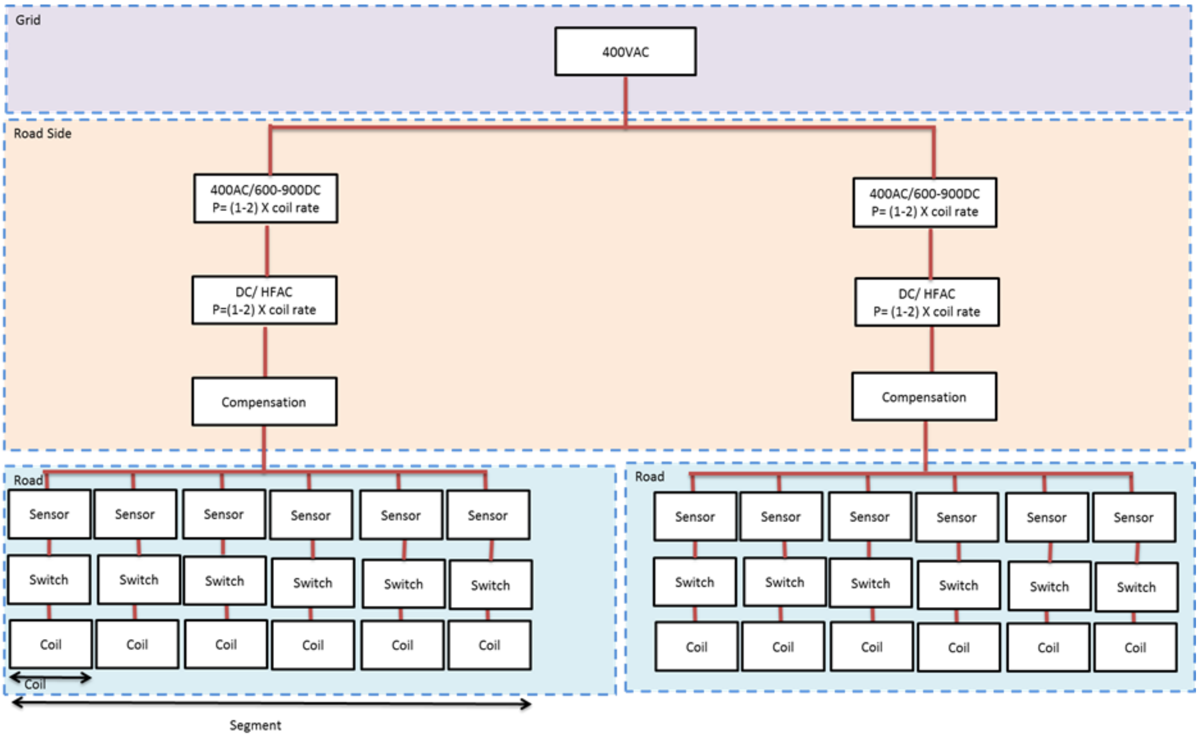


Figure 2: Power Transfer system Architecture

The current solutions are connected to three-phase 400V AC substation feeder points. However, these solutions are primarily experimental and mainly used in controlled environments where the installation is used by a small number of vehicles. The project solutions are experimental systems that were installed in an isolated track. Therefore, it is feasible for these solutions to connect to 400 V AC. However, as the solutions become more commercial and installed at larger scale, other forms of connections must be considered due to the higher demand levels, stepping up from kW to MW range.

In a reasonable configuration, for example, the grid provides three phases 10-22 kV AC, to a 600 kVA substation (with a MV-LV transformer and an AC/DC converter) whose output is a 650-700V direct current (see Figure 3).

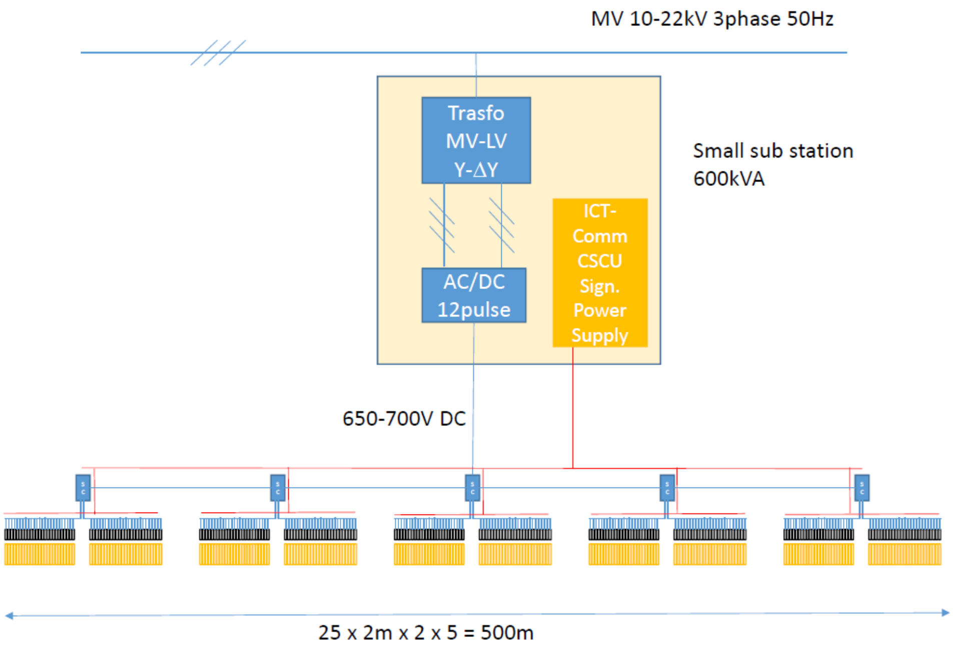


Figure 3: possible configuration for motorway application (Source: POLITO)

2.1.2 System boundary

As defined in the DoW and restated in D5.3.1, the system boundary has to include the following phases:

1. construction
2. operation
3. maintenance

Note: A fourth stage, the End of Life (EoL) has been disregarded in the guidelines defined in D5.3.1.

The impacts attributable to a pavement's end-of-life phase depend on the ultimate fates of the pavement and its constituent materials, which are notoriously difficult to determine a priori. At the end of its service life, a pavement can meet one of three fates: (1) demolished and landfilled; (2) demolished and recycled; or (3) remain in situ and serve as support for a subsequent pavement structure. Each pathway requires a unique approach for quantifying the environmental impact (Santero et al).Since the high uncertainty related to the EoL of e-Road, it has been excluded from the analysis, as stated in D5.3.1. A detailed sketch of the sub stages is depicted in Figure 4.

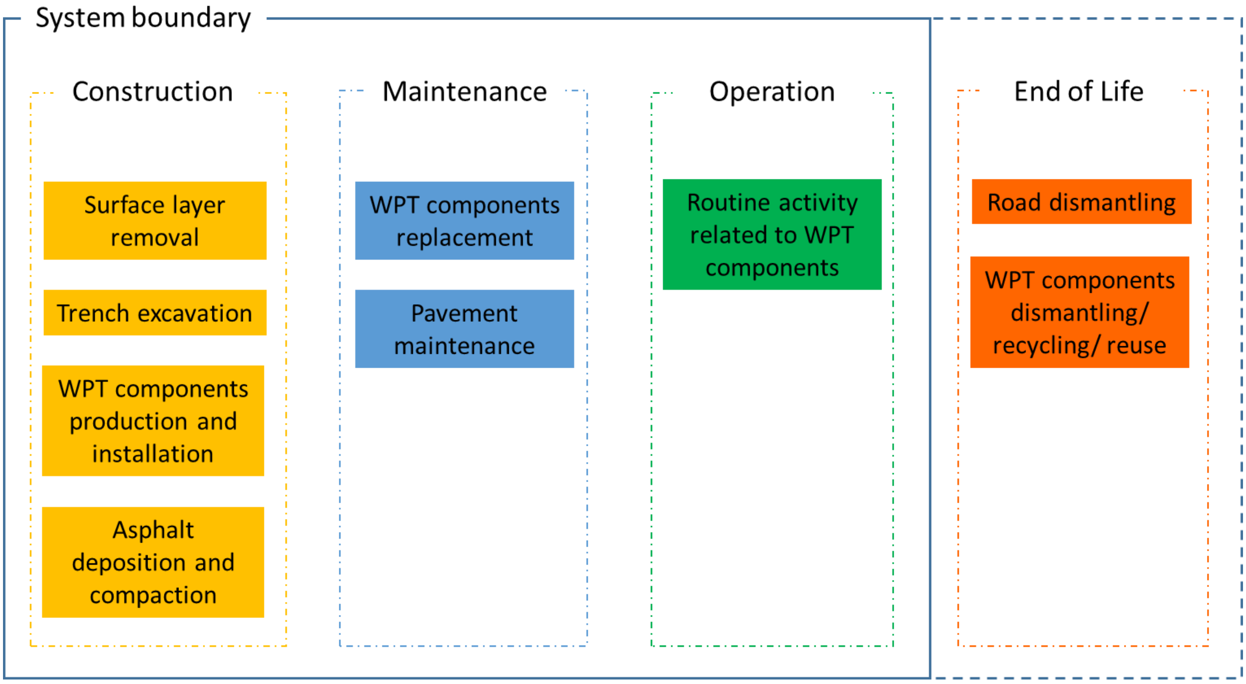


Figure 4: Phases and sub phases included in the system boundary

The construction method is modelled following the guidelines provided by TRL (D5.3.2). In this phase the production of electric equipment and construction materials (concrete, asphalt,…), transports of materials and equipment to the construction site, and machinery use for the construction are considered. For the WPT components, the system boundary includes the production and the installation of all the equipment until the interface with the national grid.

Maintenance includes ordinary operation and rehabilitation: maintenance is a periodic activity and consists of surface treatments. Rehabilitation is a periodic activity and consists of removal and replacement of the asphalt top layers.

In the construction phase the following activities are included:

- Raw materials production
- Raw materials transport to the road construction site
- On-site equipment transport
- Equipment use (fuels)
- Road infrastructure construction
- Charging unit (and any other electrical device) production
- Charging unit transport to the road construction site
- Charging unit installation

While the following are excluded:

- Subgrade preparation
- Road markings
- Fences and railings
- Road signs
- Lightning
- Traffic lights

For what concerns the maintenance phase, the included activities are the followings:

- Raw materials required for the maintenance
- Raw materials transport to the road site
- On-site equipment transport
- Equipment use (fuels)
- Charging unit maintenance

On the same line as the construction, the following activities are excluded from the analysis:

- Road markings maintenance
- Fences and railings maintenance
- Road signs maintenance
- Lightning maintenance
- Traffic lights maintenance
- Road sweeping
- De-icing

2.1.3 Functional unit

Instead of a functional unit, a declared unit has been defined (a declared unit is used instead of a functional unit when the precise function of the product is not stated or known). The declared unit expresses the impact due to the realization, maintenance and operation of an e-Road/e-corridor that designed to last for 20 years, being able to provide 50 kw to light vehicles and 100 to heavy vehicles.

The decision to use a declared unit, rather than a more compliant functional unit, lays on the fact that the function of the e-Road/e-corridor will be defined in the scenario definition, that has to be validated and released in the forthcoming deliverable D5.5.1.

The effective function of an e-corridor is to extend the range of an EV. The range however depends on too many factors, like users, behaviour, driving style, use of

accessories, etc... as a proxy of the extended range, the energy transferred to a vehicle covering the total length of the e-Road/e-corridor at 100 km/h perfectly aligned could be chosen. Moreover, the number of vehicles rechargeable on each segment is limited and it depends on the configuration of the road. So the functional unit could be the extended range × number of vehicles when comparing different e-Road solutions.

2.1.4 Data quality

Data on the construction of an e-Road has been provided by TRL, data on the materials of the infrastructure are derived by deliverable D5.3.1 describing test sites architecture and from interview with experts. As this data describes the test site solution, which is not optimized for the real world solution, adaptation has been derived by interview with experts. Data on maintenance operations are derived from deliverable D5.3.3, where a computational recursive approach has been applied to predict the lifetime of the road and the damage in the charging unit (CU). Data regarding components, material production and transportation, are derived from the database EcoInvent version 3.3.

2.1.5 Impact assessment

It was specified earlier within the scope definition which impact categories, indicators and characterisation factors should be used in the study, as the type of impact assessment influences the data procurement. According to the DoW and D5.3.1, the inventory data of interest in this study are energy usage, fuel usage and emissions. The aforementioned Inventory data are translated into the following impact categories:

1. Energy usage: Cumulative energy demand (CED) consists of different amounts that include energy consumption in the narrow sense, and the content of energy resources and other materials with calorific value in the products.
2. Fuel usage: Abiotic depletion – fossil.
3. Emissions: this label is not linked to a specific impact category, while under this label many impact categories can be identified. Considering that this study aims at evaluating a representative e-Road, rather than a specific one, it has been preferred to consider established global impact categories, i.e. climate change, instead of local, site-dependent impacts.

2.2 Life Cycle inventory calculations of POLITO solution

POLITO developed the Charge While Driving (CWD) solution in cooperation with Centro Ricerche Fiat (CRF). This section presents the inventory calculations of POLITO charging solution, while the detailed descriptions of the WPT configuration can be traced in appendix I.

2.2.1 Road geometry and construction

The optimal configuration for the POLITO technology requires the installation of the coils 4 cm beneath the road surface. It, however, permits some allowance in depth positioning, thus permitting the placement of the coils in the bitumen layer, even if the overhead wear layer can be higher than 4 cm (in the analysed case is 6 cm, see Figure 5).

At the test site the construction involves the excavation of narrow micro-trenches (80 mm depth circa) within the pavement and the coil or e-Road system was placed in within a filling material and covered with asphalt.

Many other options have been investigated and the conclusion from the testing suggested that the best approach was to excavate thin trenches in the asphalt layer, approximately 80mm deep, then to cover the system in a proprietary bitumen and pave the holes with a cold mix asphalt, as described in POLITO's report in D4.5.2.

This type of construction may be suitable for testing the technologies temporally in a test-track environment. It may not be appropriate for the actual in-service highway implementation, from the practical construction and maintenance perspectives.

From interviews with experts the installation method in motorway will require the dismantling of both the wear and binder layer, the placement of the coils coated with bitumen embedded in a low stiffness concrete and covering the system with asphalt. In Figure 5 a section of the actual design of the adaptation of POLITO solution for real roads is reported.

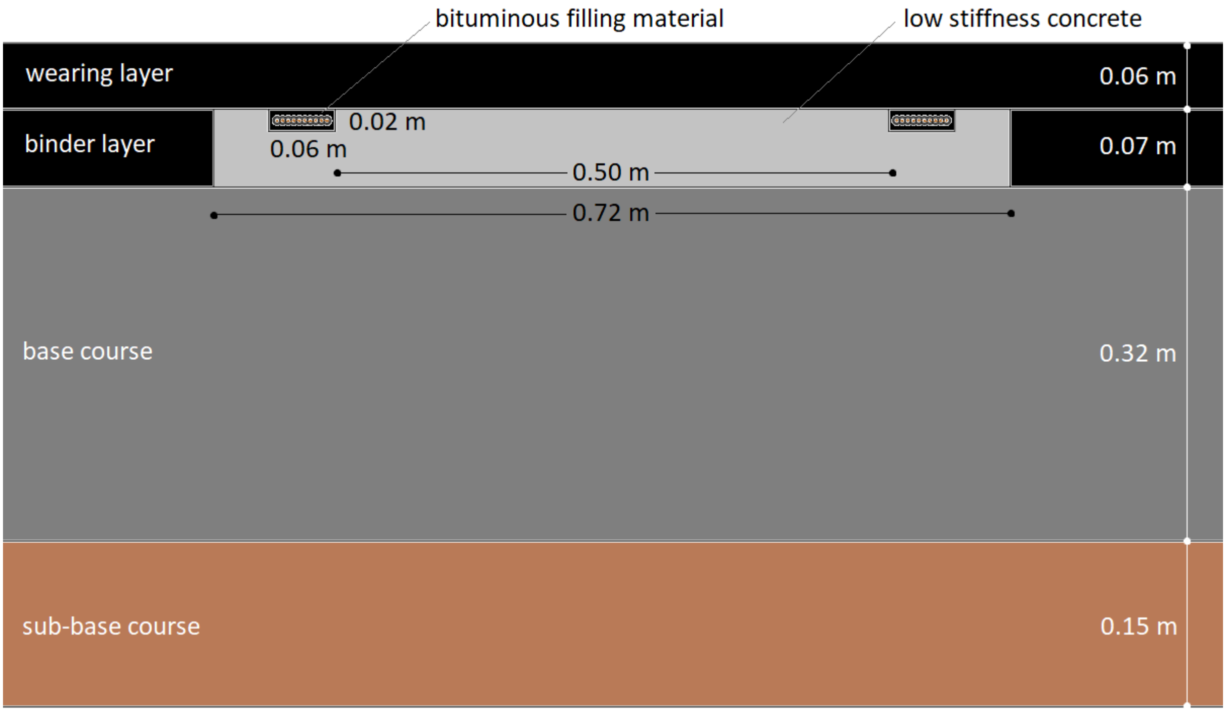


Figure 5: Section of actual configuration of POLITO solution for real road adaptation

2.2.2 Life cycle inventory

2.2.2.1 Construction

The realization of the e-Road for the POLITO solution will require the dismantling of both the wear and the binder layers. A summary of the construction method is presented below.

1. Removal of existing surfacing layer within the carriageway (lane 1) and removal of the off-site for ex-situ recycling.
2. Preparation for installation of e-Road systems.
3. Installation of e-Road solutions.
4. Connection of coils and feed to road side.
5. Connect units up to roadside cabinets (also to be installed).
6. Overlay with asphalt 0.06-0.1m (possible SAMI or geo-grid layer included in addition to LTA mixtures) and application of tack coat to ensure adequate bonding between layers.
7. Installation of any auxiliary equipment such as sensor activation units in surface.

As described in D5.3.2, a set of general e-Road construction procedures are described below in a very general way, which can be followed during the practical construction. Some changes can be made accordingly in local conditions.

- Removal of the whole surface course layer, e.g. using a jack hammer and cold planer (milling machines). This can be similar to the procedure of normal pavement rehabilitation about the replacement of the surface course layer every several years.
- Installation of e-Road solutions: e-Road units and associated connection pipework delivered to the site in precast form and for the pavement to be constructed around them.
- overlay with asphalt 0.06-0.1m (possible SAMI or geo-grid layer included in addition to LTA mixtures) and application of tack coat to ensure adequate bonding between layers.
- Installation of any auxiliary equipment such as sensor activation units in surface.

2.2.2.1.1 Milling machine

To assess emissions and fuel consumption of the milling machines used to remove the surface layers, data on milling speed and hourly consumption are derived from technical datasheet of machineries available on the market. A machine with a milling width of 2 meters and a weight of 28,9 ton has been chosen, with a construction fuel consumption of 52 l/h. the time required for the removal of the surface layers is function of the milling depth, as can be seen in Figure 6.

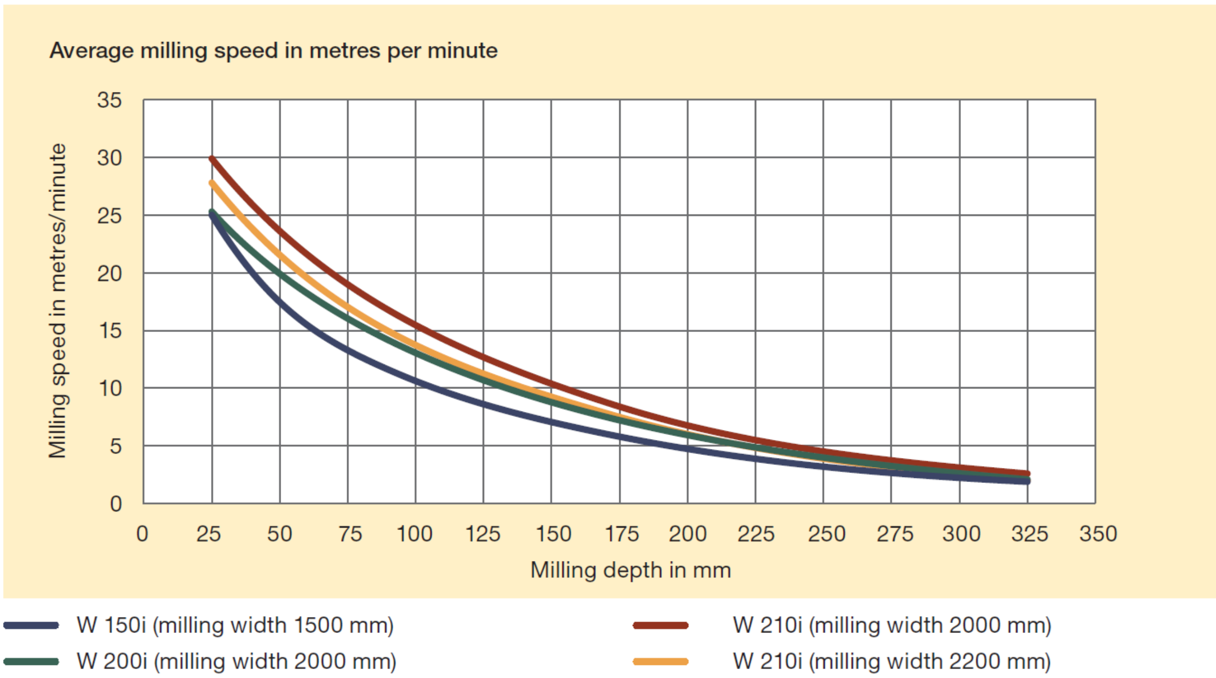


Figure 6: Average milling speed in metres per minute.

Thus fuel consumption required to mill 1 km of road at a milling depth of 13 cm (i.e. the average depth of wear and binder layer for an highway, being able to carry 4,500,000 heavy vehicles) is derived from the milling speed and the hourly consumption times two, since the full width of the lane (3.65 m) requires the machine to pass twice:

$$fuel\ consumption = \frac{hourly\ consumption\ \left[\frac{l}{h}\right]}{milling\ speed\ \left[\frac{m}{min}\right] \cdot \frac{60min}{h}} \cdot 1000\frac{m}{km} \cdot 2$$

$$= \frac{52\frac{l}{h}}{13\frac{m}{min} \cdot \frac{60min}{h}} \cdot 1000\frac{m}{km} \cdot 2 = 133.33\ \frac{l}{km} = 111.33\frac{kg}{km}$$

-Assuming a diesel density of 0.835 kg/l

Emissions are derived from the EcoInvent database, using the dataset “diesel, burned in agricultural machinery GLO". Wear from machinery use is disregarded.

2.2.2.1.2 Sweeping machine

Before the deposition of the coils and the new layers, the use of a sweeping machine is required to removes debris. To model the use of the sweeper machine, the performances of a commercially available machine with a weight of 1.8 tons are analysed. A machine with nominal power 205 kW, with a sweeping width of 4 meters consumes on average 15 l/h, and the sweeping speed is 2.5 km/h. The consumption to clean one kilometre is calculated, assuming a diesel density of 0,835 kg/l:

$$fuel\ consumption = \frac{hourly\ consumption\ \left[\frac{l}{h}\right]}{sweeping\ speed\ \left[\frac{km}{h}\right]} = \frac{15\ \left[\frac{l}{h}\right]}{2{,}5\ \left[\frac{km}{h}\right]} = 6\frac{l}{km} = 5.01\frac{kg}{km}$$

2.2.2.1.3 Trailer

Coils deposition can happen in two different ways: cast in-situ system or a pre-cast system. For a scenario where pre-cast units are used, efficiencies in delivery and installation could be gained by using specialist delivery plant. TRL has previously investigated the use of an extendible trailer (also known as a trombone) for installation of pre-cast concrete tram tracks. The trailer would be extended when it was immediately

over the location where the device was to be installed, as shown in Figure 7. The pre-cast sections could then be lowered through the extended trailer deck directly to the point where they are required, without any interference to pedestrians or traffic on the adjacent carriageway. The vehicle would then move forward the appropriate distance and drop the next section. This process avoids double handling and congestion, and the construction team is protected from collisions with site traffic.

Figure 7: Example of extendible trailer that could be used for prefabricated sections installation

Using a pre-cast system in this situation might be preferable as there would be no need to allow concrete to set, compared to the case in-situ with construction. This would mean that the asphalt layer could be laid immediately, reducing construction time.

To model the use of a trailer, the technical data of a trailer crane commercially available is used. The system is then covered to restore the binder and wear layers. The repaving goes through the following steps:

1. A paver distributes asphalt on the lane, covering the full width of the lane.
2. A roller then compacts the asphalt to make it uniform in thickness and compaction. Normally, more than one passage is required to obtain the desired compactness.
3. Application of the emulsion linking layer over the binder: there is the need to put an adequate linking coat between the road layers, to ensure a longer life of the e-Road structure. The connection can be done with a bituminous emulsion.

2.2.2.1.4 Pavers

In order to get the consumption for the reconstruction of the lane after the WPT module being embedded, a paver with an operating width of 3.75 m is considered (power 130 kW, weight 19 tons). Diesel consumption depends on the quantity of asphalt to be paved, than on the thickness of the layers. For a layer with 6 cm thickness, the paving speed is 1028.8 m^2/h and the hourly fuel consumption is 23.2 l/h. Assuming a diesel density of 0.835 kg/l, the kilometric consumption is then calculated:

$$fuel\ consumption_{paver,wear\ layer} = \frac{area_{e-corridor}}{portata\ areale} \cdot hourly\ consumtion$$
$$= \frac{3.65\ m \cdot 1000\ m}{1028.8\ m^2/h} \cdot 23.2 \frac{l}{h} = 82 \frac{l}{km} = 69\ \frac{kg}{km}$$

For the binder layer, a paver with 1.4 m operating width has been selected. Its clearance width of 1.4 m allows the arrangement of the two lateral areas side the coils, without damaging the coils. Paving speed is 30 m/min, and the nominal power is 55.4 kW while the weight is 6.4 tons. As hourly consumption is not available online they are derived from the consumption of the larger paver. Assuming a linear relation between power and consumption, the calculation can be done:

$$fuel\ consumption_{paver,binder\ layer} = \frac{power_{wear\ paver}}{power_{bineder\ paver}} \cdot kilometric\ consumption_{wear\ paver}$$
$$= \frac{55.4\ kW}{130\ kW} \cdot 69\ \frac{kg}{km} = 29.4\ \frac{kg}{km}$$

2.2.2.1.5 Roller

For the compaction of the wear layer, a roller machine with a roller width of 2 meters has been chosen. Another roller with operating width of 1.5 meters has been used for the binder layer. Technical information used to derive the fuel consumption is reported in Table 1.

Table 1 Technical data of asphalt compaction roller.

Roller	**Roller for wear layer**	**Roller for binder layer**
weight [kg]	12.5	8.6
Roller width [m]	2	1.5
Passages	6	6
Nominal power [kW]	100	55.4
speed [km/h]	0.27	0.76
Fuel consumption [l/h]	21.2	16.3

To cover the full width of the lane, the larger roller has to repeat the rolling twice, both for the binder and the wear. For the binder the slimmer roller has been selected, considering that it has to pass along the lane twice, without pressing the coils.

$$roller\ consumption_{wear} = \frac{hourly\ consumprion}{speed} \cdot 2 \cdot passages = \frac{21.2\,\frac{l}{h}}{0.27\,\frac{km}{h}} \cdot 2 \cdot 6$$

$$= 942.2\ \frac{l}{km} = 786.7\,\frac{kg}{km}$$

$$roller\ consumption_{binder} = \frac{hourly\ consumprion}{speed} \cdot 2 \cdot passages = \frac{16.3\,\frac{l}{h}}{0.76\,\frac{km}{h}} \cdot 2 \cdot 6$$

$$= 193\,\frac{l}{km} = 161\,\frac{kg}{km}$$

For precaution sake, the same fuel consumption is assumed for every passage, even though the consumption decreases as the compaction of the layers grows.

2.2.2.1.6 Emulsion sprayer machine

An adequate linking coat between the road layers is needed to ensure the designed life span of the e-Road structure. The connection can be done with a bituminous emulsion. The use of cationic bituminous emulsion is preferred, since it offers more reliability in relation to the climate, the nature of the aggregates, and the storage stability (D5.3.3).

For the bituminous emulsion layer, typical quantities can be set at 0.6 kg/m^2. The amount of emulsion is then 0.6 kg/m2* 3.65m*1000m/km=2190 kg/km.

An emulsion spraying machine is used to spray the bituminous emulsion, acting as a binder between wear and binder layers. The machine has a 265 KW power and an operation width of 4 meters (see Table 2). The operating speed is 20 km/h and the hourly fuel consumption is 8.3 l/h.

Table 2 Emulsion spraying machine: technical data.

Emulsion spraying machine	value
Operating width [m]	4
Speed [km/h]	20
Fuel consumption [l/h]	8.3
Weight [t]	11.5
Bituminous layer [kg/m^2]	0.6

The fuel consumption can thus be calculated:

$$fuel\ consumption_{emulsion\ sprayer\ machine} = \frac{hourly\ consumprion}{speed} = \frac{8.3\,\frac{l}{h}}{20\,\frac{km}{h}} = 0.415\,\frac{l}{km}$$
$$= 0.346\,\frac{kg}{km}$$

All the machinery use has been modelled as described for the milling machine.

2.2.2.1.7 Material production

Asphalt

Asphalt pavement is a blend of mineral aggregates and bitumen. Percentages vary depending on use and production techniques. Bitumen is around 4-6%, the rest is gravel, sand and/or mineral filler and possibly reclaimed asphalt (RAP).

The environmental impacts of asphalt production are heavily dependent on the bitumen content, on the content of reclaimed asphalt pavement (RAP) (Giani, Dotelli et al. 2015) and on the technology used to produce it (hot mix asphalt, warm mix asphalt, cold mix asphalt) (Butt 2014).

The environmental performance of asphalt pavements is very sensitive to transportation distances, hence the comparisons that can be done are very site specific (Miliutenko et al., 2013). The transportation of the asphalt to the construction site varies according to

the contingency, but it is suggested to keep this value as low as possible. Especially for HMA the distance between construction and production sites should not be larger than 80-100 km, because the bitumen has to be kept at high temperature to be workable during paving operations (Giani 2012).

The choice of the mixture for asphalt pavement is strictly related to the aim of the street, to site specific aspects etc. The production of traditional mix asphalt requires aggregates to dry completely to make it bind with bitumen (which is hydrophobic). This requires to heat aggregates to up to 140-160°C. WMA (Warm Mix Asphalt) is the name given to a variety of technologies that allow producing asphalt mixtures at lower temperatures. EAPA has stated that WMA is generally produced in a temperature range from 100 to 140◦C, while HWMA (Half-Warm Mix Asphalt) is fabricated between 70 and 100◦C(EAPA, 2010). Standard HMA (Hot Mix Asphalt) is produced at about 160◦C instead. Recently the Cold Mix Asphalt gained attention, since it is prepared at ambient temperature, emulsifying bitumen before adding it to aggregates. To model asphalt production, a mixture suitable for wear and binder layer is used. Weight percentages of different components in the mixture are reported in Table 3.

Table 3: Asphalt composition.

Materials	**Sand 0/3**	**Gravel 3/6**	**Gravel 6/12**	**Filler**	**Bitumen**
Percentage	16.90%	36.60%	35.70%	5.70%	5.10%

Bitumen production has been accounted using the EcoInvent database “Pitch {RoW}| market for pitch | Alloc Rec, U”. Emissions and consumption for asphalt production are derived from literature.

For the emission and consumptions due to asphalt production, data from an northern Italian industry were made available. Yearly consumption of electricity, natural gas and water of a plant producing HMA, WMA and cement compound were available.

An economic allocation is applied to ascribe consumptions to cement compound and asphalt. The results ascribe 92.8% of water, natural gas and electricity consumption and emissions to asphalt compound. A mass allocation is used to ascribe the remaining

emissions and consumptions to WMA vs HMA. The results are reported in Table 4 and Table 5.

Table 4: Emissions at plant due to the production of 1 ton of WMA

Emissions	CO_2	N_2	O_2	Particulate	NO_x	COT	PAH
Value	9.58	278.87	52.42	1.08	7.26	4.4	0.0024
Unit	kg/ton_{WMA}	kg/ton_{WMA}	kg/ton_{WMA}	g/ton_{WMA}	g/ton_{WMA}	g/ton_{WMA}	g/ton_{WMA}

Table 5: consumption at plant.

Consump -tions	Electricity	Natural Gas	Water	O_2	Particulate	NO_x	COT	PAH
Value	8.12 + 0.549	3.29 + 0.051	0.0085 + 0.053	52.42	1.08	7.26	4.4	0.0024
Unit	kWh/ton_{WMA}	Nm^3/ton_{WMA}	m^3/ton_{WMA}	kg/ton_{WMA}	g/ton_{WMA}	g/ton_{WMA}	g/ton_{WMA}	g/ton_{WMA}

The amount of asphalt required to rebuilt the surface of the e-corridor is:

$$V_{asphalt} = V_{wear} + V_{binder}$$
$$= [lane\ width \cdot wear\ layer\ depth + (lane\ width - precast\ width) \cdot binder\ layer\ depth] \cdot 1000\ m$$
$$= 3.65\ m * 0.06\ m + (3.65\ m - 0.72\ m) \cdot 0.07\ m = 424.1\ \frac{m^3}{km}$$

Average density for asphalt used in binder and wear layers is 2340 kg/m^3, so the amount of asphalt to be produced to cover 1 km of e-corridor is:

$$M_{asphalt} = V_{asphalt} \cdot density_{asphalt} = 424.1\ \frac{m^3}{km} \cdot 2340\ \frac{kg}{m^3} = 992394 \frac{kg}{km} = 992.394 \frac{ton}{km}$$

Bituminous Emulsion

Bituminous emulsion is required to bind overlapping layers. It represents a possible practice to ensure a longer life of the e-Road structure (D5.3.3). It is composed of 45% water and 55% bitumen (Giani, Dotelli et al. 2015). No reliable information regarding the production process have been found in literature, thus it has been modelled as the sum of compounds production and a generic blending process.

Table 6 Bituminous emulsion: technical data.

1 ton	Bituminous emulsion
0.55 ton	Pitch {RoW}| market for pitch | Alloc Rec, U
0.45 ton	Tap water, at user/RER U
kWh	0

For the bituminous emulsion layer, typical quantities can be set at 0.6 kg/m^2. Because it offers more reliability in relation to the climate, the nature of the aggregates, and the storage stability, the use of cationic bituminous emulsion is preferred.

The amount of emulsion is then 0.6 kg/m^2* 3.65m*1000m/km=2190 kg/km

Concrete box

In the final configuration the coils are embedded in a low stiffness concrete box covered with bitumen; the amount of concrete required for the construction of the pre-cast boxes is deduced from the geometry.

$$(0.72\,m \cdot 0.07\,m - (0.06\,m \cdot 0.02\,m) \cdot 2\,) \cdot 1000\,\frac{m}{km} = 48\,\frac{m^3}{km} = \;113760\,\frac{kg}{km}$$

The production of low stiffness concrete is modelled using the EcoInvent dataset “Concrete, normal {RoW}| unreinforced concrete production, with cement CEM II/A | Alloc Rec, U” (amount expressed in m^3; concrete density: 2370 kg/m^3).

WPT Components

POLITO provided the list of components required for the electric part of the road and the amount of each component per 1 km of e-corridor. The weight and the dimensions relevant for the environmental assessment has been inferred from technical and commercial datasheets. Table 7 shows the list of the WPT components, provided by POLITO, sorted by function, with the respective amount and significant dimension for the LCA modelling.

Table 7 POLITO WPT components - amounts and dimension.

Electric infrastructure	Amount per km of e-Road		Dimension	
Power Supply 221				
Main Transformer 120 kVA	10	units	340	kg

Power metering	10	units		
Protection and shunting circuits	10	units		
AC/DC Converter	10	units	40	kg
Distribution Shelter				
Shelter	10	units	10.2	kg
Super-capacitors box	10	units	0.06	kg
Control Power Supply	10	units	1.20	kg
SBRio PE boxes management unit	10	units	0.00994	m^2
CSCU	10	units	0.75	kg
Coil, Cabling and Capacitors				
Coil	500	coils	7.1	kg
Connectors	500	coils	0.009	kg
Capacitors	500	coils	50.5	g
Power Electronics (DC/HF)				
Power Electronics board	500	coils	0.00994	m^2
Active Bridge	500	coils		
Housing	500	coils	1.0260	kg
Connectors	500	coils	0.009	kg
Distribution lines				
Manholes	250	coils	0.0162	m3
Distribution Pipes	250	m	0.161	kg/m
650VDC Distribution cables with connectors	200	m	1.04	kg/m
Signal communication cables and connectors	200	m	1.04	kg/m
Signal power supply cables and connectors	200	m	1.04	kg/m

To account for the production of these components, the EcoInvent Database has been used. However, not for every component a suitable dataset was available. For the missing components, a specific dataset has been modelled either by creating a dataset ex-novo or by modifying an existing one.

2.2.2.2 Transport

Transports cannot be foreseen, as different construction sites across Europe will for sure involve different transport distances. However, it is notable to see how plausible transport distances would affect final results.

For common/ordinary construction materials, an average distance of 50 km between the construction site and the production plant is assumed. The transportation of the asphalt to the construction site varies according to the contingency, but it is suggested to keep

this value as low as possible. Especially for HMA the distance between construction and production sites should not be larger than 80-100 km, because the bitumen has to be kept at high temperature to be workable during paving operations (Giani 2012).

For WPT components, a longer distance is considered: 100 km. The total weight of the WPT components is calculated considering a weight of 1.04 kg/m for 650VDC Distribution cables with connectors. Signal communication cables and connectors, signal power supply cables and connectors, while is assumed of 0.161 kg/m for the Distribution Pipes. For the power electronics, whose dimension input is the square meter, the average weight of 3.92 kg/unit has been found.

The total weight of the WPT components calculated for 1 km of e-Road is 10687 kg.

For these transports it is supposed that they are distributed with smaller commercial vehicles, thus the transportation is accounted using the EcoInvent dataset “Transport, freight, lorry 3.5-7.5 metric ton, EURO6 {GLO}| market for | Alloc Rec, U”.

From the construction plant it is supposed to leave asphalt and machineries; to transport asphalt the following dataset from EcoInvent has been used the EcoInvent dataset “Transport, freight, lorry 16-32 metric ton, EURO6 {GLO}| market for **|** Alloc Rec, U”.

Concrete boxes are supposed to be produced close to the construction plant, as the other traditional construction material, thus the transport distance is set to 50 km, using “Transport, freight, lorry 16-32 metric ton, EURO6 {GLO}| market for | Alloc Rec, U”.

2.2.2.3 Maintenance

The maintenance phase has the potential to be a significant contributor to the overall environmental impact (Santero, Masanet et al. 2011a). The maintenance operations of the analysed e-Road solutions should comply with the standard methods for the t-Roads (pavement treatments, slurry-seal application, resurfacing and milling operations). Anyway, the resurfacing tasks could damage the coating of the copper coils (bituminous material). In a real rehabilitation activity this must be avoided. For example, the milling operation in the area over the CUs could be performed for a minor depth (2-3 cm), followed by other more refined milling operations in order not to damage the coil coating. Another important point in e-Roads is that the frequency of the maintenance

tasks could differ from what expected for t-Roads, and this could affect the life costs of the electric infrastructure. For this reason, the lifetime related to the wear and binder layer, as well as the damage of the CU for POLITO and SAET,s technology have been estimated in D5.3.3. A computational recursive approach has been applied to predict the lifetime of the road and the damage in the charging unit (CU) (the lifetime of an asphalt layer is commonly defined as the time required for cracks to appear on the pavement section). For more details about the procedure see D5.3.3.

In task 5.3.5 maintenance operations has been divided into:

- Preventive maintenance: its occurrence is strictly related to monitoring activities;
- Unexpected maintenance of the CU;
- Rehabilitation of the wear and binder layers;

In this LCA only the planned rehabilitations will be included, as preventive routine and urgent maintenance are difficult to predict and no data are available regarding the frequency of these operations.

2.2.2.3.1 Rehabilitation

D5.3.3 describes the rehabilitation activities of wear and binder layers.

Wear layer

As regards the rehabilitation of the wear layer, the only difference between e-Roads and t-Roads is constituted by the presence of the coil at the bottom of the layer. In this case the milling operations should be focused on two zones of the lane:

- A central area of about 1 m wide;
- Two lateral areas 1.375 m wide.

In the central area, the activities should be done with machines able to do fine milling, while for the remaining area standard machines may be used. However, nowadays, commonly used scrapers (with a width of about 2 m) can mill for steps of 5 mm at a time. This means that in a first step the two areas can be treated as a unique zone up to a desired safety depth of the milling (e.g. 55 mm). Then, a compact ripper can be used

(with a width of about 1.3 m) to perform a fine milling (a compact milling machine can mill also for steps of 1 mm a time). This means that the operations for the milling would require the following steps:

- First milling (with scraper) of the entire lane up to 0.055 m of depth: it needs 2 passes to cover 3.75 m wide;
- Second milling (with compact ripper) of the entire lane up to 0.004 m: it needs 3 passes to cover 3.75 m wide.

In this way just 1 mm of the old wear layer would remain. The operations should be followed by a worker that continuously check the surface output of the coil.

Once removed, the wear layer the Automatic Road Analyser (ARAN) vehicle equipped with a coil should check the performance of the WPT, because the milling operations could affect the bituminous protective material of the road coil. If the WPT performance is reduced a layer of protective material is applied on the specific coil or the coil is replaced. At this point a bituminous linking layer can be applied on the entire lane as is commonly done in t-Roads, and the wear layer of the pavement can be re-built.

To model the rehabilitation, the use of the machineries and the production of asphalt to replace the old one is accounted. With the maintenance operation all the processes considered during the construction are connected: transports of machineries and materials, production of construction materials.

The amount of asphalt required to replace the wear layer has been already calculated previously, and it is reported herein:

$$V_{wear} = [lane\ width \cdot wear\ layer\ depth] \cdot 1000\ m = 3.65\ m * 0.06\ m \cdot 1000\ m = 219\ \frac{m^3}{km} = 512460\,\frac{kg}{km}$$

For the first milling, the same machine used for the construction is considered: it is 2 meters wide, so two passages are enough to cover the full lane. Fuel consumption and emissions are calculated as in the construction phase, but considering the depth of the wear layer only (see Figure 8).

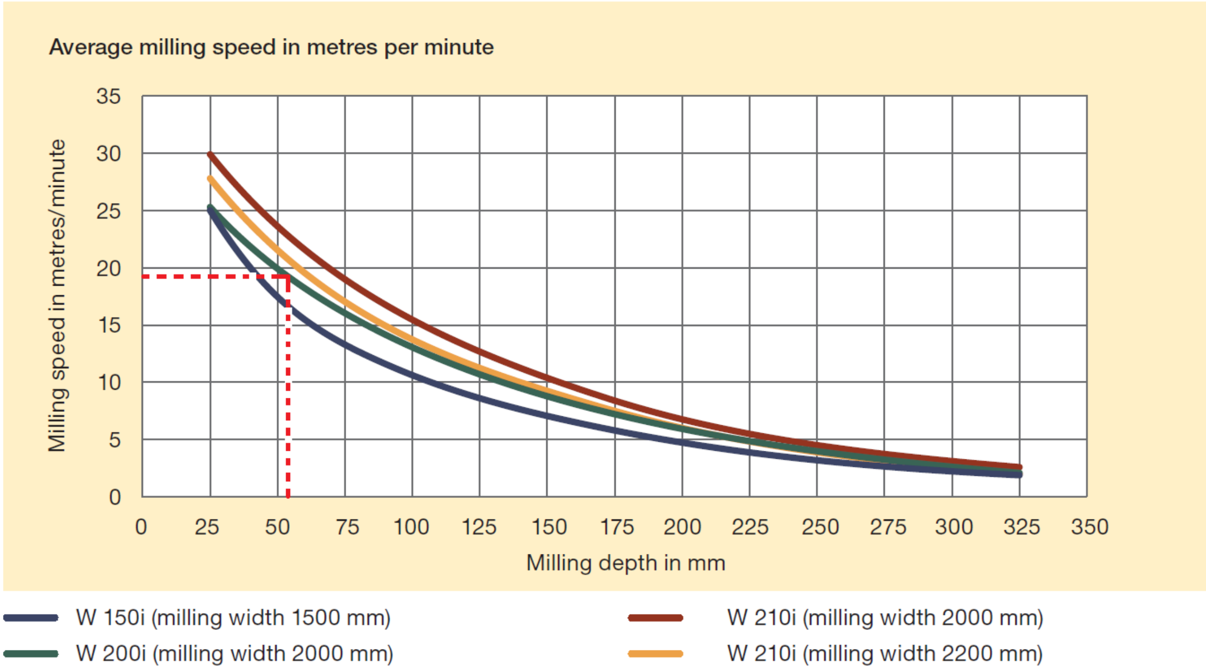


Figure 8: Milling speed considering the depth of the wear layer

$$fuel\ consumption = \frac{hourly\ consumption\ \left[\frac{l}{h}\right]}{milling\ speed\ \left[\frac{m}{min}\right] \cdot \frac{60min}{h}} \cdot 1000\frac{m}{km} \cdot 2$$

$$= \frac{38\frac{l}{h}}{19\frac{m}{min} \cdot \frac{60min}{h}} \cdot 1000\frac{m}{km} \cdot 2 = 66.66\frac{l}{km} = 55.66\frac{kg}{km}$$

For the second milling, occurring only above the coil section, a smaller and more compact milling machine is used, which also has a fine milling capability. The second milling is quicker since the milling depth is only 1 mm; the maximum speed of the scraper is in the order of 5 km/h. However to mill the wear layer in one way the speed should remain about 2.5 km/h (D5.3.3). the average hourly consumption in field mix is 30 l/h.

$$fuel\ consumption = \frac{hourly\ consumption\ \left[\frac{l}{h}\right]}{milling\ speed\ \left[\frac{km}{h}\right] \cdot} \cdot 2 = \frac{30\frac{l}{h}}{2.5\frac{km}{h}} \cdot 2 = 24\frac{l}{km} = 20.04\frac{kg}{km}$$

For the sweeping operation see the construction phase.

Paving the asphalt

In order to get the consumption for the reconstruction of the lane after WPT is laid, a paver with an operating width of 3.75 m is considered (power 130 kW, weight 19 tons). Diesel consumption depends on the quantity of asphalt to be paved. For a thickness layer of 6 cm, the paving speed is 1028.8 m^2/h and the hourly fuel consumption is 23.2 l/h. Assuming a diesel density of 0.835 kg/l, the weight of the paver is 19 tons, the kilometric consumption is then calculated:

$$fuel\ consumption_{paver,wear\ layer} = \frac{area_{e-corridor}}{portata\ areale} \cdot hourly\ consumtion$$
$$= \frac{3.65\ m \cdot 1000\ m}{1028.8\ m^2/h} \cdot 23.2 \frac{l}{h} = 82 \frac{l}{km} = 69\ \frac{kg}{km}$$

Compaction

For the compaction of the wear layer, a roller machine with a roller width of 2 meters has been chosen among roller commercially available. Technical information used to derive consumption is reported in Table 8.

Table 8 Technical information for compaction of the wear layer.

Roller compaction	weight [kg]	Roller width [m]	Passages [-]	Nominal power [kW]	speed [km/h]	Fuel consumption [l/h]
Roller for wear	12.5	2	6	100	0.27	21.2

To cover the full width of the lane, the larger roller (28.9 ton) has to repeat twice:

$$roller\ consumption_{wear} = \frac{hourly\ consumprion}{speed} \cdot 2 \cdot numero\ di\ passaggi$$

$$= \frac{21.2 \frac{l}{h}}{0.27 \frac{km}{h}} \cdot 2 \cdot 6 = 942.2\ \frac{l}{km} = 786.7 \frac{kg}{km}$$

Emulsion sprayer machine

There is the need to put an adequate linking coat between the road layers, a common practice to ensure a longer life of the e-Road structure. The connection can be done with a bituminous emulsion (D5.3.3). For the bituminous emulsion layer, typical quantities can be set at 0.6 kg/m^2. Because it offers more reliability in relation to the

climate, the nature of the aggregates, and the storage stability, the use of cationic bituminous emulsion is preferred.

The amount of emulsion is then 0.6 kg/m2* 3.65m*1000m/km=2190 kg/km.

The same machine used during the construction is considered:

$$fuel\ consumption_{emulsionatrice} = \frac{hourly\ consumprion}{speed} = \frac{8.3\frac{l}{h}}{20\frac{km}{h}} = 0.415\frac{l}{km} = 0.346\frac{kg}{km}$$

Transport

For the transportation the same assumptions as construction are considered: asphalt and machineries are transported from the production plant to the construction site for 50 km and the EcoInvent database considered is “Transport, freight, lorry 16-32 metric ton, EURO6 {GLO}| market for | Alloc Rec, U”. Milled asphalt is transported from the construction site to the construction plant, and it will be used as RAP.

The machineries to be transported are:

- Paver: 19 tons
- Milling machine (primo passaggio): 28.9 tons
- Roller: 12.5 tons
- Emulsion sprayer machine: 11.5 tons

Transport of asphalt and bituminous emulsion= 512460 + 2190= 514650 kg.

Occurrence

The occurrence of the wear layer rehabilitation has been derived from D5.3.3. Using as an input the return period of heavy vehicles, it was obtained one rehabilitation every 25 months. This result leads to 8 wear rehabilitations during the life time of the e-corridor, considering that one rehabilitation is substituted by the wider binder & wear layers rehabilitation (see section below), and one is avoided due to the final disposal of the road at its end of life.

Binder and wear layers

At least one time during the lifetime of the infrastructure, the entire asphalt layer (wear and binder) must be replaced. In this case the operation machines necessary for the

rehabilitation are the same analysed during the rehabilitation of the wear layer (in fact the scrapers can dig thickness up to about 35 cm). In this case, the lateral areas and the central one are milled separately: for the two lateral a milling machine with 1,5 m width is used.

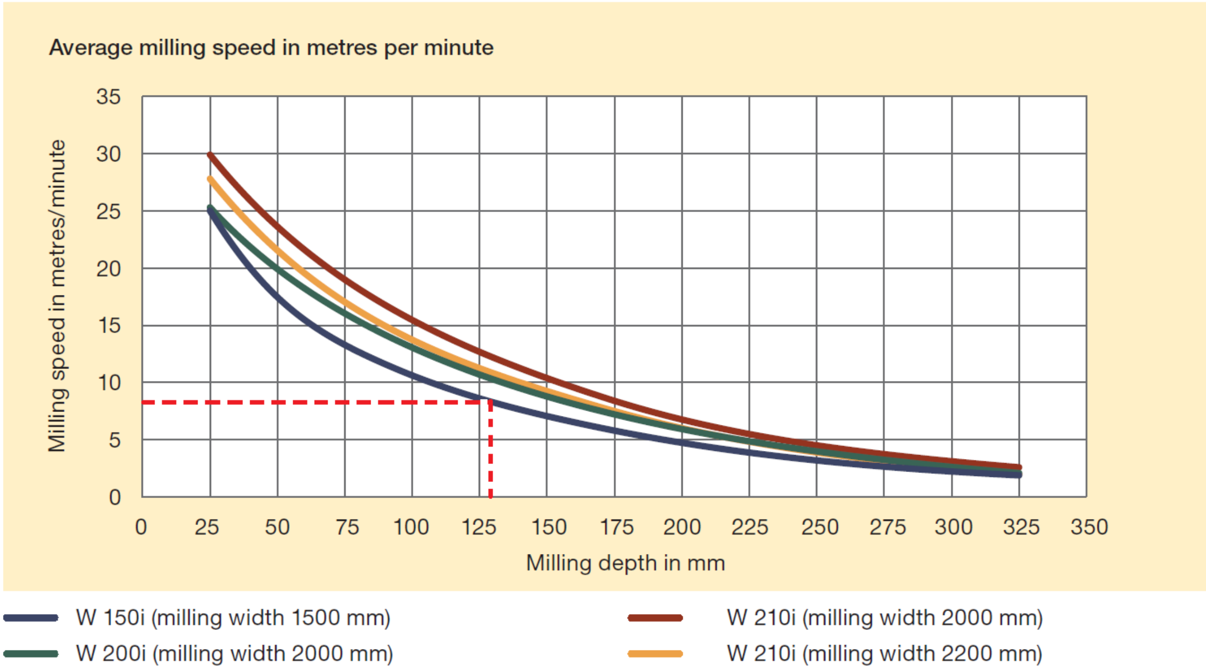


Figure 9: Average milling speed at a milling depth of binder and wear layers.

Thus, fuel consumption required to mill 1km of road at a milling depth of 13 cm is derived from the milling speed (according to Figure 9) and the hourly consumption times two (because of the two lateral areas):

$$fuel\ consumption = \frac{hourly\ consumption\ \left[\frac{l}{h}\right]}{milling\ speed\ \left[\frac{m}{min}\right] \cdot \frac{60min}{h}} \cdot 1000\frac{m}{km} \cdot 2$$

$$= \frac{38\frac{l}{h}}{8\frac{m}{min} \cdot \frac{60min}{h}} \cdot 1000\frac{m}{km} \cdot 2 = 158.33\ \frac{l}{km} = 132.2\frac{kg}{km}$$

This is based on assuming a diesel density of 0.835 kg/l, and the weight of this compact milling machine is 18.9 tons. Emissions are derived from the EcoInvent database, using the dataset “diesel, burned in agricultural machinery GLO".

For the central area, a compact milling machine with fine milling capability is used. Milling machine with high precision are available on the market: the height of the crawler units can be adjusted in steps of 1 mm to precisely set the milling depth. Hourly consumption are derived by technical data sheet of milling machines commercially available:

$$fuel\ consumption = \frac{hourly\ consumption\ \left[\frac{l}{h}\right]}{milling\ speed\ \left[\frac{m}{min}\right] \cdot \frac{60min}{h}} \cdot 1000\,\frac{m}{km} = \frac{18\,\frac{l}{h}}{9\,\frac{m}{min} \cdot \frac{60min}{h}} \cdot 1000\,\frac{m}{km}$$
$$= 33.33\,\frac{l}{km} = 27.83\,\frac{kg}{km}$$

-Machinery weight is 17.7 tons.

It is assumed that the precast coils will remain in the ground during all the whole operation unless they are damaged.

The reconstruction is the same as the construction: involving the production of asphalt and bituminous emulsion and the transport of the machineries (pavers, rollers and emulsion sprayer to the construction site and back to the plant.

For every one of the previous works treated in this subsection, one should mention also the presence of the standard operating machines, i.e. trucks, water carriers and other tankers, which transport the raw material to build the road structure and assist the others means in the performing of the works. For further details on the operating machines and other road equipment one can refer directly to the standard ISO (International Organization for Standardization) (D5.3.3).

2.2.2.4 Operation

No significant operations connected to the use of the e-Road with respect to operation of traditional road have been highlighted during the preparatory study of this project.

2.2.2.5 End of life

The impacts attributable to a pavement's end-of-life phase depend on the ultimate fates of the pavement and its constituent materials, which are notoriously difficult to determine a priori. At the end of its service life, a pavement can meet one of three fates: (1) demolished and landfilled; (2) demolished and recycled; or (3) remain in situ and

serve as support for a subsequent pavement structure. Each pathway requires a unique approach for quantifying the environmental impact (Santero, Masanet et al. 2011b).

Since the high uncertainty related to the EoL of e-Road, it has been excluded from the analysis, as stated in D5.3.1.

2.3 Life Cycle inventory calculations of SAET solution

SAET Group developed the Induction Powered Vehicle (IPV), which is based on wireless resonant inductive power transfer. The detailed description of the WPT configuration of SAET solution can be found in Appendix I.

2.3.1 Road geometry and construction

The optimal configuration for the SAET technology requires the installation of the coils 5 cm beneath the road surface. It, however, permits some allowance in depth positioning, thus permitting the placement of the coils in the bitumen layer, even if the overhead wear layer can be higher than 5 cm.

At the test site the construction involves the excavation of narrow micro-trenches (80 mm depth circa) within the pavement; the coil or e-Road system was placed in within a filling material and covered with asphalt.

The SAET solution does not show capacitive coupling between the e-Road coils and the filling material, thus the choice of the filling materials, is not so restrictive. In this analysis, the configuration experimented in the test site i.e. the embedment of the coils in concrete is assumed. This solution is also the most appropriate for the real world implementation: rather than a micro trench with 2 cm width and 5 depth for each coils, it is supposed, as for the POLITO solution, that the surface layers are completely removed and the pre cast coils are set and then covered with asphalt.

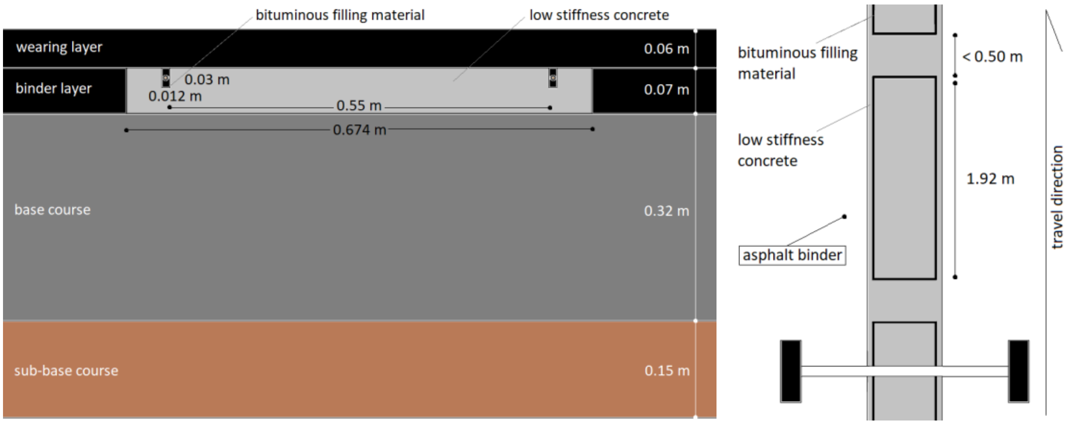


Figure 10: SAET technology: cross section (left) and top view (right).

2.3.2 Life cycle inventory

2.3.2.1 Construction

The SAET solution implementation in roads is supposed to follow the same steps as the POLITO solution, the difference lies in the amount of materials due to the slightly different geometry:

1. The pre-cast concrete block containing the coils is 0.67 m*0.07 m (rather than 0.72 m*0.07m).
2. The primary coil is one single windings, with rectangular shape 192 cm x 55 cm, with a weight of 5.23 kg.

As a consequence, it changes slightly also the amount of asphalt for the binder layer. The use of operating machine is supposed to remain the same as the POLITO solution, for details on the calculation of fuel consumption and emissions see paragraph 2.2.2.1.

For the detailed LCI see the POLITO solution section.

2.3.2.1.1 Material production

Asphalt

Asphalt composition is supposed to remain the same as the POLITO solution. For details on how the production of asphalt is accounted see section Asphalt.

The amount of asphalt required to fill the lane and cover the coils becomes:

$$V_{asphalt} = V_{wear} + V_{binder}$$
$$= [lane\ width \cdot wear\ layer\ depth + (lane\ width - precast\ width) \cdot binder\ layer\ depth] \cdot 1000\ m$$
$$= (3.65\ m * 0.06\ m + (3.65\ m - 0.674\ m) \cdot 0.07\ m) \cdot 1000\ m = 427.32 \frac{m^3}{km}$$

Average density for asphalt used in binder and wear layers is 2340 kg/m^3, so the amount of asphalt to be produced to cover 1 km of e-Road/e-corridor is:

$$M_{asphalt} = V_{asphalt} \cdot density_{asphalt} = 427.32\ \frac{m^3}{km} \cdot 2340\ \frac{kg}{m^3} = 999.928.8 \frac{kg}{km}$$

Concrete box

As for the asphalt, the concrete precast box has the same composition as the POLITO solution; the difference lies in the dimensions and the amount. The amount of concrete required for the construction of the pre-cast boxes is deduced from the geometry.

$$(0.674\ m \cdot 0.07\ m - (0.012\ m \cdot 0.03\ m) \cdot 2\ ) \cdot 1000 \frac{m}{km} = 46.46\ \frac{m^3}{km} \cdot 2370 \frac{kg}{m^3} = 110110.2\ \frac{kg}{km}$$

The production of low stiffness concrete is modelled using the EcoInvent dataset "Concrete, normal {RoW}| unreinforced concrete production, with cement CEM II/A | Alloc Rec, U" (amount expressed in m^3; concrete density: 2370 kg/m^3).

Bituminous Emulsion

The SAET solution requires the same amount of bituminous emulsion as the POLITO version. The amount of emulsion is then 0.6 kg/m^2 *3.65m*1000m/km=2190 kg/km.

WPT components

SAET provided the list of components required for the electric part of the road and the amount of each component per 1 km of e-corridor. The weight and the dimensions relevant for the environmental assessment has been inferred from technical and commercial datasheets. Table 9 lists the components, provided by SAET, sorted by function, with the respective amount and significant dimension for the LCA modelling.

Table 9: WPT components (SAET solution)

Electric Infrastructure					
Power Supply					
	Main Transformer 120 KVA	10	units	340	kg
	Power metering	10	units		
	Protection and shunting circuits	10	units		
	Secondary Transformer Y-DY	10	units	40	kg
Distribution Shelter					
	Shelter	10	units	10.2	kg
	Rectifier and Protection Circuitry	10	units	0.06	kg
	Control Power Supply	10	units	1.20	kg
	SBRio PE boxes management unit	10	units	0.00994	m^2
	Vehicle Communication unit	10	units		
	CSCU	10	units	0.75	kg
Coil, Cabling and Capacitors					
	Coil	500	coils	5.23	kg
	Connectors	500	coils	0.009	kg
	Capacitors	500	coils	50.5	g
Power Electronics (DC/HF)					
	Power Electronics board	500	coils	0.00994	m^2
	Active Bridge	500	coils		
	Housing	500	coils	1.0260	kg
	Connectors	500	coils	0.009	kg
	HF Transformer	500	coils		
	Res. Capacitors	500	coils	50.5	g
Distribution lines					
	Manholes	250	coils	0.0162	m3
	Distribution Pipes	250	m	1	m
	650VDC Distribution cables with connectors	200	m	1	m
	Signal communication cables and connectors	200	m	1	m
	Signal power supply cables and connectors	200	m	1	m

To account for the production of these components the EcoInvent Database has been used. However, not for every component a suitable dataset was available. For the missing components, a specific dataset has been modelled either by creating a dataset ex-novo or modifying an existing one.

2.3.2.1.2 Machinery use

The use of machinery is assumed to remain the same as the POLITO version. The different width of central and lateral areas changes neither the models of machinery used, nor the fuel consumptions and emissions.

Table 10 summary of the machineries used, their weight and consumption.

Process	Machine	Operating width	Passages	Machine weight	Hourly consumption [l/h]	Fuel consumption [kg/km]
Asphalt milling	Milling machine	2 m	2	28.9 tons	52	111.33
Pavement cleaning	Sweeping machine	4 m	1	11.5	15	5.01
Asphalt distribution (binder)	Paver	1.4 m	2*1	6.4	9.92	29.4
Asphalt compaction (binder)	Roller	1.5 m	2*6	8.6	16.3	161.177
Asphalt distribution (wear)	Paver	3.75 m	1	19 tons	23.3	69
Asphalt compaction (wear)	Roller	2 m	1*6	12,5 tons	21,2	786.7556
Emulsion distribution	Emulsion sprayer machine	4 m	1	11.5	8.3	0.346525

2.3.2.2 Transport

For the transport phase of the SAET solution, the same assumptions and considerations made for the POLITO version apply (see section 2.2.2.2).The total weight of the WPT components is derived from Table 9, considering a weight of 1.04 kg for 650VDC Distribution cables with connectors, Signal communication cables and connectors, signal power supply cables and connectors, while is assumed of 0.161 kg/m for the Distribution Pipes. For the power electronics, whose dimension input is the square meter, the average weight of 3.92 kg/unit has been found. The total weight is 9616 kg.

WPT components are supposed to be transported using smaller commercial vehicles, thus the transportation is accounted using the EcoInvent dataset “Transport, freight, lorry 3.5-7.5 metric ton, EURO6 {GLO}| market for | Alloc Rec, U”. Asphalt and machineries are supposed to leave from the construction plant to the construction site; to transport asphalt the following dataset from EcoInvent has been used the EcoInvent dataset “Transport, freight, lorry 16-32 metric ton, EURO6 {GLO}| market for | Alloc Rec,

U". Concrete boxes are supposed to be produced close to the construction plant, as the other traditional construction material. Thus, the transport distance is set to 50 km, using "Transport, freight, lorry 16-32 metric ton, EURO6 {GLO}| market for | Alloc Rec, U".

2.3.2.3 Maintenance and operation

To maintenance and operation apply the same assumptions and calculations as the POLITO solution.

2.4 Results of life cycle impact assessment

Aim of this phase is to present potential link between the product life cycle and the environmental impacts, and quantify it. The Impact categories considered in this analysis are the CED, AD-fossil fuel and GHG, for a detailed explanation of the selection of the impact categories see paragraph under the subsection 2.1.5.

CED designates the overall primary energy per functional unit of a product system; it is merely an aggregation of inventory results, since it expresses the total energy required to produce and maintain the e-Road.

Climate change: In this impact category, substances emitted into the atmosphere for the production of the declared unit are evaluated in order to their contribution to heat absorption over time due to their infrared radiative forcing and their persistence in atmosphere. In this analysis the climate change is evaluated using the Baseline model of 100 a by ICCP (IPCC 2013 GWP 100a V1.03); results are expressed in kilograms of CO_2-equivalents per declared unit. The conversion of substances emitted into atmosphere to a reference unit is made through the Characterisation factor "global warming potential (GWP100)".

Abiotic resource depletion – fossil fuels: this impact category, as every resource depletion impact, has to face the scarcity of resources.

In Table 11 and Table 12 synoptic views of the results of the two configurations are proposed, showing the impact of construction, wear rehabilitation and binder&wear layers rehabilitation, sorted by their sub phases, and their relative importance to the overall impact.

Table 11: Impact assessment of the e-Road (POLITO solution).

		CED [MJ/km]	AD -fossil fuel [MJ/km]	GHG [kg $CO_{2,eq}$/km]
Construction Phase	Dismantling	6,534	6,505	423
	Installation and paving	57,693	57,436	3,739
	Transport (construction materials and WPT comp.)	134,406	132,970	8,404
	Transport (machineries)	10,191	10,081	636
	HMA	3,149,172	3,002,414	44,484
	WPT production	1,470,084	1,184,449	99,834
	Bituminous emulsion	61,226	59,177	480
	Concrete	72,386	67,544	10,316
	Total	*4,961,692* *22%*	*4,520,576* *21%*	*168,317* *36%*
Wear layer rehabilitation (every 25 months)	Transports (asphalt and bituminous emulsion)	473,038	467,942	29,539
	Wear layer dismantling	36,263	36,102	2,350
	Wear layer repaving - machineries	384,627	382,914	24,925
	HMA	13,009,548	12,403,274	183,768
	Bituminous emulsion	489,812	473,415	3,842
	Transports (machinery)	66,088	65,376	4,127
	Total	*14,459,377* *64%*	*13,829,023* *64%*	*248,551* *52%*
Wear and binder layer rehabilitation	Transports (asphalt and bituminous emulsion)	113,046	113,042	7,136
	Wear&binder layer dismantling	7,650	7,649	498
	Wear&binder layer repaving - machineries	57,421	57,420	3,738
	HMA	3,003,115	3,002,413	44,484
	Bituminous emulsion	59,178	59,177	480
	Transports (machinery)	10,752	10,752	679
	Total	*3,251,162* *14%*	*3,250,453* *15%*	*57,014* *12%*
Total		22,672,230	21,600,052	473,882

Table 12: Impact assessment of the e-Road (SAET solution).

		CED [MJ/km]	AD -fossil fuel [MJ/km]	GHG [kg $CO_{2,eq}$/km]
Construction Phase	Dismantling	6,534	6,505	423
	Installation and paving	57,693	57,436	3,739
	Transport (construction materials and WPT comp.)	134,161	132,726	8,388
	Transport (machineries)	10,191	10,081	636
	HMA	3,173,054	3,025,183	44,821
	WPT production	1,375,935	1,106,700	90,653
	Bituminous emulsion	61,226	59,177	480
	Concrete	70,063	65,377	9,985
	Total	*4,888,858* *22%*	*4,463,185* *21%*	*159,126* *34%*
Wear layer rehabilitation (every 25 months)	Transports (asphalt and bituminous emulsion)	473,038	467,942	29,539
	Wear layer dismantling	36,263	36,102	2,350
	Wear layer repaving - machineries	384,627	382,914	24,925
	HMA	13,009,548	12,403,274	183,768
	Bituminous emulsion	489,812	473,415	3,842
	Transports (machinery)	66,088	65,376	4,127
	Total	*14,459,377* *64%*	*13,829,023* *64%*	*248,551* *52%*
Wear and binder layer rehabilitation	Transports (asphalt and bituminous emulsion)	113,903	113,898	7,190
	Wear&binder layer dismantling	7,650	7,649	498
	Wear&binder layer repaving - machineries	57,421	57,420	3,738
	HMA	3,025,914	3,025,207	44,822
	Bituminous emulsion	59,178	59,177	480
	Transports (machinery)	10,752	10,752	679
	Total	*3,274,817* *14%*	*3,274,104* *15%*	*57,406* *12%*
Total		22,623,051	21,566,312	465,083

Comparing the results in Table 11 and Table 12, the two solutions do not show significant differences in the relative share of each phase. For this reason, the following discussion on the results will analyse the POLITO version as a reference. The comparison between the two solutions will be undertaken in the dedicated section 2.4.3.

2.4.1 Construction

Looking into the details of the construction phase, it is possible to notice the relevance of the sub phases (Table 13). The WPT production account for 30% of the total energy consumption, 26% of the fossil fuel consumption, and it is responsible for 60% of the GHG emissions. Compared to other components, these components represent just a small amount in weight (Table 14).

Table 13: Impact assessment of the construction phase (POLITO version).

		CED [MJ/km]	AD -fossil fuel [MJ/km]	GHG [kg $CO_{2,eq}$/km]
Construction Phase	Dismantling	6,534 *0.1%*	6,505 *0.1%*	423 *0.3%*
	Installation and paving	57,693 *1.2%*	57,436 *1.3%*	3,739 *2.2%*
	Transport (construction materials and WPT comp.)	134,406 *2.7%*	132,970 *2.9%*	8,404 *5.0%*
	Transport (machineries)	10,191 *0.2%*	10,081 *0.2%*	636 *0.4%*
	HMA	3,149,172 *63.5%*	3,002,414 *66.4%*	44,484 *26.4%*
	WPT production	1,470,084 *29.6%*	1,184,449 *26.2%*	99,834 *59.3%*
	Bituminous emulsion	61,226 *1.2%*	59,177 *1.3%*	480 *0.3%*
	Concrete	72,386 *1.5%*	67,544 *1.5%*	10,316 *6.1%*
	Total	*4,961,692*	*4,520,576*	*168,317*

Table 14: Weight and impacts of materials and components (POLITO solution).

	Amount [kg/km]	CED [MJ/km]	AD -fossil fuel [MJ/km]	GHG [kg $CO_{2,eq}$/km]
HMA	992,394 *89%*	3,149,172 *66%*	3,002,414 *70%*	44,484 *29%*
Concrete	113,760 *10%*	72,386 *2%*	67,544 *2%*	10,316 *7%*
Bituminous emulsion	2,190 *0%*	61,226 *1%*	59,177 *1%*	480 *0%*
WPT components	10,687 *1%*	1,470,084 *31%*	1,184,449 *27%*	99,834 *64%*
Total	1,119,031	4,752,868	4,313,584	155,114

Even if it represents only 1% of the amount of material used for the construction of the e-corridor, it causes almost 30% of the impacts in the categories analysed (more than

60% for GHG). In Table 15 the impacts of each component of the WPT system are reported. The last column is added in order to give the relative importance, in terms of amount of materials, of each component.

Table 15: WPT components impact (POLITO solution).

Components	Impact category	CED [MJ/km]	Abiotic depletion (fossil fuels) [MJ/km]	IPCC GWP 100a [kg $CO_{2,eq}$/km]	Total weight [kg/km]
In road equipment	Capacitor (resonance capacitor)	15,560	12,123	1,025	25.25
	Coils	220,365	160,923	15,581	3550
	Connectors	665	526	45	4.5
	Sub-total	*236,591*	*173,572*	*16,651*	*3,580*
		16%	*15%*	*17%*	*33%*
Distribution lines	650VDC Distribution cables with connectors	19,620	16,430	901	208
	distribution pipe	5,486	4,153	328	40.25
	manholes	3,895	2,611	588	4.05
	Signal communication cables and connectors	1,175	1,010	52	208
	Signal power supply cables and connectors	17,723	14,262	952	208
	sub-total	*47,899*	*38,467*	*2,822*	*668*
		3%	*3%*	*3%*	*6%*
Distribution shelter	control power supply	4,412	3,608	352	12
	CSCU	2,634	2,117	177	7.5
	SBRio PE boxes management unit	544	434	39	39.2
	shelter	14,671	12,744	915	101.8752
	super-capacitor box solo POLITO	481	382	34	0.6
	sub-total	*22,742*	*19,285*	*1,517*	*161*
		1.5%	*1.6%*	*1.5%*	*1.5%*
Power electronics (DC/HF)	connector -	665	526	45	4.5
	housing	52,997	47,000	1,751	513
	power electronic board	589,485	465,853	41,959	1960.0
	sub-total	*643,147*	*513,379*	*43,755*	*2,478*
		44%	*43%*	*44%*	*23%*
Power supply	AC/DC Converter - solo POLITO	188,039	156,161	15,658	3400
	main transformer 120 KVA	331,666	283,585	19,430	400
	sub-total	*519,705*	*439,746*	*35,088*	*3,800*
		35%	*37%*	*35%*	*36%*
Total		*1,470,084*	*1,184,449*	*99,834*	*10,687*

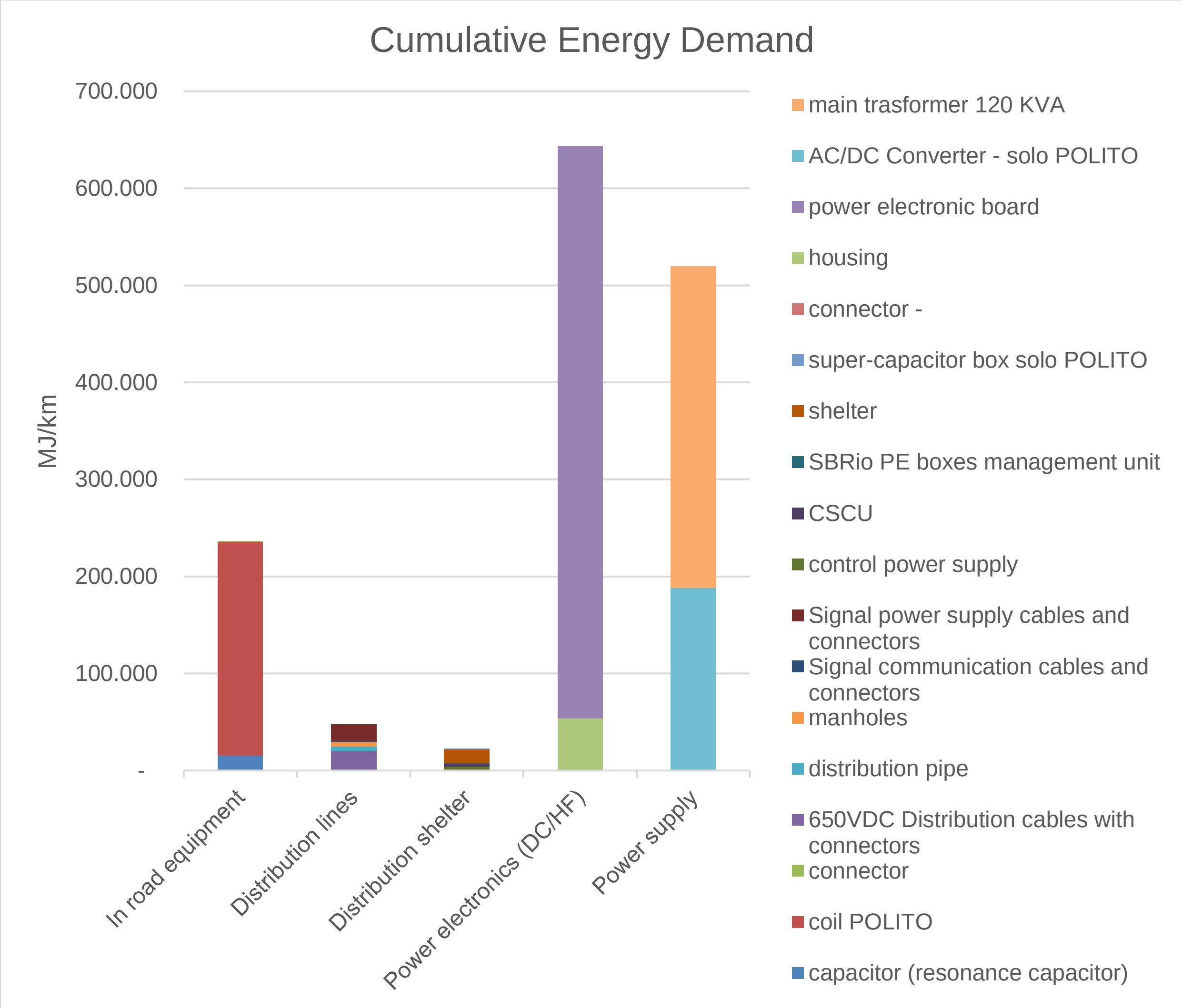


Figure 11: CED WPT components (POLITO version).

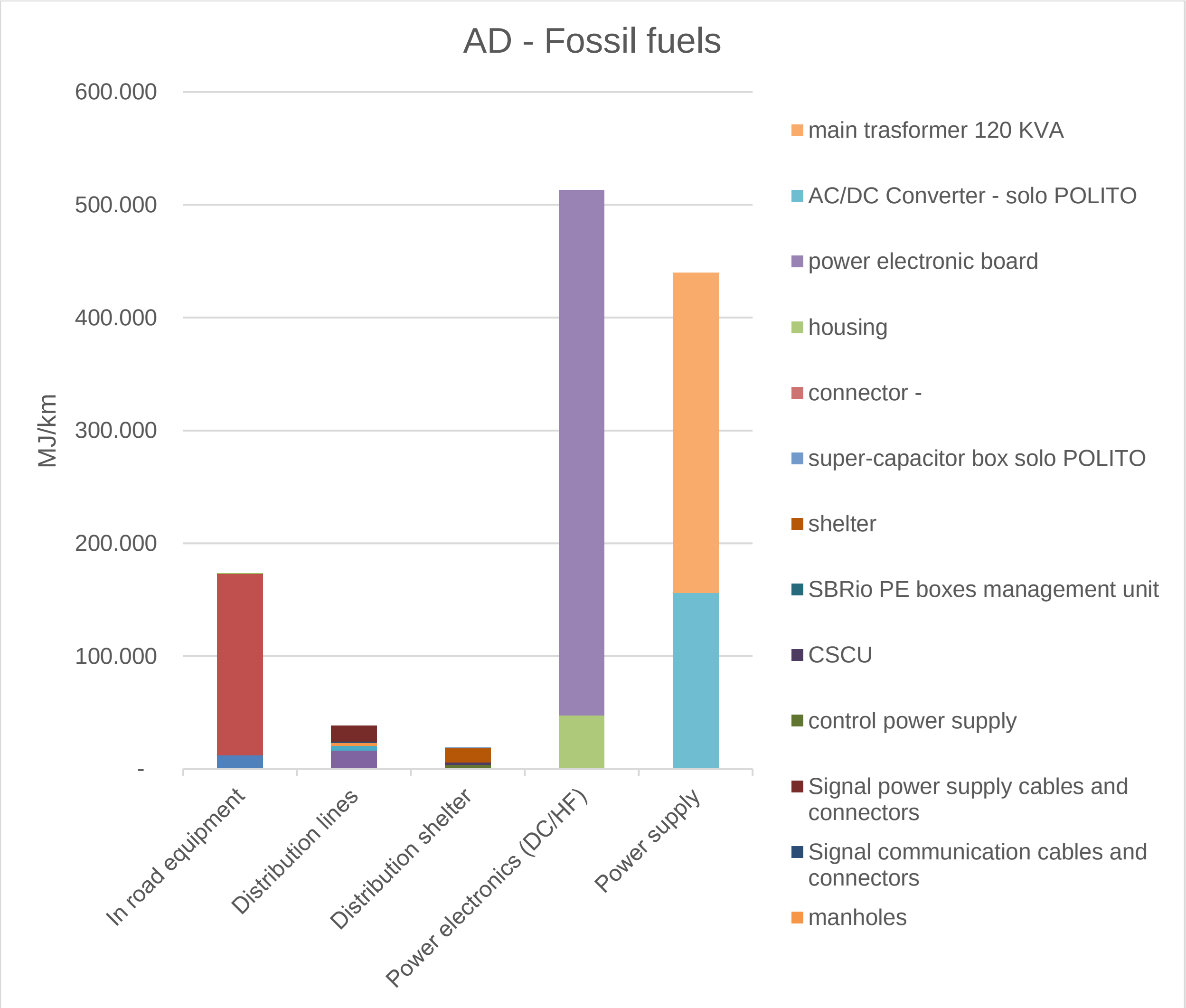


Figure 12: AD – fossil fuels WPT components (POLITO version).

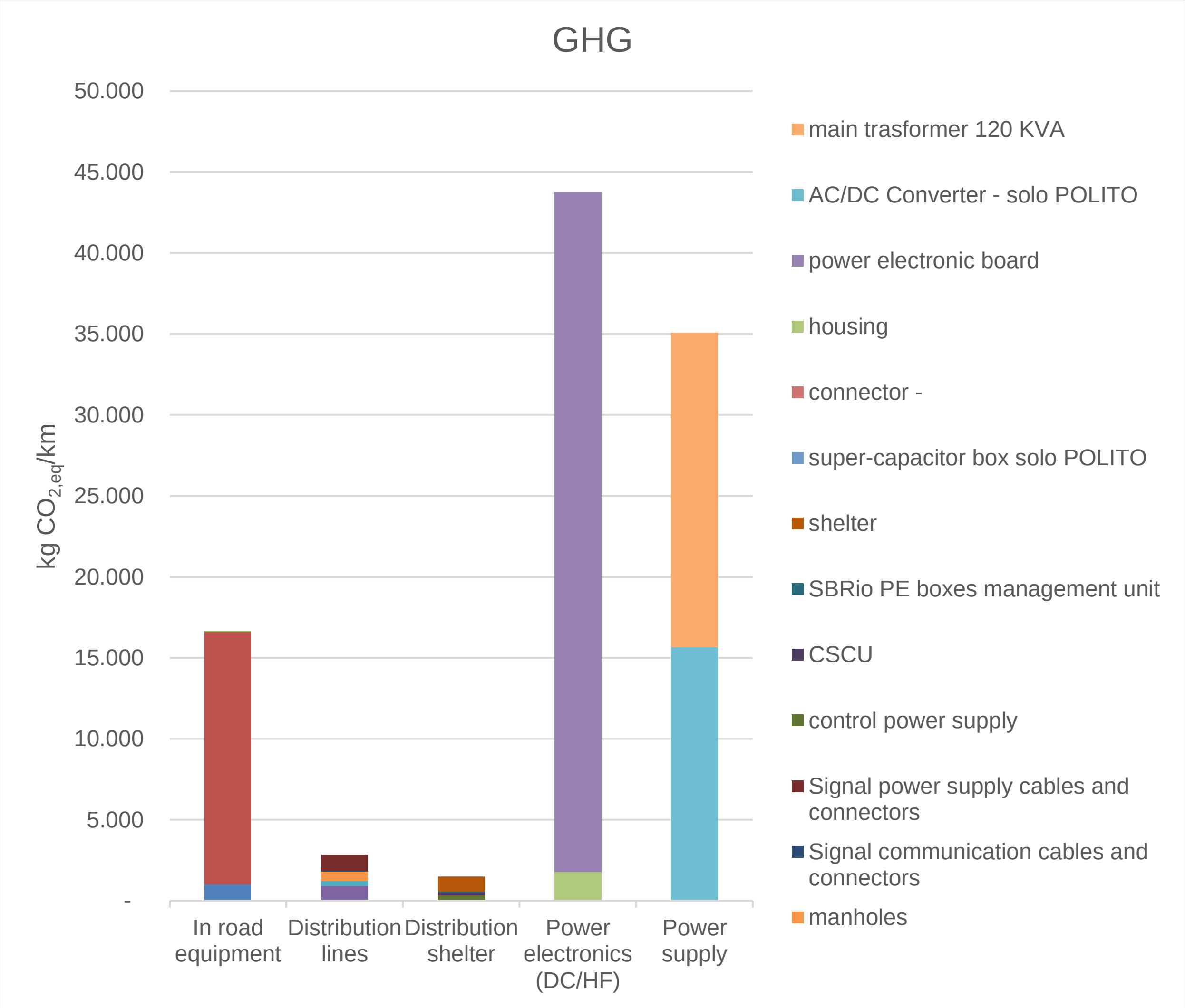


Figure 13: global warming WPT components (POLITO version).

The components that most of all concur to the whole impacts are: coils for the in-road side; power electronic board for the power electronics group and the main transformer and the AC/DC converter for the power supply side.

The three impact categories show the same pattern – as can be clearly seen in Figure 11, Figure 12 and Figure 13 – thus highlighting that most of energy still relies on fossil fuels and that GHG mainly derives from combustion of non-renewable sources.

Table 16: CED of WPT components, sorted by function (POLITO version).

	Impact category	CED [MJ/km]	Abiotic depletion (fossil fuels) [MJ/km]	IPCC GWP 100a [kg CO2,eq/km]	Total weight [kg/km]
In road equipment	capacitor (resonance capacitor)	15,560 1%	12,123 1%	1,025 1%	25.25 0.24%
	coil POLITO	220,365 15%	160,923 14%	15,581 16%	3550 33%
	connector	665 0.05%	526 0.04%	45 0.05%	4.5 0.04%
Distribution lines	650VDC Distribution cables with connectors	19,620 1%	16,430 1%	901 1%	208 2%
	distribution pipe	5,486 0.4%	4,153 0.4%	328 0.3%	40.25 0.4%
	manholes	3,895 0%	2,611 0%	588 1%	4.05 0%
	Signal communication cables and connectors	1,175 0%	1,010 0%	52 0%	208 2%
	Signal power supply cables and connectors	17,723 1%	14,262 1%	952 1%	208 2%
Distribution shelter	control power supply	4,412 0%	3,608 0%	352 0%	12 0%
	CSCU	2,634 0%	2,117 0%	177 0%	7.5 0%
	SBRio PE boxes management unit	544 0%	434 0%	39 0%	39.2 0%
	shelter	14,671 1%	12,744 1%	915 1%	101.8752 1%
	super-capacitor box solo POLITO	481 0%	382 0%	34 0%	0.6 0%
Power electronics (DC/HF)	connector -	665 0%	526 0%	45 0%	4.5 0%
	housing	52,997 4%	47,000 4%	1,751 2%	513 5%
	power electronic board	589,485 40%	465,853 39%	41,959 42%	1960.0 18%
Power supply	AC/DC Converter - solo POLITO	188,039 13%	156,161 13%	15,658 16%	3400 32%
	main transformer 120 KVA	331,666 23%	283,585 24%	19,430 19%	400 4%

As can be seen in Table 16, power electronic board and the main transformer share the highest impacts weighted on their masses.

2.4.2 Maintenance

In Table 17 the impacts of the maintenance phase, divided in the sub phases "wear layer rehabilitation" and "wear and binder layers rehabilitation" are reported. Based on the evaluation made in task 5.3.5, "wear and binder layers rehabilitation" occurs once during the lifetime of the e-corridor, while "wear layer rehabilitation" every two years (thus it occurs 8 times, excluding the End of life and the rehabilitation where also the binder is maintained, which is accounted in a dedicated stage "wear and binder layer rehabilitation"). In Table 18 the impacts due to only one wear layer rehabilitation are reported.

Table 17: Impacts of wear layer rehabilitation (POLITO Version).

		CED [MJ/km]	AD -fossil fuel [MJ/km]	GHG [kg $CO_{2,eq}$/km]
Wear layer rehabilitation	Transports (asphalt and bituminous emulsion)	59,130	58,493	3,692
		3.3%	*3.4%*	*11.9%*
	Wear layer dismantling	4,533	4,513	294
		0.3%	*0.3%*	*0.9%*
	Wear layer repaving - machineries	48,078	47,864	3,116
		2.7%	*2.8%*	*10.0%*
	HMA	1,626,194	1,550,409	22,971
		90.0%	*89.7%*	*73.9%*
	Bituminous emulsion	61,226	59,177	480
		3.4%	*3.4%*	*1.5%*
	Transports (machinery)	8,261	8,172	516
		0.5%	*0.5%*	*1.7%*
	Total	*1,807,422*	*1,728,628*	*31,069*

Table 18: Impacts of wear and binder layer rehabilitation (POLITO Version).

		CED [MJ/km]	AD -fossil fuel [MJ/km]	GHG [kg $CO_{2,eq}$/km]
Wear and binder layer rehabilitation	Transports (asphalt and bituminous emulsion)	113,046	113,042	7,136
		3.5%	*3.5%*	*12.5%*
	Wear&binder layer dismantling	7,650	7,649	498
		0.2%	*0.2%*	*0.9%*
	Wear&binder layer repaving - machineries	57,421	57,420	3,738
		1.8%	*1.8%*	*6.6%*
	HMA	3,003,115	3,002,413	44,484
		92.4%	*92.4%*	*78.0%*
	Bituminous emulsion	59,178	59,177	480
		1.8%	*1.8%*	*0.8%*
	Transports (machinery)	10,752	10,752	679
		0.3%	*0.3%*	*1.2%*
	Total	*3,251,162*	*3,250,453*	*57,014*

The impacts due to the rehabilitation reflects the impacts of the construction connected to the use of materials and machinery common to traditional roads. The impacts of this phase are thus related to the frequency of the operation rather than to the operation itself.

There is a high uncertainty related to the duration of the components and then to the frequency of the maintenance: the fatigue duration of the various components of an e-Road is a value subject to several uncertainties. In those, the endurance of the wear layer is a most uncertain quantity and can vary from about 2 years up to no more than 5 years (from 3 up to 9 rehabilitations in 20 years of design life). The average endurance of the entire asphalt layer (e.g. binder and wear) can be set around 10 years. Thus, the rehabilitation of the binder layer along 20 years of design life is commonly done 1 time (D5.3.3). Thus, Figure 14 shows how different frequencies of wear rehabilitation can influence the overall result:

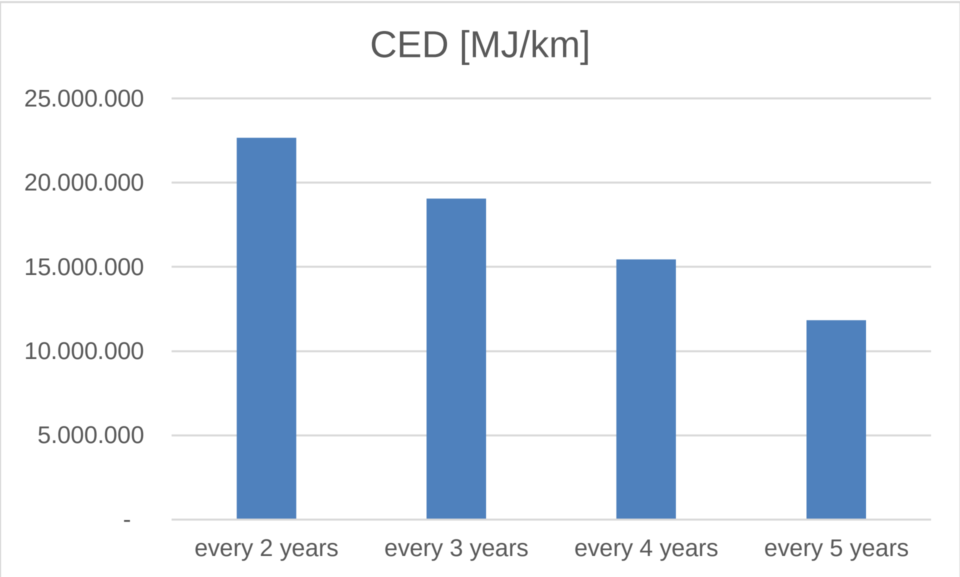


Figure 14: different maintenance operation frequency.

As can be seen from the picture the frequency of the maintenance operation can halve the final results, suggesting that future work should be done in reducing the related uncertainty and that effort on structural and material optimizations could be a valuable option.

In the rehabilitation phase the most impactful processes are the production of asphalt (for CED and Ad- fossil fuels) and the machinery use for the layer repaving (Global warming).

2.4.3 Comparison between SAET and POLITO solution

The differences in construction methods and in the amount of traditional materials (asphalt, concrete, etc…) are negligible, thus the comparison will focus on the WPT technologies.

For a clearer understanding of the differences between the two systems, in Table 19 the components used in the two different solutions are compared, along with their masses and impacts.

Table 19: Comparison of POLITO and SAET WPT components.

		POLITO				SAET			
		CED [MJ]	Abiotic depletion (fossil fuels) [MJ]	IPCC GWP 100a [kg $CO_{2,eq}$]	Total weight [kg/km]	CED [MJ]	Abiotic depletion (fossil fuels) [MJ]	IPCC GWP 100a [kg $CO_{2,eq}$]	Total weight [kg/km]
In road equipment	capacitor (resonance capacitor)	15,560	12,123	1,025	25.25	15,560	12,123	1,025	2,615.00
	coil POLITO /SAET	220,365	160,923	15,581	3550	162,325	118,539	11,477	4.50
	connector	665	526	45	4.5	665	526	45	25.25
	sub-total	*236,591*	*173,572*	*16,651*	*3,580*	*178,551*	*131,188*	*12,548*	*2,645*
		16%	*15%*	*17%*	*33%*	*13%*	*12%*	*14%*	*28%*
Distribution lines	650VDC Distribution cables with connectors	19,620	16,430	901	208	19,620	16,430	901	4.05
	distribution pipe	5,486	4,153	328	40.25	5,486	4,153	328	40.25
	manholes	3,895	2,611	588	4.05	3,895	2,611	588	208
	Signal communication cables and connectors	1,175	1,010	52	208	1,175	1,010	52	208
	Signal power supply cables and connectors	17,723	14,262	952	208	17,723	14,262	952	208
	sub-total	*47,899*	*38,467*	*2,822*	*668*	*47,899*	*38,467*	*2,822*	*668*
		3%	*3%*	*3%*	*6%*	*3%*	*3%*	*3%*	*7%*
Distribution shelter	control power supply	4,412	3,608	352	12	4,412	3,608	352	12
	CSCU	2,634	2,117	177	7.5	2,634	2,117	177	7.5
	SBRio PE boxes management unit	544	434	39	39.2	544	434	39	39.2
	shelter	14,671	12,744	915	101.8752	14,671	12,744	915	102
	super-capacitor box (POLITO) rectifier and protection circuitry (SAET)	481	382	34	0.6	0.53	0.36	0.03	0
	sub-total	*22,742*	*19,285*	*1,517*	*161*	*22,261*	*18,903*	*1,484*	*161*
		1.5%	*1.6%*	*1.5%*	*1.5%*	*2%*	*2%*	*2%*	*2%*
Power electronics (DC/HF)	connector -	665	526	45	4.5	665	526	45	4.5
	housing	52,997	47,000	1,751	513	52,997	47,000	1,751	513
	power electronic board	589,485	465,853	41,959	1960.0	589,485	465,853	41,959	1800
	HF transformer					8,751	7,009	598	0
	res. Capacitor					120,322	95,478	8,422	25.25
	sub-total	*643,147*	*513,379*	*43,755*	*2,478*	*772,221*	*615,866*	*52,775*	*2,343*
		44%	*43%*	*44%*	*23%*	*56%*	*56%*	*58%*	*24%*
Power supply	AC/DC Converter (POLITO) secondary transformer Y-DY (SAET)	188,039	156,161	15,658	3400	23,337	18,691	1,595	3400
	main transformer 120 kVA	331,666	283,585	19,430	400	331,666	283,585	19,430	400
	sub-total	*519,705*	*439,746*	*35,088*	*3,800*	*355,003*	*302,276*	*21,025*	*3,800*
		35%	*37%*	*35%*	*36%*	*26%*	*27%*	*23%*	*40%*
Total		*1,470,084*	*1,184,449*	*99,834*	10,687	*1,375,935*	*1,106,700*	*90,653*	9,616.50

In Figure 15, Figure 16 and Figure 17 the POLITO and SAET solutions are compared.

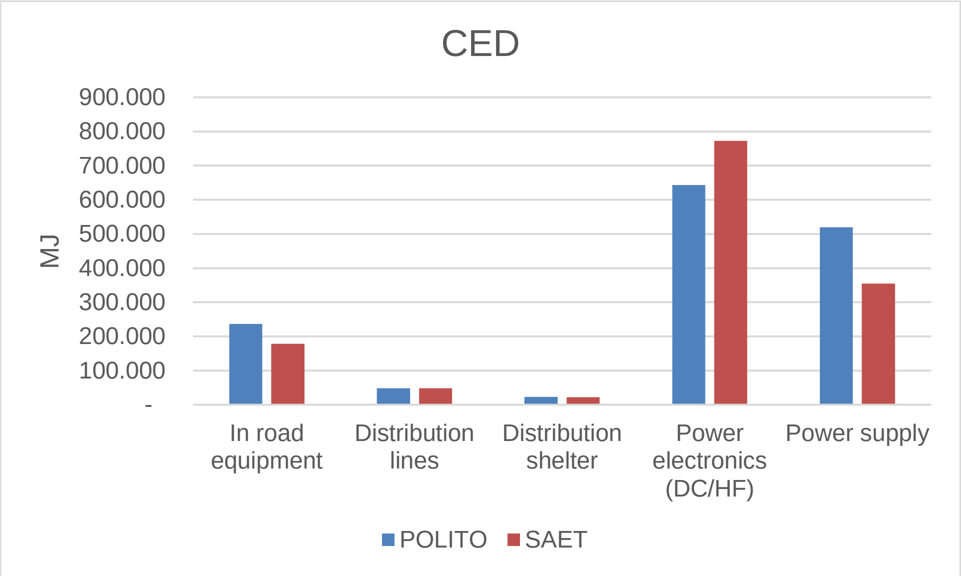


Figure 15: Comparison between POLITO and SAET solution – CED.

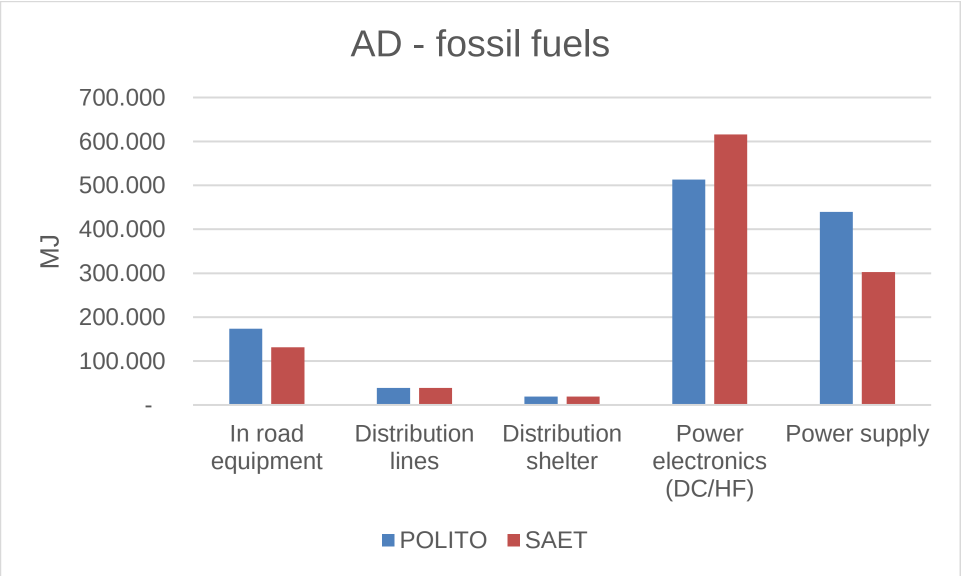


Figure 16: Comparison between POLITO and SAET solution – AD – fossil fuels.

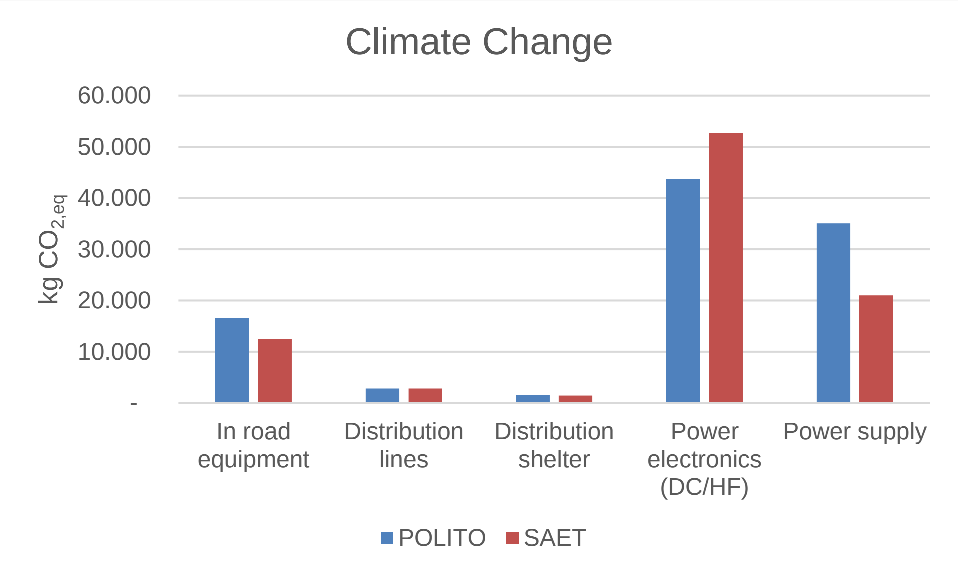


Figure 17: Comparison between POLITO and SAET solution – Climate change.

SAET solution benefits of lower impacts for the in-road equipment, mainly because of its lighter coils. It loses part of this benefit in the power electronic section, where it provides every coil with a dedicated HF transformer. In the power supply section, the main differences are the presence of an AC/DC converter for the POLITO solution, and a secondary transformer for the SAET solution. However, the final results show that there is not a significant difference between the two solutions in the impact categories analysed.

2.5 Interpretation

From the above LCA analyses, some meaningful conclusions can be drawn:

- The two solutions analysed herein, do not present significant differences according to cumulative energy demand, fossil fuel consumption and climate change impact categories.
- In the construction phase the most relevant components, in terms of impacts are the WPT components, even though they represent only the 1% of the total amount of materials in the e-corridor. This leads to the conclusion that further studies should focus on these elements. Whether further empirical data should demonstrate that the lifetime of these components is lower than expected (20 years), the overall impacts will increase significantly.

- For what concerns traditional construction materials, the most relevant share is still covered by asphalt: various studies suggest the use of warm or cold mix asphalts, rather than HMA. The use of recycled asphalt, a possible solution suggested for the reduction of environmental pressure, has to be more deeply investigated for this type of application: in some cases, it required thicker layer to ensure the same performances as the virgin asphalt.
- Maintenance accounts for almost 50% of the impacts in all the three categories. The impacts of this phase are thus related to the frequency of the operation rather than to the operation itself.
- Transports did not show a relevant impact in the construction and maintenance phases.
- Further studies should focus on the frequencies of the maintenance operations and WPT components should be investigated more: in particular only 4 components account for more than 90% of the total impacts in the POLITO solution, namely: coils, power electronic boards, main power transformer and super capacitors.
- Further analysis should check better information on those components, taking into consideration the creation of an ad hoc dataset.

It should be also pointed out: i) the actual share of construction and maintenance phases relies on the assumptions that WPT components will last 20 years and that wear layer rehabilitation occurs every 25 months. Both assumptions are relatively strong and need further support. ii) It is worth noting that there are no experimental data regarding the lifetime of the WPT components. This assumption should be revised when empirical data will be available. Nevertheless, the above general conclusions contribute to gaining some important understanding of the life cycle environmental performance of the infrastructure, and thus the WPT solutions of this project as a whole.

3 LCCA OF E-ROAD INFRASTRACTURE

In this chapter, we present the results of the LCCA. Some variations in the data inputs should be noted w.r.t to the LCA analysis, while the main difference lies into the motivation that the LCCAs will assess the investment and O&M costs of real installations, trying to figure out how they will be planned in the future.

In this, two main key dates are noted:

i) 2030, when the technology will be prepared for launching after the pending R&D challenges and

ii) 2050, when the technology will be optimised by two facts, i.e., the increasing demand of e-Roads and the optimisation processes at factory and theatre of operation levels.

In our view, the progressive market introduction of this technology will undergo the following steps:

1) In 2030 a critical mass of EVs will be on the roads to justify an investment in e-Roads, autonomous driving will be a standard, and stationary/static will be the most common way of wireless charging, which will be a standard option for all EVs. With these facts in place, first commercial e-Roads will start to be deployed using a dedicated external charging lane to avoid unplanned concerns in the conventional t-Roads. At this moment, operation and maintenance activities will not count with enough track record and therefore the less risky approach will be to separate this infrastructure from the conventional roads.

2) In 2050, the EV sales market share will be the majority in developed and developing countries and the expertise gained after 20 years of operation in e-Roads will move the installation of these DWPT lanes using any of the conventional lanes in motorways. Construction methods and O&M activities shall be optimised permitting a significant cost reduction and consequently, improving competitiveness against other charging options.

As a consequence of this view, the LCCA has been organised considering two most likely scenarios from 2030 onwards:

- **Scenario 2030**: dedicated external charging lane using a bespoke manufacturing method
- **Scenario 2050**: reconstruction of an existing lane using prefabricated slabs.

In the next deliverables, mainly D5.5.2 and D5.5.4, a complete sensibility analysis will be done to incorporate other construction methods (mainly, trench based and micro-trench based).

3.1 Definitions

Hereinafter we include some key definitions to understand the later explanations.

- **t-Roads**. Traditional motorways with 3 lanes per direction. Only the right lanes will be transformed into an e-Lane.
- **e-Lane**. A single lane that has been transformed for wireless charging.
- **e-Roads**. A motorway with three lanes per direction, with the right lanes transformed into e-lanes. The standard e-Road length will be 25 km.
- **e-Corridor**. A new, separated lane added to a motorway, constructed from the very beginning including only e-Lane. The standard e-corridor length will be also 25 km.

In some cases of “e-Roads”, we will use as a generic term, comprising both, e-Roads and e-Corridors concepts.

We include here two additional definitions:

- **e-Launcher**. An e-Corridor or e-Road of reduced length (e.g. 10 km). This applies to motorways close to cities where the available space is reduced, compared to motorways between cities.
- **e-Trench**. A small trench of road transformed as e-Lane. This applies to the small trenches of e-Lanes (about 25 m) proposed after bus stops in the city scenario.

3.2 Boundary conditions, functional unit and period analyses

The boundary conditions applied to the LCCA study, i.e. the definition of a set of conditions specified for the behaviour of the solution to a set of equations at the boundary of its

domain, refined as follows. Some differences were noted as well comparing to the boundary conditions in LCA analyses.

- The LCCA analysis is focusing on the e-Corridor construction, operation, maintenance. The energy and resources consumption by the traffic during the operation phase are not included in this study. However, those energy and resources consumptions were considered in the parallel LCA.
- The LCCA is distributed between agency costs (construction, operation, maintenance and disposal from the point of view of the investing agency) and the user costs (only those associated with the travel time and not to the energy consumption). All the analysis is focused in the infrastructure investment and the influencing factors when constructing and operating the e-Roads.
- The construction method for the e-Corridors will be **full lane construction (bespoke procedure).**
- The construction method for the e-Roads will be reconstruction with **prefabricated modules (slabs).**
- The e-Roads will have a length of 25 km in motorways.
- The average power transfer selected will be 50 kW for light vehicles, although this technology is not yet developed. However, there is a consensus that 50 kW is the most appropriate power level for light vehicles and that such technology will be prepared before 2030. For heavy vehicles, the power transfer selected has been 100 kW. The percentage of light vehicles and heavy and intermediate vehicles in motorways were assumed as **88% and 12%** respectively[1].
- We will consider R&D expenses calculating those investments till 2030 made by four main entities in charge of components development (equipment in roads) in Europe. This R&D investment will be calculated considering the approximate total km of e-Corridors and e-Roads in 2030 (according to the demand analysis included

[1] Own calculation from Department for Transport. Road Traffic Estimates Great Britain 2016, European Vehicles market Statistics Pocketbook 2016/2017 and IEA Global EV Outlook 2017

in D5.4.2) and applying a percentage for a single 25 km e-Road. The total R&D requirements was initially estimated by VEDECOM and refined by QiE.

- End of life will be considered after 20 years, recovering the expensive copper under the pavement and sold as second-hand material. We do not consider extend of life or the reuse of the asphalt. Therefore, the "salvage value," usually the net value from the recycling of materials (just the copper) at the end of a project's life will be considered, but the "remaining service life" (RSL), value of an alternative – the residual value of an improvement when its service life extends beyond the end of the analysis period – will not be considered in our calculations.
- During the construction phase, road markings, fences and railings, road signs, lighting and traffic lights are excluded, since the impact derived from them would be the same for e-Roads and t-Roads. The same applies for maintenance and operation of the above-named elements. However, some expenditure is allocated to renew (painting) of those elements affected by the minor and major additional maintenance operation after 5, 10 and 15 years.

3.3 Dimensions of e-Roads and e-Corridors.

A standard has been established for e-Road and e-Corridor dimensions:

- **e-Roads** are however constituted by the right e-lane at a motorway plus the side lane (also needed to make works for the installation of the Power Electronics). The dimensions we will consider are those explained below in Figure 18 for POLITO and Figure 19 for SAET solution.
- **e-Corridors** are constituted by the e-lane plus the service lane at the left-hand side with possibility of double directions circulation. The e-corridor width is then greater than the one in e-Roads (7 m compared to 5.75 m).

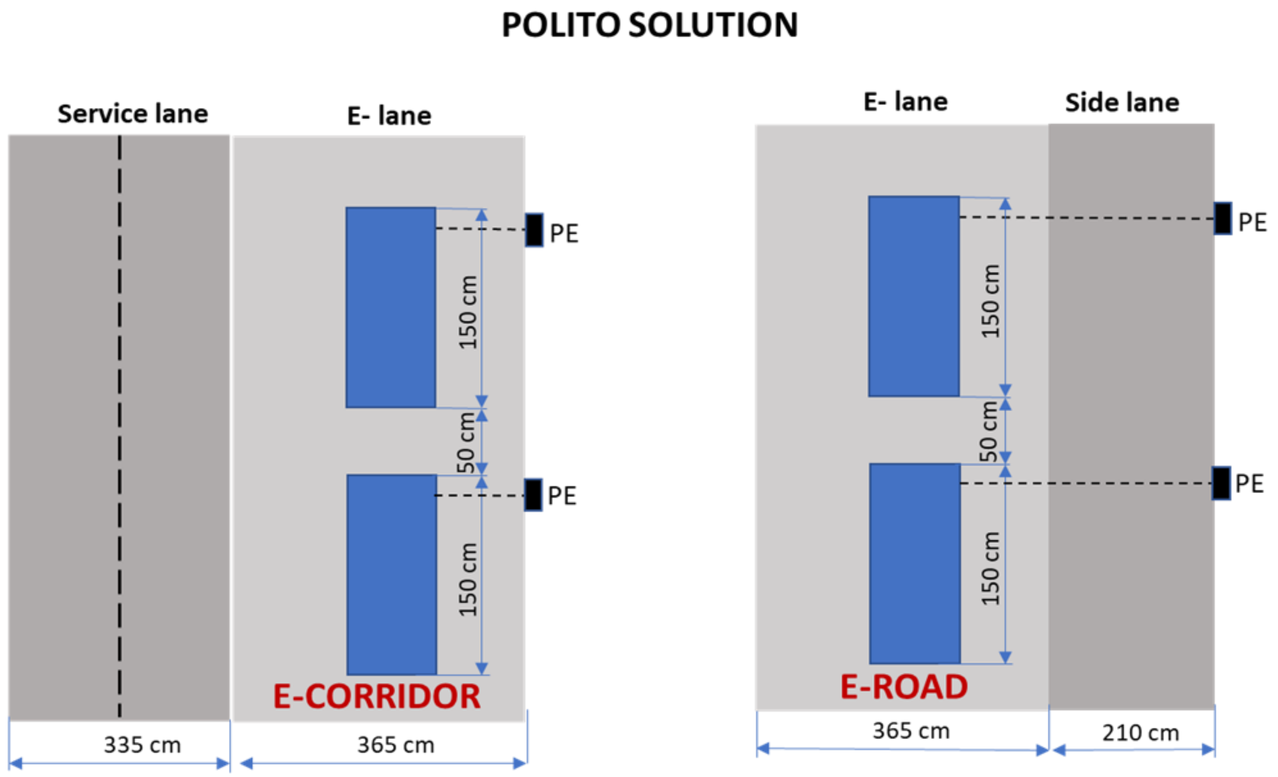


Figure 18: e-Road and e-Corridor dimensions in the POLITO solution

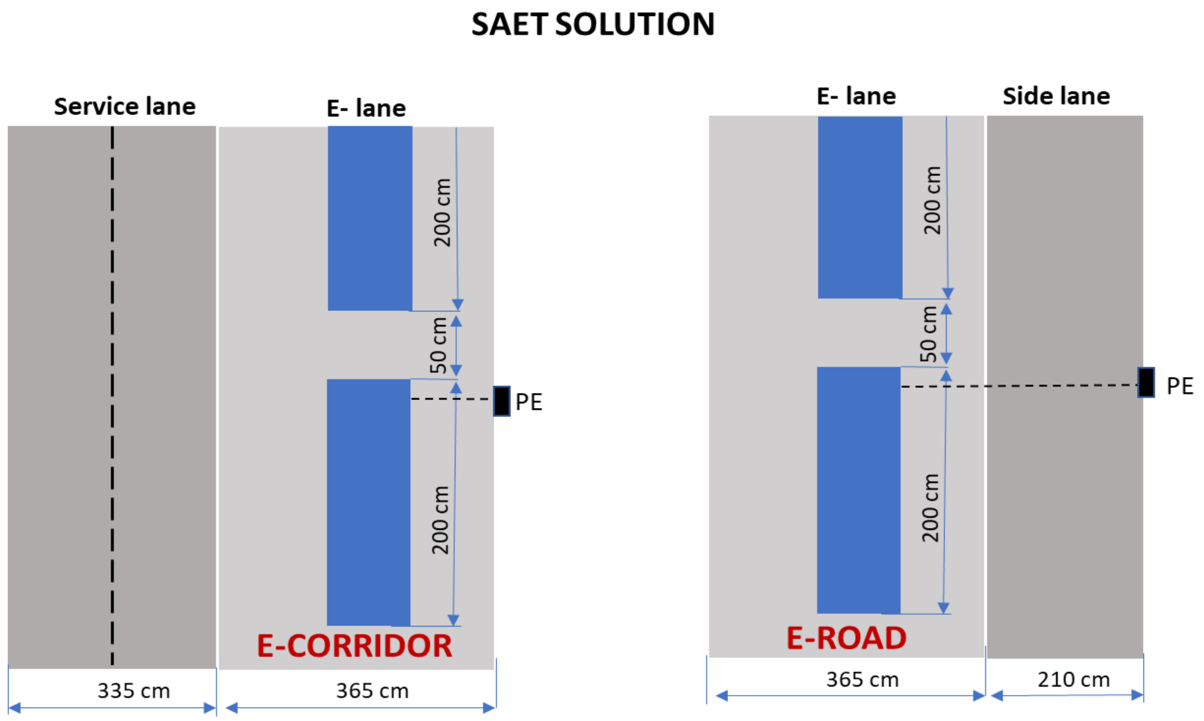


Figure 19. e-Road and e-Corridor dimensions in the SAET solution

3.4 Data collection

We will distinguish different types of data:

- **Primary data**: these data are directly measured in the specific system under study or in equivalent representative systems; clearly, in the case of e-Roads they are supplied by partners thanks to pilot activities in the demo sites.
- **Secondary data**: These data are usually taken from databases or other official sources that have calculated them on systems that can be considered equivalent to the unit process present in the product system to be analysed. These are the data which are not innovative (for instance the road works are calculated based on the usual singular prices and dedication time).
- **Tertiary data or estimated data**: generally, these data are deduced from literature works or other sources or from the primary or secondary data through estimation. In all the cases the calculation method for these data will be explained.

The three types of data are admitted by the ISO standard and all of them will be used in the present LCCA. Once all the data have been collected and pre-elaborated referring the flows to the functional unit, they can be converted into environmental impacts following the guidelines of ISO 14044, as we have seen in the previous chapter (LCA).

3.5 Quality assurance

In the LCCA calculation for e-Roads, some relevant data can be considered coming from primary sources. The way we have proceeded was receiving the real cost data from the demo sites asking the relevant partners participating in those developments. However, those data are at current prices and include some R&D activities. We also asked for the expected costs in case a short demand exists (for example an order of 100 units) and later with a large demand (for instance if 100,000 units is considered). The R&D investments are treated separately in the report. All the suppliers deducted those prices based on their commercial and production experience, but of course the way they prepared this exercise differs significantly with each other. To avoid these discrepancies, we refused illogic figures and came back to them, reaching a compromise agreement in all cases. The

demand report included in D5.4.2 shed some light in the expected number of e-Corridors in 2030 and 2050, and we adjusted the costs accordingly.

The most complex calculation, considered as tertiary data, was the O&M requirements as the text matrix prepared to prove the technology does not allow to infer the O&M needs overtime. To cover this uncertainty, we first reviewed the previous deliverables D5.3.2, D5.3.3 and D5.3.5 and then asked those partners with more experience in the maintenance and operation of conventional roads, mainly TECNOSITAF, POLITO and CEMEX (member of the External Reference Group). Their experience has been very relevant to figure out the behaviour of the e-Road itself and the electronic equipment deployed.

All the assumptions done, the boundary conditions and the obtained results has been further discussed by a group of experts in the previous workshops and General Assemblies.

3.6 LCCA calculation method

The LCCA considers all the costs that are generated by the construction, operation and maintenance of an e-Corridor/e-Road over its lifetime in a holistic manner. It can be summed up in the following formula:

> ***Life Cycle Cost*** = ***Agency costs*** *(R&D costs + Capital costs + projected life-time operating costs + projected life-time maintenance costs + projected renewal costs + projected disposal costs (asset disposal-residual value))* + ***User Costs****.*

We include in this report the following information for the analysis:

- "LCCA-Provider Acronym-Sol No." indicating the technology supplier and a solution number (1 or 2). Number 1, represents the costs in year 2030 for a dedicated new constructed e-Corridor. Number 2 means cost in year 2050 for an existing road, readapted to the DWPT technology.
- "Breakdown 2030/2050" (applied to a supplier and solution number), includes all the technical information and assumptions gathered as a base to later fulfil the LCCAs by direct linking of cells.

- “Pavement” associated also to a supplier and solution (1 or 2) gathers the information related to the works in the pavement to install the DWPT system. The fine calculations done there, are the base for the expenditure in the infrastructure set up.
- “O&M All”, includes the assumptions taken to complete the expenditure chapter associated to the operation and maintenance activities. Although these activities will differ slightly in the real theatre of operations, we consider the same figures for both scenarios and suppliers, as the experience on these costs is short at the moment we write this report.
- “User costs” is only associated to scenario (2) and includes the calculations done to reflect the impact of the time loses by the vehicle users during the construction phase just for the case of the reconstruction of an existing lane. These figures are the same for both providers (POLITO or SAET).
- In solution 1, the “e-Corridor” cost is calculated representing the cost of an e-Corridor built as a new dedicated lane, equipped with the DWPT systems from the very beginning.

We also calculated the “t-Road” costs for the construction of an average conventional road in flat terrain, with no especial construction difficulties (e.g. bridges). However, these figures were not used to establish an initial cost to charge previously to the reconstruction of the road in the solution 2. The only costs included were the reconstruction costs over an existing t-Road.

It is important to mention that the reconstruction of the t-Road (e-Road) only applies to a single t-Lane plus the side lane (totalizing 5.75 m) and the construction of the e-Corridor applies to the main lane and the service lane (totalizing 7 m).

As mentioned before, neither the value of the lane in the e-Corridors nor the cost of the original t-Road are included in the calculation, as these figures could distort the results in the comparison process. However, in a real investment project, these numbers should be included as well as the salvage value of the e-Road when transforming again to a t-Road at the end of life.

Finally, in “conclusions”, we present all the main results in a single table to allow a quick comparison among solutions.

3.7 Time to market

The moment in which the technology can be introduced in the market is important because it affects the costs that have evolved to that specific date, impacting also the competing technologies that have also evolved in parallel, putting the market uptake at risk.

The market entry is defined by a reduced demand and the absence of optimization processes. In the demand study carried out in D5.4.2 deliverable, the moment in which the technology shall be prepared for the market uptake was marked in **2030** (pilot projects shall be finished at that moment). Besides, it was considered that in the year **2050**, there would be a significant reduction in costs due to the accumulated experience and the automation of manufacturing processes. These two dates have determined two different LCCAs for each of the analysed technology providers. For more details on the calculation of the e-Roads demand please check D5.4.2.

3.8 Business Scenarios

The potential application of the e-Roads has been limited to three possible scenarios, out of the more than 10 deployment scenarios analysed in the deliverable D5.2.1. The selected scenarios were:

- **Light / heavy DWPT-EV scenario in most crowed motorways** (part of the TEN-T infrastructure), travelling a daily distance of 400-500 km/day. The e-Roads will be used as range extenders to increase the autonomy of the batteries allowing travels between close cities.
- **Peri-urban scenario with heavy duty trucks and intercity buses**. The e-Roads will provide extra capacity to allow the reduction in the size of the battery of heavy duty vehicles going from surrounding areas (like Ports or logistic centres) to the city centres or, intercity buses travelling daily distances of 250 km, enabling a new class of vehicles to compete with the conventional heavy vehicles and buses. In this scenario is where the e-Launchers are used.

- **Urban scenario with city buses**. Stationary and short dynamic charging (25 m, e-Trenches) at bus stops. This scenario will be likely the first entry point.

The first scenario (motorways) that will likely happen after the last two is the one which however, will be analysed in greater depth, since it corresponds to the test sites and information collected in the FABRIC project.

The rest of the scenarios addressed to heavy vehicles will be estimated based on partial data obtained from the VICTORIA [2] and UNPLUGGED [3] projects. For additional information on the scenarios, please refer to deliverable D5.4.2 where the demand evaluation was reported.

3.9 Results of LCCA of e-Road infrastructure

As described in section 1.2.5, LCCA will be focused in around three main scenarios (**motorways** with dual traffic of e-light vehicles and e-trucks and e-buses, **Peri-urban** scenario, just considered for e-trucks and e-buses and finally **urban** scenario only with e-buses in cities). The conclusions of the LCCA analysis are described below for each of them.

3.9.1 Motorway Scenario

The approach for the motorway scenario starts from the reasoning that a critical mass of e-vehicles with DWPT capability is needed to justify the infrastructure investment. In addition, the charging process must ensure a sufficient extension of vehicle autonomy to convince users to take the e-Roads when they are in a hurry and have no time to stop for recharging at an electric station. At the same time, the average distance of the trip must surpass the average autonomy of the battery on a single or round trip. In general, short trips will not require recharging at expensive e-Roads. All these reasons move us to consider 25 km of e-Corridor as a reasonable distance to cover these conditions on a trip of about 400 km length. 2030 is also pointed as the year where the technology will be prepared for a

[2] https://www.energynews.es/en/malaga-to-implement-a-dynamic-induction-system-for-recharging-electric-buses/
[3] http://unplugged-project.eu/

massive ramp-up in case the business model might be profitable (it will strongly depend on the evolution of the competing technologies, i.e. on-board energy storage).

It is important to highlight that the vehicle speed goes against the charging process and that the EV consumption on highways is almost double than inside cities. The following table prepared in D5.4.1 reflects these facts.

Table 20. Range extension at 50 kW and 100 kW power transfer.

Dynamic Power transfer (kW)	50			Dynamic Power transfer (kW)	100		
Vehicle speed while recharging (km/h)	34	80	100	Vehicle speed while recharging (km/h)	34	80	100
Energy recharged per vehicle over 25 km (kV	36,8	15,6	12,5	Energy recharged per vehicle over 25 km (kV	73,5	31,3	25,0
Range extension (km)				Range extension (km)			
Standard (assuming 0.15 kWh/km)	245	104	83	Standard (assuming 0.15 kWh/km)	490	208	167
Highway (assuming 0.25 kWh/km)	147	63	50	Highway (assuming 0.25 kWh/km)	294	125	100

Table 20 reflects that even at 50 kW power transfer (this technology is not commercial for the moment) the 25-km e-Road will just provide an extension of 50 km at 100 km/h in highways and considering a power transfer of 100 kW and the same speed, just 100 additional km. If we take the e-Roads at 80 km/h, the autonomy is improved by 25% in both cases. This range extension is very small, compared with existing 120-kW power transfer superchargers giving an additional 270 km of range in about 30 minutes charge and a full charge in around 75 minutes. The upcoming fully announced ultra-chargers could even provide 350 kW power transfer, which will require one third of the mentioned time.

Nevertheless, 25 km was assigned as the functional unit to calculate the costs of an e-Road. This exercise has been made according to the data provided by POLITO and SAET but modified by Qi Energy to figure out the expected initial cost reduction due to the natural maturation process of the technology and the increasing demand. Not all the items have been modified in the same way. For instance, copper coils will not suffer the same cost reduction than other equipment or consumables as the worldwide electrification process will stress down somehow the prices (please check D5.4.2 Supply chain).

As mentioned before, we have calculated the costs considering two possible alternatives: the manufacture of a new separated dedicated lane (e-Corridor) and the re-use (e-Road) of an existing lane from a traditional road (t-Road). In the latter case, the original cost of the existing t-lane was excluded from the calculations and we only considered the

restructuring costs. It must be pinpointed that the rehabilitation of an existing lane in a motorway during a given period (we considered 1 month works) will automatically induce an increasing congestion in the remaining lanes. This extra congestion produces the so-called "user costs", or in other words, additional delays that can be quantified (explained later). Some other delays in the operation process are not quantified, as they are minor in comparison with those during the construction works. The impact of the user costs in the overall budget is very relevant in case the selected motorway is rather busy, to the extent that from the two options, in some cases, the cheapest one might be the dedicated separate lane (e-Corridor). This is not the case for our exercise despite we made the calculation with a very busy motorway, (i.e. with 18,000 daily vehicles per lane -AADT-), but it could happen in a more crowded real scenario.

Hereinafter, we will deeply explain the costs for the case of POLITO, while the one from SAET will not be so detailed as the process is quite similar and we will just report the main conclusions.

3.9.1.1 POLITO calculations

a. Pavement costs

In this subsection we included all the cost derived from the works in the pavement. These works include: i) manufacture of a dedicated new e-Corridor or ii) reconstruction of a t-Road. The e-reconstruction has been made according to the dimensions and indications emanated from the pilot test installations, considering as well the dimension and constructive conditions of the selected road formed by the main lane and the side lane (e-Road) or service lane (e-Corridor).

The t-Roads are made of asphalt (wear and binder layers), while the trench where the coils are installed could be made of concrete (with asphalt as option). The coils are introduced in holes in the asphalt and covered with a bituminous coating. Finally, the binder layer and the asphalt layer are sealed with a slurry emulsion. For additional details, please review D5.3.2 on construction of e-Road.

For the LCCA calculation, we have considered the following procedure.

a) Year 2030. Initial deployment. e-Corridors only, bespoke manufacturing

Only e-Corridors are built as the technology is still young and there is not track record on O&M activities and durability of components. A service lane is needed at the left side with two directions to allow circulation of maintenance services and eventually e-vehicles, unable to charge due to system fails and requiring coming back to the entry point.

The e-Corridors are built as new roads from the beginning using a bespoke procedure by the help of wooden or plastic formwork for a fast assembly of the coils and the associated power electronics. However, all the system costs will be higher than the solution adopted after 20 years of track record (2050).

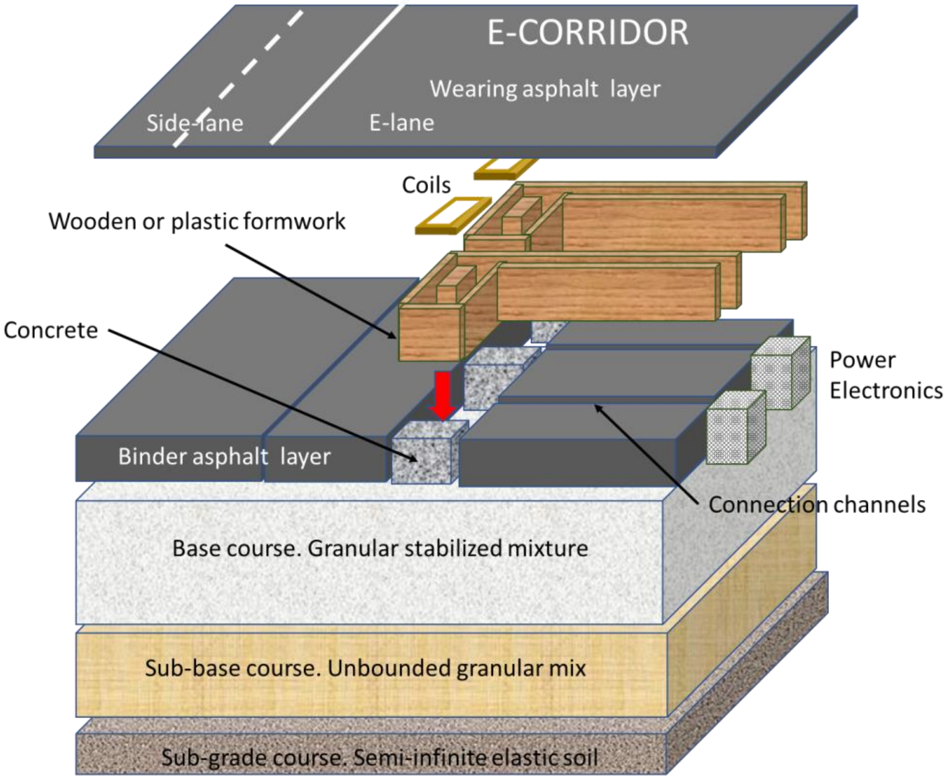


Figure 20. Bespoke construction method for first e-Corridors (2030)

The process to build a new e-Corridor might be as follows:

1. Prepare de subgrade, sub-base and base courses following traditional methods.
2. Complete the binder asphalt layer with the help of some wooden or plastic formworks to leave the space for the coils assembly. The concrete will be used in the specific area of the binders (outside the formworks and inside till the height where the coils will be placed).

3. Install the coils and the cabling to the power electronics and between consecutive coils.
4. Cover the wiring pipes with asphalt/concrete and the coils with a proprietary bitumen (emulsion just over the area of the coils).
5. Remove the formworks after drying and re-fill the joints with concrete.
6. Seal all the binder layer to stick it to the upper layer (asphalt wearing layer).
7. Complete the wearing layer.

b) Year 2050. System optimised. e-Roads, prefabricated structures.

In 2050, some optimization processes will be in place. Construction will be on conventional t-Roads (not in dedicated external e-Corridors) but using prefabricated modules to avoid increasing user costs due to long working periods.

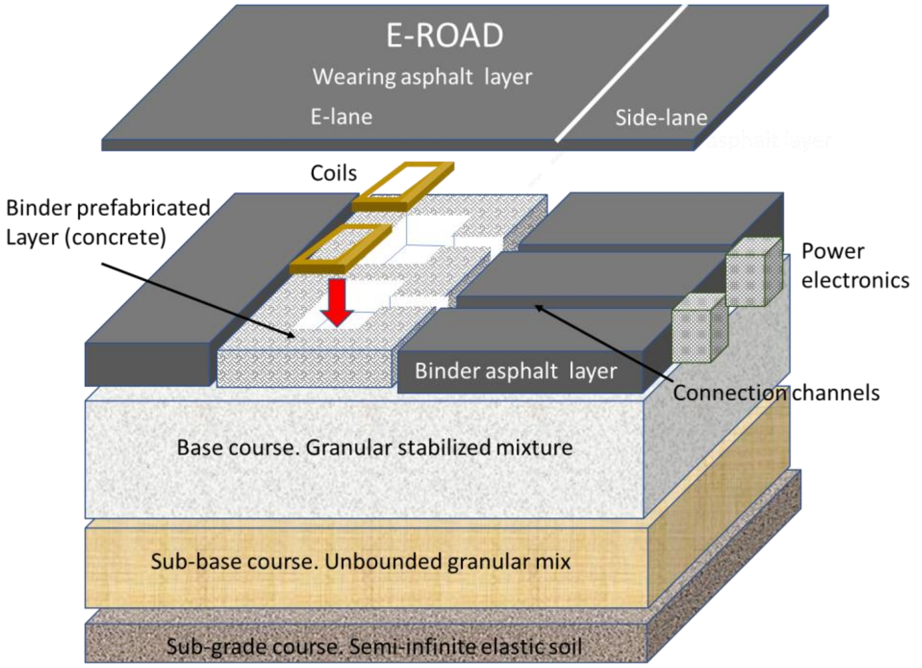


Figure 21. Prefabricated construction method for e-Roads (2050)

The process to build a new e-Road will be as follows:

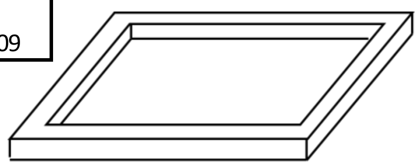
1. Remove the wearing layer.
2. Remove the section of the binder layer where the prefabricated module will be installed.

3. Drill the transversal gutters for the wiring.
4. Install the prefabricated modules and assembly the coils and the wiring.
5. Cover the wiring pipes with asphalt and the coils with a proprietary bitumen (emulsion just over the area of the coils).
6. Seal all the binder layer to stick it to the upper layer (asphalt wearing layer).
7. Complete the wearing layer.

a.1. Year 2030. e-Corridor new construction. POLITO

We have started from the calculation of the main coils' features according to the dimensions provided by POLITO, listed in

Table 21. Coils' main features according to expected dimensions.

COIL MAIN FEATURES		COIL MAIN DIMENSIONS (m)			
1.44	dm^3	Ext. Length	Ext.Width	Int. Length	Int. Width
8.94	kg/l	1.50	0.58	1.42	0.50
12.87	kg	Thick			
6,437	kg/km	0.009			
160,920	kg/25 km				
500	coils				

Then, in the next table, we have defined the amounts of the different pavement, components for the POLITO installations. The second column describes the formulation applied in third column for an easy understanding. The column labelled with the word "density" represents the expected density of the material which has been estimated, although the final composition of those materials is still under discussion by the technical groups. However, this average "density" could be accepted and we do not believe it will change significantly.

Table 22. Pavement amount of materials to build an e-Corridor with 7 m width (365 cm main lane and 335 service lane)

Component (POLITO)	Dimensions	Amount	Unit	Amount	Unit / 25 km	Density	Unit
Wearing asphalt (compacted)	0,06*7*25.000	10,500	m^3/strech	24,570,000	kg/stretch	2,340.00	kg/m^3
Bituminous emulsion linking	(1,50*0,62-1,46*0,50)*0,02/2*25.000*20%	8.00	m^3/strech	12,400	kg/stretch	1,550.00	kg/m^3
Slurry-seal coating	0,006*7*25.000	1,050	m^3/strech	1,050	m^3/stretch		
Binder asphalt (compacted)	(7-0,72)*0,07*25.000	10,990	m^3/strech	25,716,600	kg/stretch	2,340.00	kg/m^3
Concrete (Excavation and filling)	0,72*0,07*25.000	1,260	m^3/strech	1,260	m^3/stretch		
Copper coil	Report O&M D533	6.44	kg/m	160,920	kg/stretch		
	Length E-Corridor	25,000	m				

Then, this base information has been used to evaluate the costs of the pavement cost (without the electric components) in the scenario envisaged for 2030 (short demand and low-level automation of the whole process and bespoke construction using wooden or plastic formworks). Costs originate from the figures provided in deliverables D5.3.2 and D5.3.3 with some adjustments.

Table 23. Construction costs for an e-Corridor of 25 km length (without electric components)

POLITO CONSTRUCTION COSTS OF PAVEMENT FOR AN E-CORRIDOR

Components	Sub-components	Depreciation Period	Unitary Cost	Unit	Amount (25 km)	Units/e-corridor (25km, 1 lane)	Total Initial Cost	Units (25 km, 2 lane)	Total Rehab Cost Equip/Mater (5% Red every 5y)	Total COST (20 Y)
Cost components include labour and equipment rental in this initial section.										
E-road PAVEMENT WORKS										
Asphalt (Excavation and filling)	Wear	5	0.440	€/kg	24,570,000	kg/e-corridor	10,810,800	€/e-corridor	33,460,507	44,271,307
	Rest of Binder	10	0.322	€/kg	25,716,600	kg/e-corridor	8,280,745	€/e-corridor	7,452,671	15,733,416
Bituminous coatings	Emulsion	10	0,47	€/kg	12,400.0	kg/e-corridor	5,828	€/e-corridor	5,245	11,073
	Sealing	10	2.0	€/m^3	1,050.0	m^3/e-corridor	2,100	€/e-corridor	1,890	3,990
Concrete (Excavation and filling)	Binder (area coils)	10	140	€/m^3	1,260.0	m^3/e-corridor	176,400	€/e-corridor	158,760	335,160
Base course	Granular stabilized mixture	>20	0.040	€/kg	84,000,000	kg/e-corridor	3,360,000	€/e-corridor	0	3,360,000
Subbase course	Unbounded granular mix	>20	26.60	€/m^3	26,250	m^3/e-corridor	698,250	€/e-corridor	0	698,250
Subgrade course	Semi-infnite elastic soil	>20	12.20	€/m^3	35,000	m^3/e-corridor	427,000	€/e-corridor	0	427,000
Draining	4 Culvert/km	>20					30,600	€/e-corridor	0	
		Road width	7.00	m	SUBTOTAL T-ROAD PAVEMENT		23,791,723	€/e-corridor	41,079,073	64,870,796
					COST PER KM		951,669		1,643,163	2,594,832
				1.25%	From which man power is aprox		297,397		513,488	810,885
					Average salary (company costs)		3,300			
					Man-months		90			
					Number of daily workers		45			
					Period in months to implement works		2.0			

We have considered the substitution of the wearing layer every 5 years and the rehabilitation of the binder layer (coil area) every 10 years.

We have then simulated a usual **breakdown of costs** for the construction of an e-Corridor, with the specific dimensions (7 m width) and the costs arisen from the previous table but adding some other concepts (engineering, design, etc.).

Table 24. Pavement works cost breakdown for a dedicated e-Corridor.

E-CORRIDOR CONSTRUCTION

Polito Sol 1, 2030

MAIN ASSUMPTIONS **7 m (1 e-lane 3,65 m, 1 side lane 3,35 m)**

COST OF PAVEMENT RECONSTRUCTION	TOTAL BASE (1 km, one lane+one side lane)	TOTAL ESTIMATE (25 km, 1 lane+sidelane)
PLANNING		
PLANNING TOTAL	**9,524**	**238,103**
DESIGN		
PRELIMINARY DESIGN	19,048	476,205
DETAILED DESIGN SERVICES	74,555	1,863,868
DESIGN TOTAL	**93,603**	**2,340,074**
PROJECT MANAGEMENT		
PROJECT MANAGEMENT TOTAL	**37,944**	**948,597**
PROPERTY		
MARKET VALUE OF LAND	0	0
VARIABLE COSTS	0	0
PROPERTY TOTAL	**0**	**0**
ENVIRONMENT AND PERMITS		
ENVIRONMENT TOTAL	**28,550**	**713,752**
ROAD CONSTRUCTION		
GRADE CONSTRUCTION	*179,410*	*4,485,250*
Surveying	449	11,213
Clearing and pilling	89,705	2,242,625
Earthwork	41,264	1,031,608
Finish grading	47,992	1,199,804
PAVING CONSTRUCTION	*771,035*	*19,275,873*
DRAINING	*1,224*	*30,600*
ROAD CONSTRUCTION TOTAL	**950,445**	**23,791,723**
TOTAL	***1,072,598***	***28,032,248***
	Average/km	***1,121,290***

Please be aware that the **value of land** has not been included as this concept could vary a lot among different locations.

However, in a real project, we should add it as the business model could vary significantly.

Operations and maintenance.

Next table simulates the costs associated to the O&M activities. It includes labour for the operation and maintenance activities, and the cost for the billing, IT, communication and traffic management equipment, depreciated in 5 years. All these are fully explained in D5.3.3 O&M cost. Please review this deliverable for additional details. This table keeps the same for the two options and suppliers (POLITO and SAET).

Table 25. Cost breakdown of the operation and maintenance activities of e-Roads during 20 years.

OPERATION AND MAINTENANCE (EQUAL FOR SCENARIOS AND SUPPLIERS)

Item	Sub-item	Depreciation period (years)	Unitary Cost €/year	Unit	Nº units/year	Total Cost /year	TOTAL 20 y (€/e-corridor)
OPERATION							
Labour	Head of service (24 h)		30,000	€/man	3	90,000	1,800,000
	Traffic management labour (24 h)		18,000	€/man	5	90,000	1,800,000
	Metering and billing administration (24 h)		25,000	€/man	5	125,000	2,500,000
	Customer service (24 h)		20,000	€/man	5	100,000	2,000,000
				SUBTOTAL LABOUR		**405,000**	**8,100,000**
Consumables	Advertising and marketing		20,000	€/year		20,000	400,000
	Software and data bases		16,000	€		16,000	320,000
				SUBTOTAL CONSUMABLES		**36,000**	**720,000**
Equipment	Billing equipment	5	30,000	€/unit	1	6,000	120,000
	IT Equipment	5	18,000	€/unit	1	3,600	72,000
	Communication Equipment	5	18,000	€/unit	1	3,600	72,000
	Traffic management equipment (e.g. metering)	5	15,000	€/unit	1	3,000	60,000
				SUBTOTAL EQUIPMENT		**16,200**	**324,000**
Overtime, outsource and other costs	Labour overtime, i.e. 5% labour					20,250	405,000
	Outsource as external services (5% Direct Costs)		-			22,860	457,200
	Other operating costs (1% of Direct Cost)		-			4,572	91,440
				SUBTOTAL OTHER		**47,682**	**953,640**
MAINTENANCE							
Preventive maintenance	DWPT system repairs		150	€/day	365	54,750	1,095,000
	Small Repairs		10% Equip				
Corrective maintenance	DWTP System unplanned repairs (20% Preventive)		30	€/day	365	10,950	219,000
	Small Repairs		25% PM				
				SUBTOTAL MAINTENANCE		**65,700**	**1,314,000**

User costs

User costs are, in the frame of this type of projects, commonly associated to the users (e-DWPT drivers) of the e-lane and the parallel conventional lanes of the motorway (transited by other vehicle drivers), during the construction and operation phases of the e-infrastructure. As mentioned before, we have not calculated the energy costs in the vehicles and the environmental impact (this was done in the LCA). We have just considered under the “user costs” concept, the delays inferred in the conventional lanes (2) aside to the projected e-lane during the works implemented to transform the t-lane in a given period (thus, only **the construction phase in scenario 2**). The users’ costs during construction of the e-Corridor (scenario 1) are considered negligible as the conventional lanes are slightly affected.

Besides, the **user costs during operation** are not included as well. This is due to the fact that although the e-DWPT drivers leaving the highway to take the e-Corridors likely reduce the congestion of the 3 lanes motorway in some degree, after the 25 km, they reverse the situation when reintegrating into it generating some traffic jams in the entrance that offset the gaining of the exit.

So, in summary, users’ costs during operation are considered negligible and construction costs in the e-Corridor scenario has been also discarded.

Breakdown of costs (CAPEX)

The next table gathers all the previous information and add some other (electric configuration), representing the most important data sheets that feed the LCCA. Block O, “Preliminary R&D”, was agreed with main project researchers determining pending expenditure in Europe to reach the final market products. This has been distributed among the expected demand of e-Roads and proportionally to just one. The table shows a column with the unitary costs in 2017 and the expected unitary costs in 2030 (according to our estimations). Based on this final figure, we calculated the cost of 1 km of e-Corridor and the cost for the full 25 km e-Corridor. Block 2 “Infrastructure” is derived from direct information from POLITO and the proposed architecture illustrated in diagram 1. The main architecture of the different systems was taken from previous technical deliverables, but

adapting it to 50 kW instead of 20 kW power transfer. Pavement Costs are considered stable from 2017 to 2030.

Table 26. CAPEX breakdown (POLITO, Scenario 1 Dedicated e-Corridor construction, 2030).

SCENARIO 1. POLITO Sol 1 Dedicated New e-Corridor Low demand, 2.030. 50kW Power transfer									
(Calculation for 1 e-corridor 25 km length, 50 kW Power transfer)									
0. PRELIMINARY R+D		R&D Inv	Nº Units			Nº E-corr	km E-corr	Cost /1 km	Cost /25 km
0.1. R+D on road works	VEDE	5,000,000 €	4	Devlpers		120	1,350	14,815 €	370,370 €
0.2. R+D on electric components design	VEDE	5,000,000 €	4	Devlpers				14,815 €	370,370 €
0.3 Future Research needs	VEDE	5,000,000 €	4	Devlpers				14,815 €	370,370 €
TOTAL PRELIMINARY R+D		60,000,000						44,444 €	1,111,111 €
	SOURCE	TYPE	Nº units	Unit	Cost/unit 2017	Cost/unit 2030	Unit	Cost /1 km	Cost /25 km
1. DESIGN AND ENGINEERING (ROAD RECONSTRUCTION)									
1.1. Planning and Design	QiE	Labour			2,578,176	2,578,176		103,127 €	2,578,176 €
1.2. Project management	QiE	Labour			948,597	948,597		37,944 €	948,597 €
1.3 Property	QiE	assets	25	acres	15,000	15,000	€/acre	0 €	0 €
1.4 Environmental analysis	QiE	Labour						28,550 €	713,752 €
TOTAL DESIGN AND ENGINEERING								169,621 €	4,240,525 €
2. INFRASTRUCTURE EXPENDITURE (E-CORRIDOR CONSTRUCTION)									
2.1 e-Corridor construction costs (pavement, All concepts)	POLITO	All			951,669	951,669		951,669 €	23,791,723 €
TOTAL Construction Costs								951,669 €	23,791,723 €
2.2 Electric Infrastruture	CALCULATION FOR 1 KM ROAD				2,017	2,030	year	Cost /1 km	Cost /25 km
221 Power Supply (HV/MV, Trafo 25 MVA)	INGETEAM		1	units	11,000	11,000	€/unit	11,000 €	275,000 €
222 Power Supply (MV/LV, Trafo 1MVA, rectifier 400V AC to 650V DC)					128,700	90,090	€/unit	90,090 €	2,252,250 €
2211 Main Transformer (MV/DC, 1 MVA)	INGETEAM	Equipment	1	units	38,000	26,600	€/unit	26,600 €	665,000 €
2212 Power metering	POLIMI	Consumable	1	units	600	420	€/unit	420 €	10,500 €
2213 Protection and shunting circuits	POLITO	Consumable	1	units	100	70	€/unit	70 €	1,750 €
2214 AC/DC Converter (400V AC to 650V DC)	POLITO	Equipment	1	units	90,000	63,000	€/unit	63,000 €	1,575,000 €
223 Distribution Shelter								85,552 €	2,138,800 €
2231 Shelter	TECNO	Equipment	10	units	2,036	1,425	€/unit	14,252 €	356,300 €
2232 Super-capacitors box	POLITO	Equipment	10	units	5,000	3,500	€/unit	35,000 €	875,000 €
2233 Control Power Supply	POLITO	Equipment	10	units	80	80	€/unit	800 €	20,000 €
2234 SBRio PE boxes management unit	POLITO	Equipment	10	units	100	50	€/unit	500 €	12,500 €
2235 Vehicule Communication unit	CRF	Equipment	10	units	1,000	700	€/unit	7,000 €	175,000 €
2236 CSCU	TUB	Equipment	10	units	4,000	2,800	€/unit	28,000 €	700,000 €
224 Power Electronics (DC/HF)								95,000 €	2,375,000 €
2241 Power Electronics board	POLITO	Equipment	500	coils	143	100	€/coil	50,000 €	1,250,000 €
2242 Active Bridge	POLITO	Equipment	500	coils	86	60	€/coil	30,000 €	750,000 €
2243 Housing	POLITO	Equipment	500	coils	29	20	€/coil	10,000 €	250,000 €
2244 Connectors	POLITO	Consumable	500	coils	14	10	€/coil	5,000 €	125,000 €
225 Coil, Cabling and Capacitors								105,000 €	2,625,000 €
2251 Coil	POLITO	Equip/Lab	500	coils	400	200	€/coil	100,000 €	2,500,000 €
2252 Connectors	POLITO	Consumable	500	coils	2	2.0	€/coil	1,000 €	25,000 €
2253 Capacitors	POLITO	Equipment	500	coils	11	8	€/coil	4,000 €	100,000 €
226 Distribution lines								51,250 €	1,281,250 €
2261 Manholes (Plastic box - 55x55cm)	QIE	Consumable	250	boxes	50	35	€/2 coils	8,750 €	218,750 €
2262 Distribution Pipes	QIE	Consumable	50,000	m	0.10	0.10	€/m	5,000 €	125,000 €
2263 650VDC Distribution cables with connectors	QIE	Consumable	50,000	m	0.25	0.25	€/m	12,500 €	312,500 €
2264 Signal communication cables and connectors	QIE	Consumable	50,000	m	0.30	0.30	€/m	15,000 €	375,000 €
2265 Signal power supply cables and connectors	QIE	Consumable	50,000	m	0.20	0.20	€/m	10,000 €	250,000 €
227 Monitoring								12,482 €	312,060 €
2271 Optical Fiber	QIE	Consumable	17,472	m	0.70	0.49	€/m	12,230 €	305,760 €
2272 Surface sensors (4/km)	QIE	Consumable	4	units	30	21	€/unit	84 €	2,100 €
2273 Data Processing Unit	QiE	Computer	2	units	3,000	2,100	€/unit	168 €	4,200 €
228 Labour & Outsourcing (Vehicles Rental)								7,109 €	191,255 €
2281 Labour (Electric)	QIE	Labour	20	month-h	2,750.00	2,750.00	€/month	4,406 €	110,147 €
2282 Outsourcing	QIE	HV Rental	15	veh	90.00	90.00	€/day	2,704 €	81,108 €
TOTAL Electric Infrastructure								457,484 €	11,450,615 €
TOTAL INFRASTRUCTURE EXPENDITURE								1,409,153 €	35,242,338 €
TOTAL CAPEX								1,578,774 €	39,482,863 €

The investment on the electric chapter (dot 2.2 from previous table), was recovered from the main R&D performers. They prepared three costs: the current cost, the expectation for

2030 and the expectation for 2050. Due to the big discrepancies among RTD performers, we revised those costs and provided some data trying to gather all the view points and information from the supply chain in deliverable D5.4.2.

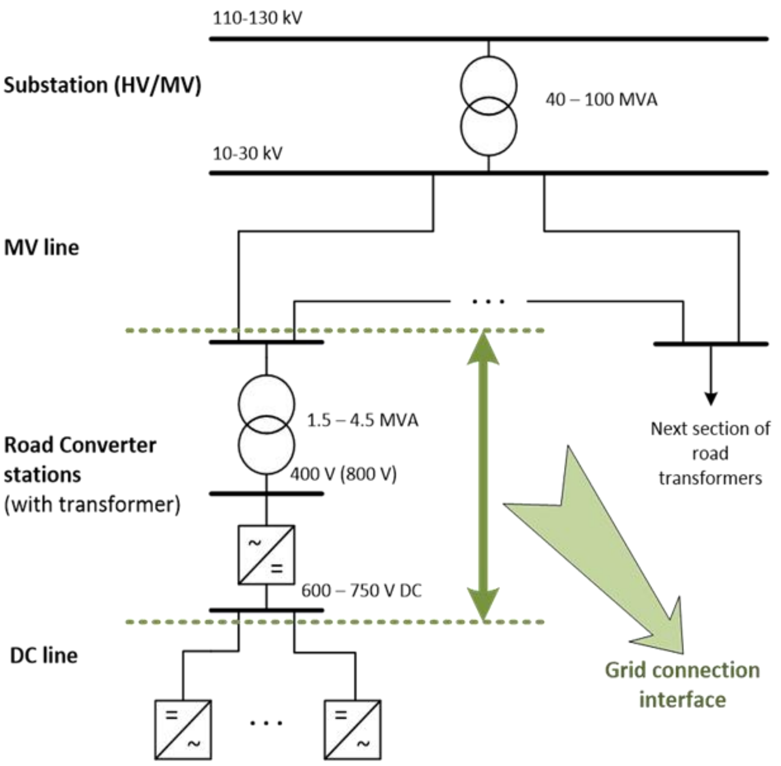


Figure 22: Expected architecture of E-Roads (20 kW).

Next diagram reflects the most likely electric configuration using the POLITO coils adapted to 20 kW Power transfer and used in the experimental sites. Qi Europe made then some adaptations to increase the power transfer to 50 kW.

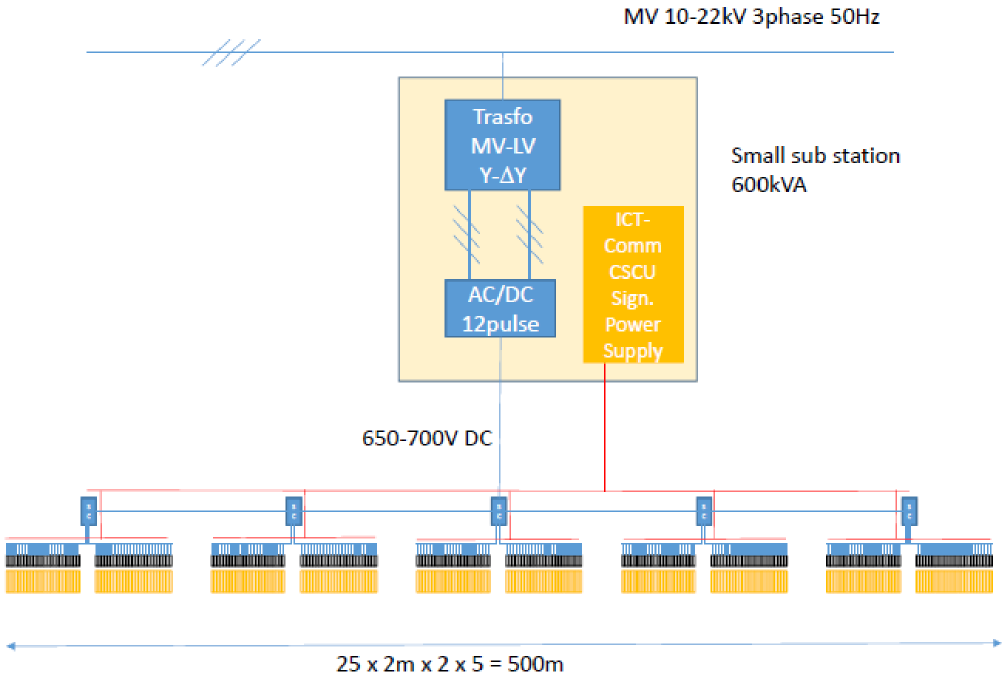


Figure 23: Reasonable configuration for an e-Road, POLITO (20 kW).

Breakdown of costs (OPEX)

Next table gathers the information related to operation, maintenance, renewal of equipment and disposal costs. These costs are spent every year during the whole 20 years lifetime. In some cases, various equipment and the pavement (some parts) are renewed according to a defined strategy in D5.3.2. In year 20, we have included the recovery of the copper in the last asphalt wear maintenance (year 2020), as the copper price could justify the investment. No other waste recovering is considered. If the e-Corridor is abandoned after the 20 years lifetime, the most likely scenario will be that the contractor will have to replace the area as it was originally removing the asphalt by replacing the natural conditions. In that case, reselling the copper will be the most rational option to reduce costs.

Table 27. Operation, maintenance, renewal and disposal costs (Scenario 1, e-Corridor Construction, 2030).

SCENARIO 1. POLITO Sol 1 Dedicated New e-Corridor Low demand, 2.030. 50kW Power transfer, OPEX											
3.	**OPERATION E-CORRIDOR**								**1 year**	**20 years**	**Lifetime**
3.1.	**Labor**								**405,000 €**	**8,100,000 €**	
311	Head of service (24 h)	QiE	Labour	3	units/y	30,000	30,000	€/year	90,000 €	1,800,000 €	1
312	Traffic management labour (24 h)	QiE	Labour	5	units/y	18,000	18,000	€/year	90,000 €	1,800,000 €	1
313	Metering and billing administration (24 h)	QiE	Labour	5	units/y	25,000	25,000	€/year	125,000 €	2,500,000 €	1
314	Customer service (24 h)	QiE	Labour	5	units/y	20,000	20,000	€/year	100,000 €	2,000,000 €	1
3.2.	**Consumables**								**36,000 €**	**720,000 €**	
321	Advertising and marketing	QiE	Consumable	1	un.	20,000	20,000	€/year	20,000 €	400,000 €	1
322	Software and data bases	QiE	Consumable	1	un.	16,000	16,000	€/year	16,000 €	320,000 €	1
3.3	**Equipments**								**64,800 €**	**239,760 €**	
331	Billing Equipment	QiE	Equipment	1	un.	30,000	24,000	€	24,000 €	88,800 €	5
332	IT Equipment	QiE	Equipment	1	un.	18,000	14,400	€	14,400 €	53,280 €	5
333	Communication Equipment	QiE	Equipment	1	un.	18,000	14,400	€	14,400 €	53,280 €	5
334	Traffic management equipment	QiE	Equipment	1	un.	15,000	12,000	€	12,000 €	44,400 €	5
3.4	**Overtime and outsource**								**45,540 €**	**910,800 €**	
341	Labour overtime (% Labour costs)	POLIMI	Labour	5.0%	Labour	20,250	20,250	€/year	20,250 €	405,000 €	1
342	Outsource (external services) (% Direct Costs)	POLIMI	External	5.0%	Direct Cost	25,290	25,290	€/year	25,290 €	505,800 €	1
3.4	**Other operating costs**								**5,513 €**	**110,268 €**	
341	Other operating costs (% of direct costs)	POLIMI	Consumable	1.0%	Direct Cost	2,555	5,513	€/year	5,513 €	110,268 €	1
	TOTAL OPERATION								**556,853 €**	**10,080,828 €**	
4.	**MAINTENANCE OF E-CORRIDOR (ADDED MAINTENANCE OVER A CONVENTIONAL ROAD)**								**1 year**	**20 years**	**Lifetime**
4.1.	**Preventive maintenance**								**64,841 €**	**1,296,815 €**	
411	DWPT system inspection and testing	POLIMI	Labour	365	days		150	€/day	54,750 €	1,095,000 €	1
412	Small Repairs (2% Equipment/Consumable)	QIE	Equip/Consum				10,091	€/year	10,091 €	201,815 €	1
4.2.	**Corrective maintenance**								**18,733 €**	**374,657 €**	
421	DWTP System umplanned repairs (25% Prevent. Maint.)	POLIMI	Equip/Cons/lab	1	per year		16,210	€/year	16,210 €	324,204 €	1
422	Small Repairs (25% of Repairs Preventive Maintenance)	QIE	Equip/Consum				2,523	€/year	2,523 €	50,454 €	1
	TOTAL MAINTENANCE								**83,574 €**	**1,671,472 €**	
5.	**RENEWAL COSTS OF E-CORRIDOR (ADDED RENEWED ASSETS IN THE E-CORRIDOR)**								**Initial CAPEX**	**Rest CAPEX (20 y)**	**Lifetime**
	ELECTRIC EQUIPMENT RENEWAL										
5.1.	**Major electric equipment repairs**										
511	Power Supply (HV/MV, Trafo 25 MVA)	QIE							275,000 €	0 €	20
512	Power Supply (MV/LV, Trafo 1MVA, rectifier 400V AC to 6	QIE							2,252,250 €	0 €	20
513	Distribution Shelter	QIE							2,138,800 €	0 €	20
514	Power Electronics (DC/HF)	QIE	Cost reduction		10%	100%	Substituted		2,375,000 €	2,137,500 €	10
515	Coil, Cabling and Capacitors	QIE	Cost copper increased		5%	30%	Deteriorated		2,625,000 €	826,875 €	10
516	Distribution lines	QIE							1,281,250 €	0 €	20
517	Monitoring	QIE	Cost reduction		5%	Every five years			312,060 €	842,562 €	5
518	Labour & Outsourcing (Vehicles Rental)	QIE							191,255 €	64,666 €	10
	TOTAL MAJOR ELECTRIC REPAIRS								**11,450,615 €**	**3,871,603 €**	
	PAVEMENT RENEWAL										
5.2.	**T-Road preventive Rehabilitation (years 5 and 15)**								**10,810,800 €**	**19,459,440 €**	
521	Asphalt wear (years 5 and 15)	QIE							10,810,800 €	19,459,440 €	5,15
5.3	**E-Road Rehabilitation (year 10)**								**19,273,773 €**	**17,346,396 €**	10
531	Bituminous coating (emulsion and sealing)	QIE							5,828 €	5,245 €	
532	Asphalt wear and binder	QIE							19,091,545 €	17,182,391 €	
533	Concrete binder (area of coils)	QIE							176,400 €	158,760 €	
	TOTAL PAVEMENT RENEWAL									**36,805,836 €**	
	TOTAL MAJOR PAVEMENT REFURBISHMENT									**36,805,836 €**	
5.4	**Refurbisment in major repairs**										
541	Repainting road surface and signs	QIE	Consumable, vehicle leasing and labour						**12,800 €**	**38,400 €**	5
			(years 5,10,15)	16	h	3	800	€/h	12,800 €	38,400 €	
	TOTAL PAVEMENT REFURBISMENT									**38,400 €**	
6.	**DISPOSAL COSTS**										
6.1.	**Cost of assets disposal**										
611	Removal of asphalt wear and take our coils	QIE							1,081,080 €	864,864 €	Year 20
6.2.	**Residual value**									**885,060 €**	
621	Copper recovery	QiE	Consumable	5.50	€/kg		160,920	kg		885,060 €	
	TOTAL COPPER RECOVERED									**885,060 €**	Year 20

The last result is the **LCCA itself**. Next table reflect the main results for scenario 1 (e-Corridor for POLITO). The complete data sheet is attached in the annex 1 and annex 2.

Table 28. LCCA for POLITO Scenario 1. Main results

FABRIC Feasibility analysis and development of on-road charging solutions for future electric vehicles

QiEurope Technology to Market

Life Cycle Costing Assessment (e-Corridor)

PROJECT DETAILS	
PROJECT TITLE	FABRIC E-CORRIDORS. LIFE CYCLE COSTING
AUTHOR	QI ENERGY Collaborators; KTH, ICCS, POLITO, POLIMI, ERTICO, CIRCE
DATE	30-dic.-17
OPTION DETAILS	
DESCRIPTION	POLITO (SCENARIO 1, Low Demand-2030, New Road, e-Corridor)
OPTION No.	Sol. 1. 2030. Full lane New Road
Number of Years to Analyze:	20

COST ITEM	DESCRIPTIONS	TOTALS
OPTION SUMMARY		
TOTAL COSTS		**€ 94,386,690**
PRESENT VALUE TOTAL COSTS		**€ 77,417,177**
CUMULATIVE COSTS		
YEARS OF ANALYSIS	Number of years of analysis.	**20**
AVERAGE ANNUALIZED COSTS (UNDISCOUNTED)	Total Costs / Number of years of analysis.	**€ 4,719,335**
AVERAGE ANNUALIZED COSTS (DISCOUNTED)	Present Value Total Costs / Number of years of analysis.	**€ 3,870,859**

The first scenario with a dedicated external e-Corridor of 25 km length requires an investment of € **94,386,690** during 20 years, representing **€ 77,417,177** at present value with an estimated Weighted Average Cost Of Capital (Wacc) of 4%. The average annualized cost is **€ 4,719,335** and the same figure discounted (present value) reaches **€3,870,859**. In table 25, we showed that a conventional trench of 25 km with the same dimensions than the e-Corridor but without the electric equipment and without considering 0&M activities, might cost on average 28,032,248 as a base for comparison.

In the next table, we make a breakdown of costs with the most relevant cost items.

Table 29. Breakdown of costs summary (POLITO, SCENARIO 1)

POLITO (SCENARIO 1, Low Demand-2030, New Road, e-Corridor)		
REAL VALUES		**2030**
0. R+D (E-Roads)	1,111,111 €	1,111,111
A. Capital Cost	81,531,921 €	39,482,863
A.1/2. Project Planning and Engineering	4,240,525 €	4,240,525
A3. Construction	60,433,554 €	23,791,723
A.4/5. Electric infrastructure and others	16,857,843 €	11,450,615
B. Operating Costs	10,080,828 €	64,800
C. Maintenance Costs	1,644,626 €	0
D. Renewal Costs	38,400 €	0
E. Disposal Costs	-20,196 €	0
F. User costs	0 €	0
TOTAL REAL VALUES	**94,386,690 €**	**40,658,774**
PRESENT VALUES		
0. R+D (E-Roads)	1,111,111	
A. Capital Cost	68,298,911	
A.1/2. Project Planning and Engineering	4,240,525	
A3. Construction	48,943,361	
A.4/5. Electric infrastructure and others	15,115,025	
B. Operating Costs	6,872,547	
C. Maintenance Costs	1,117,550	
D. Renewal Costs	26,275	
E. Disposal Costs	-9,217	
F. User costs	0	
TOTAL PRESENT VALUES	**77,417,177**	

Number of years of analysis.	**20**
Total Costs / Number of years of analysis.	**4,719,335 €**
Discount rate	**4.0%**
Present Value Total Costs / Number of years of analysis.	**3,870,859 €**

The initial investment reaches almost **€39.48 Million**, **€ 4.24 Million** goes to the initial planning and engineering, **€23.8 Million** are allocated to the road construction without electric components, which then represents **€11.45 Million**. Later, every five years, there will be additional re-investment that move up the total capital costs to **€ 81.53 Million** over the 20 years (at real yearly costs). So, as a general figure to remember, the electrification of a road supposes in this scenario, to increase the costs almost 50% over the equivalent investment without the DWPT system.

O&M activities represent about **€ 500k** and **€ 82k** per year respectively, totalising around **€11.7** Million for the whole 20 years. Disposal costs are included here although it is a singular investment, reflecting that re-open the wearing layer in an e-Corridor at the end of the life to extract the copper for reselling could be as expensive as the extra incomes received for the operation, so maybe it does not make sense if the e-Corridor is not going to be used anymore and there is not an obligation by the owner to refurbish it.

a.2. Year 2050. E-Road reconstruction using an existing lane. POLITO

Main differences with the previous scenario.

The main differences are identified hereinafter.

- Pavement costs are different as the road width affected is lower (5.75 m against 7 m)
- Pavement costs also differs because the technology used will be based on prefabricated structures (concrete slabs) reducing the time spent at works although the cost of the slabs will be higher. There will also a 10% reduction on costs due to optimisation and experience curve.
- We will not consider the cost of the original t-lane in the calculation for a better comparison with the e-Corridors where we did not consider the value of land.
- User costs will be relatively important in this case, as the works in a specific lane will infer additional traffic congestion in the remaining two lanes.
- Disposal costs will be also higher as the e-lane will be repaved at the end of the lifetime of the DWPT system to allow the normal traffic use.

Pavement calculations for scenario 2

The amounts of materials for the reconstruction of an existing t-lane are similar to those in the e-Corridor, with the difference of the trench width.

Table 30. Components and quantities for the e-Road reconstruction

COMPONENTS IN E-LANE RECONSTRUCTION

Component (POLITO)	Dimensions	Amount	Unit 25 km	Amount	Unit / 25 km	Density	Unit
Wearing asphalt (compacted)	0,06*5,75*25.000	8,625.00	m^3/strech	20,182,500	kg/stretch	2,340.00	kg/m^3
Bituminous emulsion linking	(1,50*0,62-1,46*0,50)*0,02/2*25.000*20%	8.00	m^3/strech	12,400	kg/stretch	1,550.00	kg/m^3
Slurry-seal coating	0,006*5,75*25.000	862.5	m^3/strech	862.5	m^3/stretch		
Binder asphalt (compacted)	(5,75-0,72)*0,07*25.000	8,802.50	m^3/strech	20,597,850	kg/stretch	2,340.00	kg/m^3
Excavation (Prefabricated concrete)	0,72*0,07*25000	1,260	m^3/strech	1,260.0	m^3/stretch		
Copper coil	Report O&M D533	6.44	kg/m	160,920.0	kg/stretch	5.50	€/kg
	Length E-Corridor	25,000	m				

In *Table 31*, we include the calculation of costs in the pavement due to the reconstruction of the t-lane converting it in an e-lane. Please be aware that the cost of equipment is not included in this table. Manpower is significantly reduced due to the use of prefabricated slabs minimising the time at work.

Table 31. Cost of an e-Road construction over a conventional t-Road

E-ROAD PAVEMENT WORKS (RECONSTRUCTION)										
Asphalt (Excavation and filling)	Wear	10	0.396	€/kg	20,182,500.0	kg/e-corridor	7,992,270	€/e-corridor	0	7,992,270
	Binder	10	0.249	€/kg	20,597,850.0	kg/e-corridor	5,138,752	€/e-corridor	4,624,876	9,763,628
Bituminous coatings	Emulsion	10	0.42	€/kg	12,400.0	kg/e-corridor	5,245	€/e-corridor	4,721	9,966
	Sealing	10	1.8	€/m^3	862.5	m^3/e-corridor	1,553	€/e-corridor	1,397	2,950
Prefabricated Concrete (Excavation and placement)	Binder (area coils)	10	210.00	€/m^3	1,260.0	m^3/e-corridor	264,600	€/e-corridor	238,140	502,740
Nº Coils	**12,500**				**SUBTOTAL PAVEMENT E-ROAD**		**13,402,419**	€/e-corridor	**4,869,134**	**18,271,554**

We present here in after the breakdown of costs related to the investment (CAPEX) an also the operation and maintenance activities, the renewal costs, the disposal costs and the user costs.

Breakdown of costs in 2050 (CAPEX, Scenario 2).

Table 32. Breakdown of costs (CAPEX) in 2050 for Scenario 2, POLITO

SCENARIO 2. POLITO Sol 2 Full lane Reconstruction (e-Road). High demand, 2.050. 50kW Power transference									
(Calculation for 1 e-corridor 25 km length, 50 kW Power transfer)									25
0. PRELIMINARY R+D		R&D Inv	Nº Units			Nº E-corr	km E-cor	Cost /1 km	Cost /25 km
0.1. R+D on road works	VEDE	5,000,000 €	4	Devlpers		480	5,130	3,899 €	97,466 €
0.2. R+D on electric components design	VEDE	5,000,000 €	4	Devlpers				3,899 €	97,466 €
0.3 Future Research needs	VEDE	5,000,000 €	4	Devlpers				3,899 €	97,466 €
TOTAL PRELIMINARY R+D		60,000,000						11,696 €	292,398 €
	SOURCE	TYPE	Nº units	Unit	Cost/unit 2030	Cost/unit 2050	Unit	Cost /1 km	Cost /25 km
1. DESIGN AND ENGINEERING (T-ROAD AND RECONSTRUCTION)									
1.1. Planning and Design	QiE	Labour				58,165		58,165 €	1,454,130 €
1.2. Project management	QiE	Labour				21,401		21,401 €	535,023 €
1.3 Property	QiE	assets	25	acres		0	€/acre	0 €	0 €
1.4 Environmental analysis	QiE	Labour				16,087		16,087 €	402,164 €
TOTAL DESIGN AND ENGINEERING								95,653 €	2,391,317 €
2. INFRASTRUCTURE EXPENDITURE (T-ROAD AND RECONSTRUCTION)									
2.1 T-ROAD Construction costs (pavement, All concepts)	POLITO	All	Not considered			0		0 €	0 €
2.2. Reconstruction (E-Road adaptation, all concepts)	POLITO	All				536,219		536,219 €	13,405,479 €
TOTAL Construction Costs								536,219 €	13,405,479 €
2.3 Electric Infrastruture		CALCULATION FOR 1 KM ROAD			2,030	2,050		Cost /1 km	Cost /25 km
231 Power Supply (HV/MV, Trafo 25 MVA)	INGETEAM		1	units	11,000	9,900		9,900 €	275,000 €
232 Power Supply (MV/LV, Trafo 1MVA, rectifier 400V AC to 650V DC)			1	units	90,090	81,081		81,081 €	2,027,025 €
2321 Main Transformer (MV/DC, 1 MVA)	INGETEAM	Equipment	1	units	26,600	23,940	€/unit	23,940 €	598,500 €
2322 Power metering	POLIMI	Consumable	1	units	420	378	€/unit	378 €	9,450 €
2323 Protection and shunting circuits	POLITO	Consumable	1	units	70	63	€/unit	63 €	1,575 €
2324 AC/DC Converter (400V AC to 650V DC)	POLITO	Equipment	1	units	63,000	56,700	€/unit	56,700 €	1,417,500 €
233 Distribution Shelter								76,997 €	1,924,920 €
2331 Shelter	TECNO	Equipment	10	units	1,425	1,283	€/unit	12,827 €	320,670 €
2332 Super-capacitors box	POLITO	Equipment	10	units	3,500	3,150	€/unit	31,500 €	787,500 €
2333 Control Power Supply	POLITO	Equipment	10	units	80	72	€/unit	720 €	18,000 €
2334 SBRio PE boxes management unit	POLITO	Equipment	10	units	50	45	€/unit	450 €	11,250 €
2335 Vehicule Communication unit	CRF	Equipment	10	units	700	630	€/unit	6,300 €	157,500 €
2336 CSCU	TUB	Equipment	10	units	2,800	2,520	€/unit	25,200 €	630,000 €
234 Power Electronics (DC/HF)								85,500 €	2,137,500 €
2341 Power Electronics board	POLITO	Equipment	500	coils	100	90	€/coil	45,000 €	1,125,000 €
2342 Active Bridge	POLITO	Equipment	500	coils	60	54	€/coil	27,000 €	675,000 €
2343 Housing	POLITO	Equipment	500	coils	20	18	€/coil	9,000 €	225,000 €
2344 Connectors	POLITO	Consumable	500	coils	10	9	€/coil	4,500 €	112,500 €
235 Coil, Cabling and Capacitors								94,500 €	2,362,500 €
2351 Coil	POLITO	Equip/Lab	500	coils	200	180	€/coil	90,000 €	2,250,000 €
2352 Connectors	POLITO	Consumable	500	coils	2	1.8	€/coil	900 €	22,500 €
2353 Capacitors	POLITO	Equipment	500	coils	8	7	€/coil	3,600 €	90,000 €
236 Distribution lines								46,125 €	1,153,125 €
2361 Manholes (Plastic box - 55x55cm)	QIE	Consumable	250	boxes	35	32	€/2 coils	7,875 €	196,875 €
2362 Distribution Pipes	QIE	Consumable	50,000	m	0.10	0.09	€/m	4,500 €	112,500 €
2363 650VDC Distribution cables with connectors	QIE	Consumable	50,000	m	0.25	0.23	€/m	11,250 €	281,250 €
2364 Signal communication cables and connectors	QIE	Consumable	50,000	m	0.30	0.27	€/m	13,500 €	337,500 €
2365 Signal power supply cables and connectors	QIE	Consumable	50,000	m	0.20	0.18	€/m	9,000 €	225,000 €
237 Monitoring								11,234 €	280,854 €
2371 Optical Fiber	QIE	Consumable	15,725	m	0.49	0.44	€/m	11,007 €	275,184 €
2372 Surface sensors (4/km)	QIE	Consumable	4	units	21	19	€/unit	76 €	1,890 €
2373 Data Processing Unit	QiE	Computer	2	units	2,100	1,890	€/unit	151 €	3,780 €
238 Labour & Outsourcing (Vehicles Rental)								3,103 €	77,572 €
2381 Labour (Electric)	QIE	Labour	20	month-h	2,750.00	2,475.00	€/month	1,787 €	44,675 €
2382 Outsourcing	QIE	HV Rental	15	veh	90.00	81.00	€/day	1,316 €	32,897 €
TOTAL Electric Infrastructure								408,440 €	10,238,496 €
TOTAL INFRASTRUCTURE EXPENDITURE								944,659 €	23,643,975 €
TOTAL CAPEX								1,040,312 €	26,035,292 €

Breakdown of costs (OPEX, Scenario 2)

Table 33. Breakdown of costs (OPEX) in 2050 for Scenario 2, POLITO

SCENARIO 2. POLITO Sol 2 Full lane Reconstruction (e-Road). High demand, 2.050. 50kW Power transference, OPEX										
3.	OPERATION E-ROAD					2,030	2,050		1 year	20 years
3.1.	Labor								405,000 €	8,100,000 €
311	Head of service (24 h)	QiE	Labour	3	units/y	30,000	30,000	€/year	90,000 €	1,800,000 €
312	Traffic management labour (24 h)	QiE	Labour	5	units/y	18,000	18,000	€/year	90,000 €	1,800,000 €
313	Metering and billing administration (24 h)	QiE	Labour	5	units/y	25,000	25,000	€/year	125,000 €	2,500,000 €
314	Customer service (24 h)	QiE	Labour	5	units/y	20,000	20,000	€/year	100,000 €	2,000,000 €
3.2.	Consumables								36,000 €	720,000 €
321	Advertising and marketing	QiE	Consumable	1	un.	20,000	20,000	€/year	20,000 €	400,000 €
322	Software and data bases	QiE	Consumable	1	un.	16,000	16,000	€/year	16,000 €	320,000 €
3.3	Equipments								64,800 €	239,760 €
331	Billing Equipment	QiE	Equipment	1	un.	30,000	24,000	€	24,000 €	88,800 €
332	IT Equipment	QiE	Equipment	1	un.	18,000	14,400	€	14,400 €	53,280 €
333	Communication Equipment	QiE	Equipment	1	un.	18,000	14,400	€	14,400 €	53,280 €
334	Traffic management equipment	QiE	Equipment	1	un.	15,000	12,000	€	12,000 €	44,400 €
3.4	Overtime and outsource								45,540 €	910,800 €
341	Labour overtime (% Labour costs)	POLIMI	Labour	5.0%	Labour	20,250	20,250	€/year	20,250 €	405,000 €
342	Outsource (external services) (% Direct Costs)	POLIMI	External	5.0%	Direct Cc	25,290	25,290	€/year	25,290 €	505,800 €
3.4	Other operating costs								5,513 €	110,268 €
341	Other operating costs (% of direct costs)	POLIMI	Consumable	1.0%	)irect Cos	2,555	5,513	€/year	5,513 €	110,268 €
	TOTAL OPERATION								556,853 €	10,080,828 €
4.	MAINTENANCE OF E-ROAD (ADDED MAINTENANCE OVER A CONVENTIONAL ROAD)					2,030	2,050		1 year	20 years
4.1.	Preventive maintenance								63,946 €	1,278,917 €
411	DWPT system inspection and testing	POLIMI	Labour	365	days		150	€/day	54,750 €	1,095,000 €
412	Small Repairs (2% Equipment/Consumable)	QIE	Equip/Consum				9,196	€/year	9,196 €	183,917 €
4.2.	Corrective maintenance								18,285 €	365,709 €
421	DWTP System unplanned repairs (25% Prevent. Maint.)	POLIMI	Equip/Cons/lab	1	per year		15,986	€/year	15,986 €	319,729 €
422	Small Repairs (25% of Repairs Preventive Maintenance)	QIE	Equip/Consum				2,299	€/year	2,299 €	45,979 €
	TOTAL MAINTENANCE								82,231 €	1,644,626 €
5.	RENEWAL COSTS OF E-ROAD (ADDED RENEWED ASSETS IN THE E-CORRIDOR)								Initial CAPEX	Rest CAPEX (20 y)
	ELECTRIC EQUIPMENT RENEWAL									
5.1.	Major electric equipment repairs									
511	Power Supply (HV/MV, Trafo 25 MVA)	QIE							275,000 €	0 €
512	Power Supply (MV/LV, Trafo 1MVA, rectifier 400V AC to 6	QIE							2,027,025 €	0 €
513	Distribution Shelter	QIE							1,924,920 €	0 €
514	Power Electronics (DC/HF)	QIE	Cost reduction		10%	100%	Substituted		2,137,500 €	1,923,750 €
515	Coil, Cabling and Capacitors	QIE	Cost copper increased		5%	30%	Deteriorated		2,362,500 €	744,188 €
516	Distribution lines	QIE							1,153,125 €	0 €
517	Monitoring	QIE	Cost reduction		5%	Every five years			280,854 €	758,306 €
518	Labour & Outsourcing (Vehicles Rental)	QIE							77,572 €	26,157 €
	TOTAL MAJOR ELECTRIC REPAIRS								10,238,496 €	3,452,400 €
	PAVEMENT RENEWAL									
5.2.	T-Road preventive Rehabilitation (years 5 and 15)								7,992,270 €	14,386,086 €
521	Asphalt wear (years 5 and 15)	QIE							7,992,270 €	14,386,086 €
5.3	E-Road Rehabilitation (year 10)								13,402,419 €	12,062,177 €
531	Bituminous coating (emulsion and sealing)	QIE							6,798 €	6,118 €
532	Asphalt wear and binder	QIE							13,131,022 €	11,817,919 €
533	Concrete binder (area of coils)	QIE							264,600 €	238,140 €
	TOTAL PAVEMENT RENEWAL								21,394,689 €	26,448,263 €
	TOTAL MAJOR PAVEMENT REFURBISHMENT									26,448,263 €
5.4	Refurbisment in major repairs									
541	Repainting road surface and signs	QIE	Consumable, vehicle leasing and labour						12,800 €	38,400 €
			(years 5,10,15)	16	h	3	800	€/h	12,800 €	38,400 €
	TOTAL PAVEMENT REFURBISMENT								12,800 €	38,400 €
6.	DISPOSAL COSTS									
6.1.	Cost of assets disposal									
611	Removal of asphalt wear and take our coils	QIE							7,992,270 €	6,393,816 €
6.2.	Residual value									885,060 €
621	Copper recovery	QiE	Consumable	5.50	€/kg		160,920	kg		885,060 €
	TOTAL COPPER RECOVERED									885,060 €

We kept the same OPEX in Scenario 2 than 1 as it is difficult to estimate the potential disaligning under this item. However, there is a major difference in this scenario related to the need to repave the e-Road at the end of the lifetime as mentioned before.

The second great difference are the user costs in the construction phase.

User costs. POLITO. Scenario 2.

For the calculation of the travel costs increased by the pavement works, we have followed the indications of the Guide to Cost-Benefit Analysis of Investment Projects. Economic appraisal tool for Cohesion Policy 2014-2020, edited by the European Commission in December 2014. In carrying out CBA or LCCA, different methods are possible to value time for passengers, whilst a distinction is usually made between the estimation of work and non-work travel time (including commuting). For the work travel time, we got the average wage rates for the whole Europe and estimated in 15.5 €/h as the average gross salary. Following the indications of the mentioned report, the non-work time can be assumed as a share of the work-related value. The review of the economic literature about value of time in specific countries suggests that non-working time usually ranges between 25 % and 40 % of the work time. We assumed 30%.

Finally, we needed to estimate a driving cycle representing an average congested European motorway. Taking the information from some driving cycles in the Spanish motorways estimated in D5.4.1, we created our own curves considering a daily traffic of 18.000 vehicles. The selection of such congested example is due to the fact that in general terms, cities at a distance of 400 km in pro-electric environmental awareness countries in Europe (please check the demand report in D5.4.2) usually present a high congestion level.

We have to mention that the user costs, although in some way are hidden costs, may modify greatly the best investment option from the point of view of the administrations. Blocking one lane in a three-lanes motorway during one month increased significantly the congestion in the remaining lanes, and reduced drastically the average speed and consequently the travel duration of the 1.3 passengers on average for short trips. In our study, the user costs reached more than **10.8** Million € of equivalent time losses.

In the next figure, we represent the variation of the traffic density and the average speed due to the accumulation of three lanes traffic in two, due to the e-lane works.

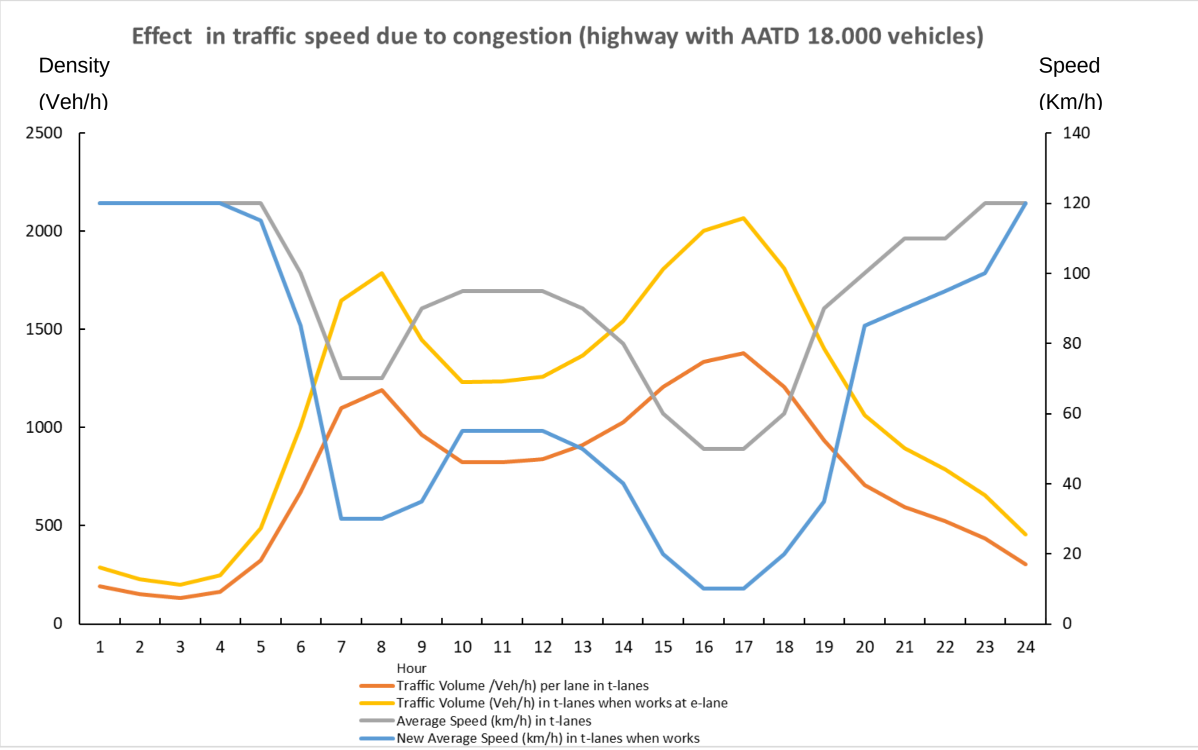


Figure 24. Relation between traffic density and average speed by daily hour in a motorway.

The results of the calculations for user costs are deployed in the following Table 34.

Table 34. User costs calculation due to time losses during e-lane reconstruction works.

User-Cost during Construction (Opportunity Cost Model)

Basic Assumptions	Quantity	Unit
Total AADT per lane (daily average vehicles per lane in busy highways)	18,000	Veh/lane
Duration of works to convert a t-lane into e-lane	27.1	days
Stretch under construction	25	km
Stretch of jammed traffic (affected)	30	km
Calculation	**Quantity**	**Unit**
Total time losses during works	1,022,243	h
Average occupancy of vehicles (Nº of persons)	1.35	persons
Average cost of working hour by European citizen	15.5	€/h
Opportunitty costs for none working people (30% of working rate)	4.6	€/h
Rate working people /Total population in Europe (Eurostats,2016)	29%	%
TOTAL USER COSTS DUE TO TIME LOSSES DURING WORKS	**10,796,797**	**€**

In this option where a conventional t-lane is reconstructed, there is a consensus of the experts that all the vehicles will be able to use this e-lane, regardless whether or not they recharge on it. Therefore, the traffic will not be affected by the hidden coils below the pavement, and consequently there will be no variations on the traffic flow.

Final result-LCCA for Scenario 2, POLITO Part I (CAPEX)

Table 35. LCCA for POLITO Scenario 2. Main results.

FABRIC
Feasibility analysis and development of on-road charging solutions for future electric vehicles

QiEurope Technology to Market

Life Cycle Costing Assessment (E-Road)

PROJECT DETAILS	
PROJECT TITLE	FABRIC E-CORRIDORS. LIFE CYCLE COSTING
AUTHOR	QI ENERGY Collaborators; KTH, ICCS, POLITO, POLIMI, ERTICO, CIRCE
DATE	30-dic.-17
OPTION DETAILS	
DESCRIPTION	POLITO (SCENARIO 2, High Demand-2050, Reconstruction Exiting Road, e-Road)
OPTION No.	Sol. 2. 2050. Full lane Existing Road, e-Road
Number of Years to Analyze:	20

COST COMPONENTS	DESCRIPTIONS	TOTALS
OPTION SUMMARY		
TOTAL COSTS		**85,033,400 €**
PRESENT VALUE TOTAL COSTS		**68,525,665 €**
CUMULATIVE COSTS		
YEARS OF ANALYSIS	Number of years of analysis.	**20**
AVERAGE ANNUALIZED COSTS (UNDISCOUNTED)	Total Costs / Number of years of analysis.	**4,251,670 €**
AVERAGE ANNUALIZED COSTS (DISCOUNTED)	Present Value Total Costs / Number of years of analysis.	**3,426,283 €**

The second scenario is related to the use of one of the existing lanes as e-Road with the same 25 km length, requiring an investment of € **85,033,400** during 20 years, representing **€ 68,525,655** at present value with an estimated Weighted Average Cost Of Capital (Wacc) of 4%. The average annualized cost is in this case of **€ 4,251,670** and the same figure discounted (present value) reaches **€3,426,283**. These figures are slightly cheaper than those from the first scenario and the gap should be higher were it not for the introduction of the user costs.

In the next table, we make a breakdown of costs with the most relevant cost items where this effect can be appreciated.

Table 36. Breakdown of costs summary (POLITO, SCENARIO 1)

POLITO (SCENARIO 2, High demand-2050, e-Road reconstructed)		
REAL VALUES		2050
0. R+D (E-Roads)	292,398 €	292,398
A. Capital Cost	56,671,596 €	25,633,128
A.1/2. Project Planning and Engineering	1,989,153 €	1,989,153
A3. Construction	39,609,485 €	13,405,479
A.4/5. Electric infrastructure and others	15,072,958 €	10,238,496
B. Operating Costs	10,080,828 €	64,800
C. Maintenance Costs	1,644,626 €	0
D. Renewal Costs	38,400 €	0
E. Disposal Costs	5,508,756 €	0
F. User costs	10,796,797 €	10,796,797
TOTAL REAL VALUES	**85,033,400 €**	**36,787,122**
PRESENT VALUES		
0. R+D (E-Roads)	292,398	
A. Capital Cost	46,905,974	
A.1/2. Project Planning and Engineering	1,989,153	
A3. Construction	31,402,003	
A.4/5. Electric infrastructure and others	13,514,818	
B. Operating Costs	6,872,547	
C. Maintenance Costs	1,117,550	
D. Renewal Costs	26,275	
E. Disposal Costs	2,514,124	
F. User costs	10,796,797	
TOTAL PRESENT VALUES	**68,525,665**	

Number of years of analysis.	**20**
Total Costs / Number of years of analysis.	**4,251,670 €**
Discount rate	**4.0%**
Present Value Total Costs / Number of years of analysis.	**3,426,283 €**

Summary of final results (Scenario 2)

We summarise the final results for Scenario 2 (high demand and optimization of the production process envisaged for 2050). Although costs are slightly better than in the previous scenario, we must highlight the great impact of the user costs. Any cost reduction in this factor will affect significantly the overall costs, making the business model more attractive in the second scenario.

In next figure, we compare both solutions for 2030 and 2050. Although final results look similar, the composition of the cost concepts differs significantly. The comparison has been done using the present values of different concepts.

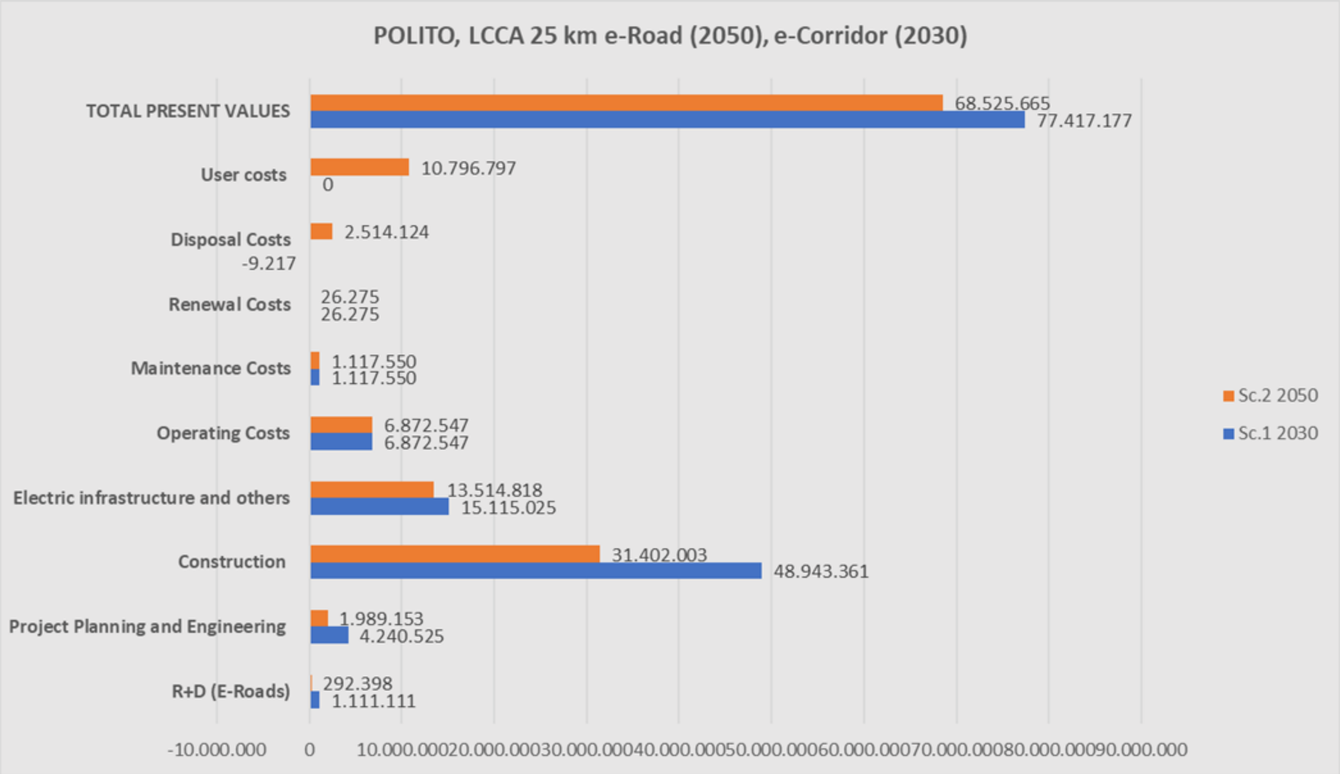


Figure 25. Annualized Costs (POLITO, Scenarios 1 and 2)

The explanation for the major differences are the following:

- R&D costs differs substantially. The reason is that research costs estimated for the period 2030 to 2070 will reach €120 Million but the first €60 Million between 2030 and 2050 must be distributed among the expected e-Corridors for that period (120) but the second €60 Million will be done among 480 e-Corridors, so the figure applied to each singular e-Corridor (amortization) in that period is lower.
- Project planning and engineering for the reconstruction of an existing lane is almost half that making a completely new dedicated e-Corridor in parallel to the motorway.

- The construction of a new dedicated e-Corridor (without electrification) will reach €60.4 Million whilst the reconstruction cost of an existing lane reaches only € 40 Million.
- The electrification infrastructure slightly differs because the width of the road in the e-Corridors is higher than that of the e-Lane and therefore requires more connection cables, although the main equipment is the same.
- Operational and maintenance costs are equal as probably the working teams, consumables and equipment will be the same.
- Disposal costs differs significantly. The reason is that in the 2 scenarios at the end of the lifetime, the lane of the motorway where the wireless technology is installed will have to be disassembly completely to leave the road as it was originally. In scenario 1 by the contrary, probably the installation will be kept underground disconnected but without taking out the buried equipment, because that road is not critical.
- Finally, user costs introduce an important cost gap. The gaining of making the electrification using a conventional lane instead of an external corridor is offset by the impact of the works in the traffic flow (rest of lanes) during the construction period, especially if the highway is very congested. This impact does not exist or remains insignificant in case of an external dedicated e-Corridor is built.
- As a conclusion, the two options diverge just in €9 Million, although apparently the scenario 2 should has provided much more advantages, but those were minimised by the user and disposal costs effects.

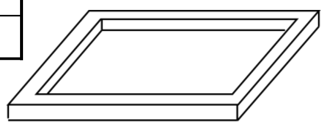
3.9.1.2 SAET calculations

The calculations for SAET were performed in the same way than those from POLITO, and vary due to some differences in the technology (especially in the electrical components and the size of the coil).

SAET uses a 2 m coils instead of 1.5 m from POLITO. As a result, the number of coils per km reaches 500 in the POLITO technology and 400 in the SAET one. This fact affects the

pavement works. Some details of the SAET coil are listed in next table. Please refer to former technical deliverables for a better understanding of the technology.

Table 37. SAET coil main dimensions

COIL MAIN FEATURES		COIL MAIN DIMENSIONS (m)			
1.75	dm^3	Ext. Length	Ext.Width	Int. Length	Int. Width
8.94	kg/l	2.00	0.57	1.92	0.55
15.63	kg	Thick			
6,251	kg/km	0.019			
156,271	kg/25 km				
400	coils				

The electric infrastructure also varies resulting in some extra costs, compensated partially by the pavement costs which are slightly reduced. There will be likely less costs in the O&M activities as the number of coils and the power electronics associated are reduced by 20%, but the lack of real data prevents us to understand to what extend this effect could offset the mentioned extra costs and consequently the LCCA provides worse figures in this first analysis. So, the final data of SAET **should be considered as provisional** pending the availability of a larger O&M track record.

In next table below, we include the electric costs taken in the SAET analysis for the Scenario 2030 (e-Corridor).

Table 38. SAET electric infrastructure costs (Scenario 2030, e-Corridor).

2.	**INFRASTRUCTURE EXPENDITURE (E-CORRIDOR CONSTRUCTION)**									
2.1	**e-Corridor construction costs (pavement, All concepts)**	**SAET**	**All**			**944,034**	**944,034**		**944,034 €**	**23,600,838 €**
	TOTAL Construction Costs								**944,034 €**	**23,600,838 €**
2.3	**Electric Infrastruture**	**CALCULATION FOR 1 KM ROAD**				**2,017**	**2,030**	**year**		
231	**Power Supply (HV/MV, Trafo 25 MVA)**	INGETEAM		**1**	**units**	**11,000**	**11,000**	**€/unit**	**11,000 €**	**275,000 €**
232	**Power Supply (MV/LV, Trafo 1MVA, rectifier 400V AC to 650V DC)**					**128,700**	**90,090**	**€/unit**	**90,090 €**	**2,252,250 €**
2321	Main Transformer (MV/DC, 1 MVA)	INGETEAM	Equipment	1	units	38,000	26,600	€/unit	26,600 €	665,000 €
2322	Power metering	POLIMI	Consumable	1	units	600	420	€/unit	420 €	10,500 €
2323	Protection and shunting circuits	POLITO	Consumable	1	units	100	70	€/unit	70 €	1,750 €
2324	AC/DC Converter (400V AC to 650V DC)	POLITO	Equipment	1	units	90,000	63,000	€/unit	63,000 €	1,575,000 €
233	**Distribution Shelter**								**54,052 €**	**1,351,300 €**
2331	Shelter	TECNO	Equipment	10	units	2,036	1,425	€/unit	14,252 €	356,300 €
2332	Rectifier and protection circuit	POLITO	Equipment	10	units	500	350	€/unit	3,500 €	87,500 €
2333	Control Power Supply	POLITO	Equipment	10	units	80	80	€/unit	800 €	20,000 €
2334	SBRio PE boxes management unit	POLITO	Equipment	10	units	100	50	€/unit	500 €	12,500 €
2335	Vehicule Communication unit	CRF	Equipment	10	units	1,000	700	€/unit	7,000 €	175,000 €
2336	CSCU	TUB	Equipment	10	units	4,000	2,800	€/unit	28,000 €	700,000 €
234	**Power Electronics (DC/HF)**								**158,800 €**	**3,970,000 €**
2341	Power Electronics board	POLITO	Equipment	400	coils	143	100	€/coil	40,000 €	1,000,000 €
2342	Active Bridge	POLITO	Equipment	400	coils	86	60	€/coil	24,000 €	600,000 €
2343	Housing	POLITO	Equipment	400	coils	29	20	€/coil	8,000 €	200,000 €
2344	HF Transformer	SAET	Equipment	400	coils	150	105	€/coil	42,000 €	1,050,000 €
2345	Res. Capacitors	SAET	Consumable	400	coils	160	112	€/coil	44,800 €	1,120,000 €
235	**Coil, Cabling and Capacitors**								**111,733 €**	**2,793,333 €**
2351	Coil	POLITO	Equip/Lab	400	coils	533	267	€/coil	106,667 €	2,666,667 €
2352	Connectors	POLITO	Consumable	400	coils	2	2.0	€/coil	800 €	20,000 €
2353	Capacitors	POLITO	Equipment	400	coils	15	11	€/coil	4,267 €	106,667 €
236	**Distribution lines**								**41,000 €**	**1,025,000 €**
2361	Manholes (Plastic box - 55x55cm)	QIE	Consumable	200	boxes	50	35	€/2 coils	7,000 €	175,000 €
2362	Distribution Pipes	QIE	Consumable	40,000	m	0.10	0.10	€/m	4,000 €	100,000 €
2363	650VDC Distribution cables with connectors	QIE	Consumable	40,000	m	0.25	0.25	€/m	10,000 €	250,000 €
2364	Signal communication cables and connectors	QIE	Consumable	40,000	m	0.30	0.30	€/m	12,000 €	300,000 €
2365	Signal power supply cables and connectors	QIE	Consumable	40,000	m	0.20	0.20	€/m	8,000 €	200,000 €
237	**Monitoring**								**17,724 €**	**312,060 €**
2371	Optical Fiber	QIE	Consumable	24,960	m	0.70	0.49	€/m	17,472 €	305,760 €
2372	Surface sensors (4/km)	QIE	Consumable	4	units	30	21	€/unit	84 €	2,100 €
2373	Data Processing Unit	QiE	Consumable	2	units	3,000	2,100	€/unit	168 €	4,200 €
238	**Labour & Outsourcing (Vehicles Rental)**								**4,371 €**	**109,263 €**
2381	Labour (Electric)	QIE	Labour	20	month-h	2,750.00	2,750.00	€/month	4,371 €	109,263 €
2382	Outsourcing	QIE	HV Rental	15	Veh	90.00	90.00	€/day	0 €	0 €
	TOTAL Electric Infrastructure								**488,770 €**	**12,088,206 €**
	TOTAL INFRASTRUCTURE EXPENDITURE								1,432,803 €	35,689,045 €
	TOTAL CAPEX								1,601,064 €	39,895,550 €

In the following tables we show the final results for SAET in scenario 2030 (e-Corridor) and scenario 2050 (e-Road) using the same methodology applied with POLITO. The results reflect that SAET technology is € 4 Million more expensive than the equivalent from POLITO but considering that the O&M costs could not be appropriately evaluated (as indicated above).

Table 39. Comparison of LCCA analysis between POLITO and SAET (Scenario 2030, e-Corridor)

POLITO (SCENARIO 1, Low Demand-2030, New Road, e-Corridor)	
REAL VALUES	
0. R+D (E-Roads)	1,111,111 €
A. Capital Cost	81,531,921 €
A.1/2. Project Planning and Engineering	4,240,525 €
A3. Construction	60,433,554 €
A.4/5. Electric infrastructure and others	16,857,843 €
B. Operating Costs	10,080,828 €
C. Maintenance Costs	1,644,626 €
D. Renewal Costs	38,400 €
E. Disposal Costs	-20,196 €
F. User costs	0 €
TOTAL REAL VALUES	**94,386,690 €**
PRESENT VALUES	
0. R+D (E-Roads)	1,111,111
A. Capital Cost	68,298,911
A.1/2. Project Planning and Engineering	4,240,525
A3. Construction	48,943,361
A.4/5. Electric infrastructure and others	15,115,025
B. Operating Costs	6,872,547
C. Maintenance Costs	1,117,550
D. Renewal Costs	26,275
E. Disposal Costs	-9,217
F. User costs	0
TOTAL PRESENT VALUES	**77,417,177**

Number of years of analysis.	**20**
Total Costs / Number of years of analysis.	**4,719,335 €**
Discount rate	**4.0%**
Present Value Total Costs / Number of years of analysis.	**3,870,859 €**

SAET (SCENARIO 1, Low Demand-2030, New Road, e-Corridor)	
REAL VALUES	
0. R+D (E-Roads)	1,111,111 €
A. Capital Cost	84,005,528 €
A.1/2. Project Planning and Engineering	4,206,505 €
A3. Construction	60,732,952 €
A.4/5. Electric infrastructure and others	19,066,070 €
B. Operating Costs	9,340,524 €
C. Maintenance Costs	1,665,744 €
D. Renewal Costs	38,400 €
E. Disposal Costs	5,372 €
F. User costs	0 €
TOTAL REAL VALUES	**96,166,679 €**
PRESENT VALUES	
0. R+D (E-Roads)	1,111,111
A. Capital Cost	70,103,881
A.1/2. Project Planning and Engineering	4,206,505
A3. Construction	49,083,694
A.4/5. Electric infrastructure and others	16,813,682
B. Operating Costs	6,369,498
C. Maintenance Costs	1,131,900
D. Renewal Costs	26,275
E. Disposal Costs	2,452
F. User costs	0
TOTAL PRESENT VALUES	**78,745,118**

Number of years of analysis.	**20**
Total Costs / Number of years of analysis.	**4,808,334 €**
Discount rate	**4.0%**
Present Value Total Costs / Number of years of analysis.	**3,937,256 €**

Table 40. Comparison of LCCA analysis between POLITO and SAET (Scenario 2050, e-Road)

POLITO (SCENARIO 2, High demand-2050, e-Road reconstructed)	
REAL VALUES	
0. R+D (E-Roads)	292,398 €
A. Capital Cost	56,671,596 €
A.1/2. Project Planning and Engineering	1,989,153 €
A3. Construction	39,609,485 €
A.4/5. Electric infrastructure and others	15,072,958 €
B. Operating Costs	10,080,828 €
C. Maintenance Costs	1,644,626 €
D. Renewal Costs	38,400 €
E. Disposal Costs	5,508,756 €
F. User costs	10,796,797 €
TOTAL REAL VALUES	**85,033,400 €**
PRESENT VALUES	
0. R+D (E-Roads)	292,398
A. Capital Cost	46,905,974
A.1/2. Project Planning and Engineering	1,989,153
A3. Construction	31,402,003
A.4/5. Electric infrastructure and others	13,514,818
B. Operating Costs	6,872,547
C. Maintenance Costs	1,117,550
D. Renewal Costs	26,275
E. Disposal Costs	2,514,124
F. User costs	10,796,797
TOTAL PRESENT VALUES	**68,525,665**

Number of years of analysis.	**20**
Total Costs / Number of years of analysis.	**4,251,670 €**
Discount rate	**4.0%**
Present Value Total Costs / Number of years of analysis.	**3,426,283 €**

SAET (SCENARIO 2, High demand-2050, e-Road reconstructed)	
REAL VALUES	
0. R+D (E-Roads)	220,588 €
A. Capital Cost	60,705,589 €
A.1/2. Project Planning and Engineering	1,993,236 €
A3. Construction	39,679,299 €
A.4/5. Electric infrastructure and others	19,033,053 €
B. Operating Costs	9,340,524 €
C. Maintenance Costs	1,665,744 €
D. Renewal Costs	38,400 €
E. Disposal Costs	5,534,324 €
F. User costs	10,818,966 €
TOTAL REAL VALUES	**88,324,135 €**
PRESENT VALUES	
0. R+D (E-Roads)	220,588
A. Capital Cost	50,235,280
A.1/2. Project Planning and Engineering	1,993,236
A3. Construction	31,458,095
A.4/5. Electric infrastructure and others	16,783,949
B. Operating Costs	6,369,498
C. Maintenance Costs	1,131,900
D. Renewal Costs	26,275
E. Disposal Costs	2,525,793
F. User costs	10,818,966
TOTAL REAL VALUES	**71,328,301**

Number of years of analysis.	**20**
Total Costs / Number of years of analysis.	**4,416,207 €**
Discount rate	**4.0%**
Present Value Total Costs / Number of years of analysis.	**3,566,415 €**

LCCA results for SAET in the two considered scenarios are shown in the figure below.

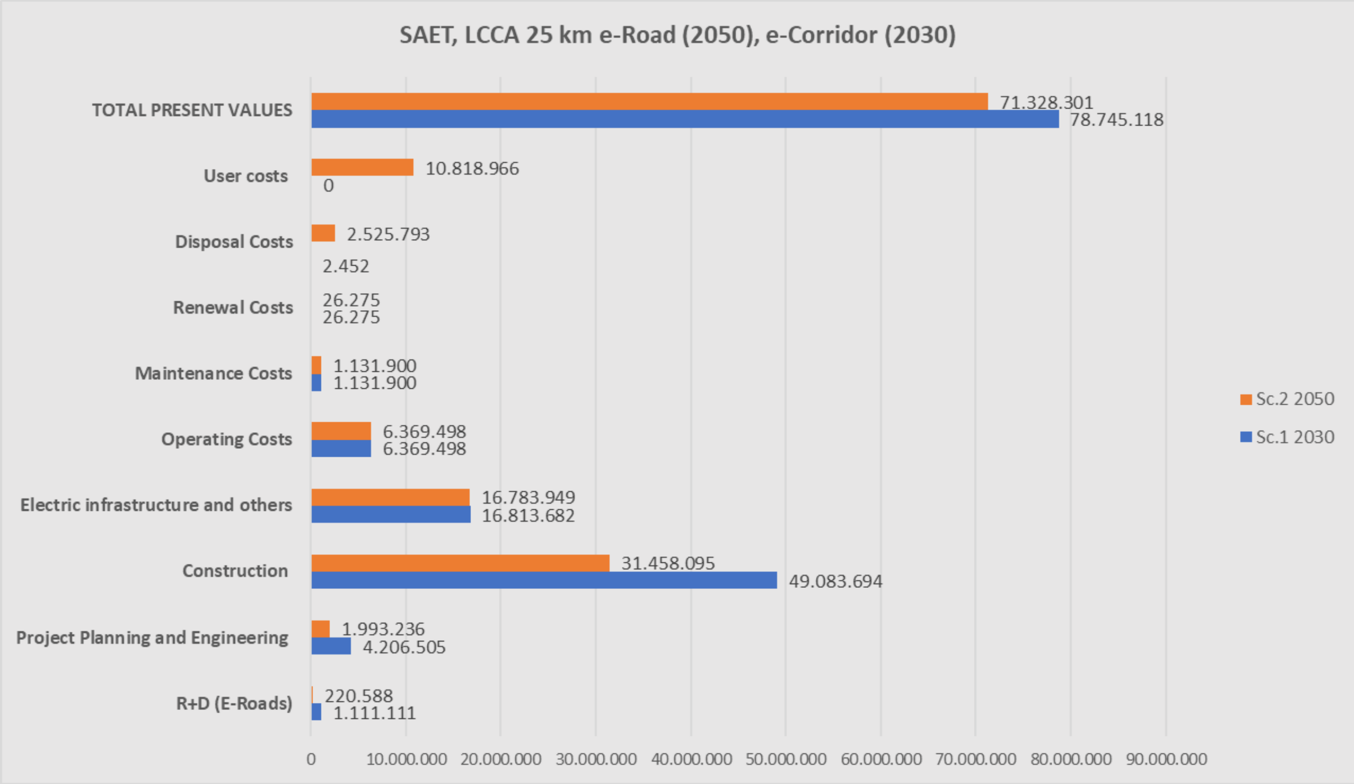


Figure 26. SAET LCCA, comparison of Scenario 2030 (e-Corridor) and Scenario 2050 (e-Road).

The annualized costs also depicted below for both scenarios.

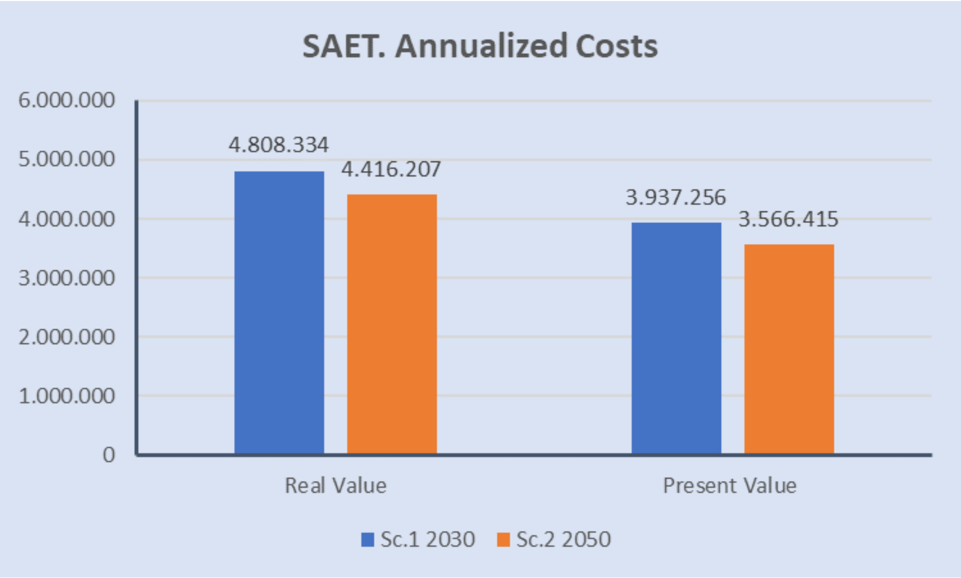


Figure 27. Annualized Costs (SAET, Scenarios 2030 and 2050)

3.9.2 Peri-urban Scenario

The Peri-urban scenario is an adaptation of the motorway scenario. It is addressed to e-trucks, e-buses and/or e-duty vans in the surroundings of bigger cities to enlarge the autonomy of these e-commercial vehicles covering distances between 200 to 250 km per day. This type of vehicles travel this distance on a daily basis for the distribution of goods, parcels, etc, between the logistic centres, ports or Peri-urban warehouses and the city centre. These e-Corridors (called hereinafter e-launchers) would be reserved to this type of vehicles exclusively through pre-established contracts that guarantee a critical mass of vehicles circulating daily throughout them. These vehicles cross the same Peri-urban road many times a day in their daily distribution and they must optimise their autonomy and reduce time losses in the charging process. Conventional EVs will charge at home or in the offices covering their daily autonomy needs, so they will probably not use these expensive chargers (in comparison).

In the next table, assumptions for the Peri-urban scenario compared with the motorway scenario are summarised. In the Peri-urban, we have considered 100 kW power transfer as the most likely for this type of heavy vehicles although any increase in the power transfer shall enlarge the autonomy in the dynamic charging process. The average speed has been reduced to 80 km/h compared with the motorway scenario for light vehicles (100 km/h). The range extension for e-trucks assuming 0.75 kWh/km at 100 kW power transfer is limited to 17 km. For e-vans and conventional e-buses with 0.60 kWh/km average consumption (more for buses and less for vans), the autonomy extension is 21 km, which can be considered an acceptable figure if for instance, these vehicles take the e-corridor twice a day reaching an autonomy extension of 42 km/day – approximately 1/8 of the expected average daily autonomy for these vehicles in 2030. These e-launchers will have a smaller extension than e-corridors of the highway scenario. It has been considered 10 km since the available space near the cities is very limited. We consider that the option of an external dedicated e-Launcher could be more realistic that using a conventional lane, as the user costs during the construction might be, in that case, incredible high as close to city motorways are very crowded.

Table 41. Main assumptions for the Peri-urban Scenario and Motorway Scenario.

COMPARISON SCENARIOS	PERIURBAN	UNITS	MOTORWAY	UNITS
km e-Corridor (e-launchers)	10	km	25	km
Safety distance (s)	2	s	2	s
Driving cycle: Constant highway speed (km/h)	80	km/h	100	km/h
Number of vehicles per day (approx.)	3,600	units	12,000	units
Traffic profile: max/avg ratio	4	units	3	units
Max. number of vehicles per km (safety rule)	17	Veh/km	17	Veh/km
Max. number of vehicles per km (according traffic)	8	Veh/km	15	Veh/km
Max. number of vehicles per e-corridor	188	Veh/e-cor	375	Veh/e-cor
Time to cross the e-corridor	0.13	h	0.25	h
Max. hourly traffic (veh/h)	600	Veh/h	1500	Veh/h
Heavy Vehicles / Total vehicles (in %)	100%	%	12%	%
Dynamic Power transfer (kW)	100	kW	50	kW
Total POWER required for the e-corridor	23.4	MW/e-cor	23.4	MW/e-cor
Energy recharged in the e-corridor				
One vehicle (kWh)	12.5	kWh/veh	12.5	kWh/veh
Total on average day (MWh)	45	MWh/day	150	MWh/day
Range extension (km)				
e-Trucks (assuming 0.75 kWh/km)	17	km	17	km
e-Vans and e-buses (assuming 0.60 kWh/km)	21	km	21	km
e-light Veh. Standard (assuming 0.15 kWh/km)			83	km
e-light Veh Highway (assuming 0.25 kWh/km)			50	km
Number of coils in the e-corridor	5,000	coils	12,500	coils
Number of LV transformers per e-corridor	25	LV units	25	LV units
Nominal power per LV transformer (MVA)	1.0	MVA	1.0	MVA
Number of HV/MV transformers	1	HV-MV Trafo	1	HV-MV Trafo
Nominal power per MV transformer (MVA)	25	MVA/MV Trafo	25	MVA/MV Trafo

In the motorway scenario 88% of vehicles are light vehicles and 12% heavy. With an AADT of 12,000 vehicles per lane and direction and considering a safety distance of 2 sg (around 60 m between consecutive vehicles), in 25 km of e-Corridor, only 375 vehicles can charge simultaneously. The power transfer in such corridors will be 50 kW for all types of vehicles as light vehicles due to space restrictions may not accept such power transfer on board (at least in the short term), so also trucks and buses charge at that power transfer with 80% efficiency. With these figures, the e-Corridors of this type will need no more than 25 MW of power. However, any reduction on the safety distance, due to the autonomous driving that allows less distance for reaction, shall increase the number of vehicles charging at same time and consequently, the total power required to feed the installation.

In the Peri-urban scenario, we consider that the power transfer will be 100 kW, as trucks, buses and intermediate vehicles with more than 3.500 kg tare and more space available, may accept such power transfer. The routes where the e-Launchers will be installed are those with a bigger percentage of heavy traffic (30%) close to logistic centres, ports, etc. In this scenario the maximum number of heavy vehicles charging at same time will be 188 and the total power required the same than in the motorway scenario.

We include also in the previous table, the range extension of the different vehicles crossing the e-Launchers and the e-Corridors according to their average consumption. It is important to mention that these e-Launchers will be likely used more than one time on the daily route.

In the next table, an exercise has been performed to adapt the LCCA costs of the Scenario 2030 (e-Corridor) to the Peri-urban one (10 km e-Launcher). The architecture of these Peri-urban e-launchers is similar to the motorway one. We have made the adaptation using the POLITO technology as the figures are close to those from SAET.

Most of the Peri-urban LCCA cost items will be reduced proportional to the e-corridor (25 km /10 km) except for the power supply which is similar in both cases. This is because the Peri-urban scenario with less traffic (3,600 vehicles instead of 12,000) needs, by the contrary, more power due to the heavy vehicles higher power requirements.

The column marked with a red square represents the cost assumptions for the e-Launcher. The right column is the comparable figures for the motorway. The power supply as explained before keeps constant and identical in both cases.

Table 42. Breakdown of Investment costs (e-launcher / e-Corridor, Scenario 2030, POLITO)

SCENARIO 1. POLITO Sol 1 Dedicated New e-LAUNCHER Low demand, 2.030. 50kW Power transfer										
(Calculation for 1 e-corridor 25 km length, 50 kW Power transfer)									10	25
0. PRELIMINARY R+D		**R&D Inv**	**Nº Units**			**Nº E-corr**	**km E-cor**	**Cost /1 km**	**Cost /10 km**	**Cost /25 km**
0.1. R+D on road works	VEDE	5,000,000 €	4	Devlpers		120	1,350	14,815 €	148,148 €	370,370 €
0.2. R+D on electric components design	VEDE	5,000,000 €	4	Devlpers				14,815 €	148,148 €	370,370 €
0.3 Future Research needs	VEDE	5,000,000 €	4	Devlpers				14,815 €	148,148 €	370,370 €
TOTAL PRELIMINARY R+D		60,000,000						44,444 €	444,444 €	1,111,111 €
	SOURCE	**TYPE**	**Nº units**	**Unit**	**Cost/unit 2017**	**Cost/unit 2030**	**Unit**	**Cost /1 km**	**Cost /10 km**	**Cost /25 km**
1. DESIGN AND ENGINEERING (ROAD RECONSTRUCTION)										
1.1. Planning and Design	QiE	Labour			1,174,132	1,174,132		117,413 €	1,174,132 €	2,578,176 €
1.2. Project management	QiE	Labour			379,439	379,439		37,944 €	379,439 €	948,597 €
1.3 Property	QiE	assets	25	acres	15,000	15,000	€/acre	0 €	0 €	0 €
1.4 Environmental analysis	QiE	Labour						28,550 €	285,501 €	713,752 €
TOTAL DESIGN AND ENGINEERING								183,907 €	1,839,072 €	4,240,525 €
2. INFRASTRUCTURE EXPENDITURE (E-CORRIDOR CONSTRUCTION)										
2.1 e-Corridor construction costs (pavement, All concepts)	**POLITO**	**All**			**380,668**	**380,668**		**380,668 €**	**9,516,689 €**	**23,791,723 €**
TOTAL Construction Costs								**380,668 €**	**9,516,689 €**	**23,791,723 €**
2.2 Electric Infrastruture		**CALCULATION FOR 1 KM ROAD**			**2,017**	**2,030**	**year**	**Cost /1 km**	**Cost /25 km**	**Cost /25 km**
221 Power Supply (HV/MV, Trafo 25 MVA)	INGETEAM		**1**	**units**	**11,000**	**11,000**	**€/unit**	**27,500 €**	**275,000 €**	**275,000 €**
222 Power Supply (MV/LV, Trafo 1MVA, rectifier 400V AC to 650V DC)					**128,700**	**90,090**	**€/unit**	**90,090 €**	**2,252,250 €**	**2,252,250 €**
2211 Main Transformer (MV/DC, 1 MVA)	INGETEAM	Equipment	1	units	38,000	26,600	€/unit	26,600 €	665,000 €	665,000 €
2212 Power metering	POLIMI	Consumable	1	units	600	420	€/unit	420 €	10,500 €	10,500 €
2213 Protection and shunting circuits	POLITO	Consumable	1	units	100	70	€/unit	70 €	1,750 €	1,750 €
2214 AC/DC Converter (400V AC to 650V DC)	POLITO	Equipment	1	units	90,000	63,000	€/unit	63,000 €	1,575,000 €	1,575,000 €
223 Distribution Shelter								**85,552 €**	**855,520 €**	**2,138,800 €**
2231 Shelter	TECNO	Equipment	10	units	2,036	1,425	€/unit	14,252 €	142,520 €	356,300 €
2232 Super-capacitors box	POLITO	Equipment	10	units	5,000	3,500	€/unit	35,000 €	350,000 €	875,000 €
2233 Control Power Supply	POLITO	Equipment	10	units	80	80	€/unit	800 €	8,000 €	20,000 €
2234 SBRio PE boxes management unit	POLITO	Equipment	10	units	100	50	€/unit	500 €	5,000 €	12,500 €
2235 Vehicule Communication unit	CRF	Equipment	10	units	1,000	700	€/unit	7,000 €	70,000 €	175,000 €
2236 CSCU	TUB	Equipment	10	units	4,000	2,800	€/unit	28,000 €	280,000 €	700,000 €
224 Power Electronics (DC/HF)								**95,000 €**	**950,000 €**	**2,375,000 €**
2241 Power Electronics board	POLITO	Equipment	500	coils	143	100	€/coil	50,000 €	500,000 €	1,250,000 €
2242 Active Bridge	POLITO	Equipment	500	coils	86	60	€/coil	30,000 €	300,000 €	750,000 €
2243 Housing	POLITO	Equipment	500	coils	29	20	€/coil	10,000 €	100,000 €	250,000 €
2244 Connectors	POLITO	Consumable	500	coils	14	10	€/coil	5,000 €	50,000 €	125,000 €
225 Coil, Cabling and Capacitors								**105,000 €**	**1,050,000 €**	**2,625,000 €**
2251 Coil	POLITO	Equip/Lab	500	coils	400	200	€/coil	100,000 €	1,000,000 €	2,500,000 €
2252 Connectors	POLITO	Consumable	500	coils	2	2.0	€/coil	1,000 €	10,000 €	25,000 €
2253 Capacitors	POLITO	Equipment	500	coils	11	8	€/coil	4,000 €	40,000 €	100,000 €
226 Distribution lines								**51,250 €**	**512,500 €**	**1,281,250 €**
2261 Manholes (Plastic box - 55x55cm)	QIE	Consumable	250	boxes	50	35	€/2 coils	8,750 €	87,500 €	218,750 €
2262 Distribution Pipes	QIE	Consumable	50,000	m	0.10	0.10	€/m	5,000 €	50,000 €	125,000 €
2263 650VDC Distribution cables with connectors	QIE	Consumable	50,000	m	0.25	0.25	€/m	12,500 €	125,000 €	312,500 €
2264 Signal communication cables and connectors	QIE	Consumable	50,000	m	0.30	0.30	€/m	15,000 €	150,000 €	375,000 €
2265 Signal power supply cables and connectors	QIE	Consumable	50,000	m	0.20	0.20	€/m	10,000 €	100,000 €	250,000 €
227 Monitoring								**12,432 €**	**310,800 €**	**312,060 €**
2271 Optical Fiber	QIE	Consumable	17,472	m	0.70	0.49	€/m	12,230 €	305,760 €	305,760 €
2272 Surface sensors (4/km)	QIE	Consumable	4	units	30	21	€/unit	34 €	840 €	2,100 €
2273 Data Processing Unit	QiE	Computer	2	units	3,000	2,100	€/unit	168 €	4,200 €	4,200 €
228 Labour & Outsourcing (Vehicles Rental)								**7,109 €**	**191,255 €**	**191,255 €**
2281 Labour (Electric)	QIE	Labour	20	month-h	2,750.00	2,750.00	€/month	4,406 €	110,147 €	110,147 €
2282 Outsourcing	QIE	HV Rental	15	veh	90.00	90.00	€/day	2,704 €	81,108 €	81,108 €
TOTAL Electric Infrastructure								**473,933 €**	**6,397,325 €**	**11,450,615 €**
TOTAL INFRASTRUCTURE EXPENDITURE								854,601 €	15,914,014 €	35,242,338 €
TOTAL CAPEX								1,038,508 €	17,753,086 €	39,482,863 €

In the next table, we compare the O&M cost from the e-Launcher to an e-Corridor applying the same procedure.

Table 43. Breakdown of costs (O&M) of e-Launcher compared to an e-Corridor

PERIURBAN SCENARIO. POLITO Sol 1 Dedicated New e-LAUNCHER Low demand, 2.030. 50kW Power transfer, OPEX											
3.	OPERATION E-LAUNCHER SCENARIO 1					10 km	25 km		1 year 10 km	20 years 10 km	20 years 25 km
3.1.	**Labor**								**243,000 €**	**4,860,000 €**	**8,100,000 €**
311	Head of service (24 h)	QiE	Labour	1.8	units/y	30,000	30,000	€/year	54,000 €	1,080,000 €	1,800,000 €
312	Traffic management labour (24 h)	QiE	Labour	3.0	units/y	18,000	18,000	€/year	54,000 €	1,080,000 €	1,800,000 €
313	Metering and billing administration (24 h)	QiE	Labour	3.0	units/y	25,000	25,000	€/year	75,000 €	1,500,000 €	2,500,000 €
314	Customer service (24 h)	QiE	Labour	3.0	units/y	20,000	20,000	€/year	60,000 €	1,200,000 €	2,000,000 €
3.2.	**Consumables**								**36,000 €**	**720,000 €**	**720,000 €**
321	Advertising and marketing	QiE	Consumable	1.0	un.	20,000	20,000	€/year	20,000 €	240,000 €	400,000 €
322	Software and data bases	QiE	Consumable	1.0	un.	16,000	16,000	€/year	16,000 €	300,000 €	320,000 €
3.3	**Equipments**					**81,000**	**64,800**		**64,800 €**	**239,760 €**	**239,760 €**
331	Billing Equipment	QiE	Equipment	1.0	un.	30,000	24,000	€	24,000 €	88,800 €	88,800 €
332	IT Equipment	QiE	Equipment	1.0	un.	18,000	14,400	€	14,400 €	53,280 €	53,280 €
333	Communication Equipment	QiE	Equipment	1.0	un.	18,000	14,400	€	14,400 €	53,280 €	53,280 €
334	Traffic management equipment	QiE	Equipment	1.0	un.	15,000	12,000	€	12,000 €	44,400 €	44,400 €
3.4	**Overtime and outsource**								**29,340 €**	**586,800 €**	**910,800 €**
341	Labour overtime (% Labour costs)	POLIMI	Labour	5.0%	Labour	12,150	20,250	€/year	12,150 €	243,000 €	405,000 €
342	Outsource (external services) (% Direct Costs)	POLIMI	External	5.0%	Direct Cc	17,190	25,290	€/year	17,190 €	343,800 €	505,800 €
3.4	**Other operating costs**								**3,731 €**	**74,628 €**	**110,268 €**
341	Other operating costs (% of direct costs)	POLIMI	Consumable	1.0%	)irect Cos	3,731	5,513	€/year	3,731 €	74,628 €	110,268 €
	TOTAL OPERATION								**376,871 €**	**6,481,188 €**	**10,080,828 €**
4.	MAINTENANCE OF E-CORRIDOR (ADDED MAINTENANCE OVER A CONVENTIONAL ROAD)								1 year 10 km	20 years 10 km	20 years 25 km
4.1.	**Preventive maintenance**								**38,904 €**	**778,089 €**	**1,296,815 €**
411	DWPT system inspection and testing	POLIMI	Labour	365	days		150	€/day	32,850 €	657,000 €	1,095,000 €
412	Small Repairs (2% Equipment/Consumable)	QIE	Equip/Consum				10,091	€/year	6,054 €	121,089 €	201,815 €
4.2.	**Corrective maintenance**								**13,359 €**	**267,176 €**	**374,657 €**
421	DWTP System unplanned repairs (25% Prevent. Maint.)	POLIMI	Equip/Cons/lab	1	per year		9,726	€/year	9,726 €	194,522 €	324,204 €
422	Small Repairs (25% of Repairs Preventive Maintenance)	QIE	Equip/Consum				2,523	€/year	3,633 €	72,653 €	50,454 €
	TOTAL MAINTENANCE								**52,263 €**	**1,045,265 €**	**1,671,472 €**
5.	RENEWAL COSTS OF E-CORRIDOR (ADDED RENEWED ASSETS IN THE E-CORRIDOR)								Initial CAPEX	Rest CAPEX (20 y)	Rest CAPEX (20 y)
	ELECTRIC EQUIPMENT RENEWAL										
5.1.	**Major electric equipment repairs**										
511	Power Supply (HV/MV, Trafo 25 MVA)	QIE							275,000 €	0 €	0 €
512	Power Supply (MV/LV, Trafo 1MVA, rectifier 400V AC to 6	QIE							2,252,250 €	0 €	0 €
513	Distribution Shelter	QIE							855,520 €	0 €	0 €
514	Power Electronics (DC/HF)	QIE	Cost reduction		10%	100%	Substituted		950,000 €	855,000 €	2,137,500 €
515	Coil, Cabling and Capacitors	QIE	Cost copper increased		5%	30%	Deteriorated		1,050,000 €	330,750 €	826,875 €
516	Distribution lines	QIE							512,500 €	0 €	0 €
517	Monitoring	QIE	Cost reduction		5%	Every five years			310,800 €	839,160 €	842,562 €
518	Labour & Outsourcing (Vehicles Rental)	QIE							191,255 €	62,402 €	64,666 €
	TOTAL MAJOR ELECTRIC REPAIRS								**6,397,325 €**	**2,087,312 €**	**3,871,603 €**
	PAVEMENT RENEWAL										
5.2.	**T-Road preventive Rehabilitation (years 5 and 15)**								**4,324,320 €**	**7,783,776 €**	**19,459,440 €**
521	Asphalt wear (years 5 and 15)	QIE							4,324,320 €	7,783,776 €	19,459,440 €
5.3	**E-Road Rehabilitation (year 10)**								**14,195,989 €**	**12,776,390 €**	**17,346,396 €**
531	Bituminous coating (emulsion and sealing)	QIE							2,331 €	2,098 €	5,245 €
532	Asphalt wear and binder	QIE							14,123,098 €	12,710,788 €	17,182,391 €
533	Concrete binder (area of coils)	QIE							70,560 €	63,504 €	158,760 €
	TOTAL PAVEMENT RENEWAL									**20,560,166 €**	**36,805,836 €**
	TOTAL MAJOR PAVEMENT REFURBISHMENT									**20,560,166 €**	**36,805,836 €**
5.4	**Refurbishment in major repairs**										
541	Repainting road surface and signs	QIE	Consumable, vehicle leasing and labour						**7,680 €**	**23,040 €**	**38,400 €**
			(years 5,10,15)	16	h	3	800	€/h	7,680 €	23,040 €	38,400 €
	TOTAL PAVEMENT REFURBISMENT									**23,040 €**	**38,400 €**
6.	DISPOSAL COSTS										
6.1.	**Cost of assets disposal**										
611	Removal of asphalt wear and take our coils	QIE							432,432 €	345,946 €	864,864 €
6.2.	**Residual value**									**354,024 €**	**885,060 €**
621	Copper recovery	QiE	Consumable	5.50	€/kg		64,368	kg		354,024 €	885,060 €
	TOTAL COPPER RECOVERED									**354,024 €**	**885,060 €**

The results of this e-Launcher (10 km) are compared with the e-Corridor (25 km length).

Table 44. Comparison Present Values Scenario 1, e-Launcher (10 km) / e-Corridor (25 km)

PRESENT VALUES POLITO, 2030	Sc.1 e-Launcher	Sc.1 e-Corridor
R+D (E-Roads)	444,444	1,111,111
Project Planning and Engineering	1,839,072	4,240,525
Construction	23,521,175	48,943,361
Electric infrastructure and others	13,652,988	15,115,025
Operating Costs	4,426,533	6,872,547
Maintenance Costs	710,274	1,117,550
Renewal Costs	15,765	26,275
Disposal Costs	-3,687	-9,217
User costs	0	0
TOTAL PRESENT VALUES	**44,606,564**	**77,417,177**
TOTAL PRESENT VALUES/km	**4,460,656**	**3,096,687**
ANNUALIZED COST (20 years lifetime)	**Sc.1 e-Launcher**	**Sc.1 e-Corridor**
Real Value	2,752,954	4,719,335
Present Value	2,230,328	3,870,859

In absolute values the e-Launchers are cheaper as they are 10 km length instead of 25, but by km the cost is increased 45% over the e-Corridors.

A comparative table is depicted below for e-Corridors and e-Launchers.

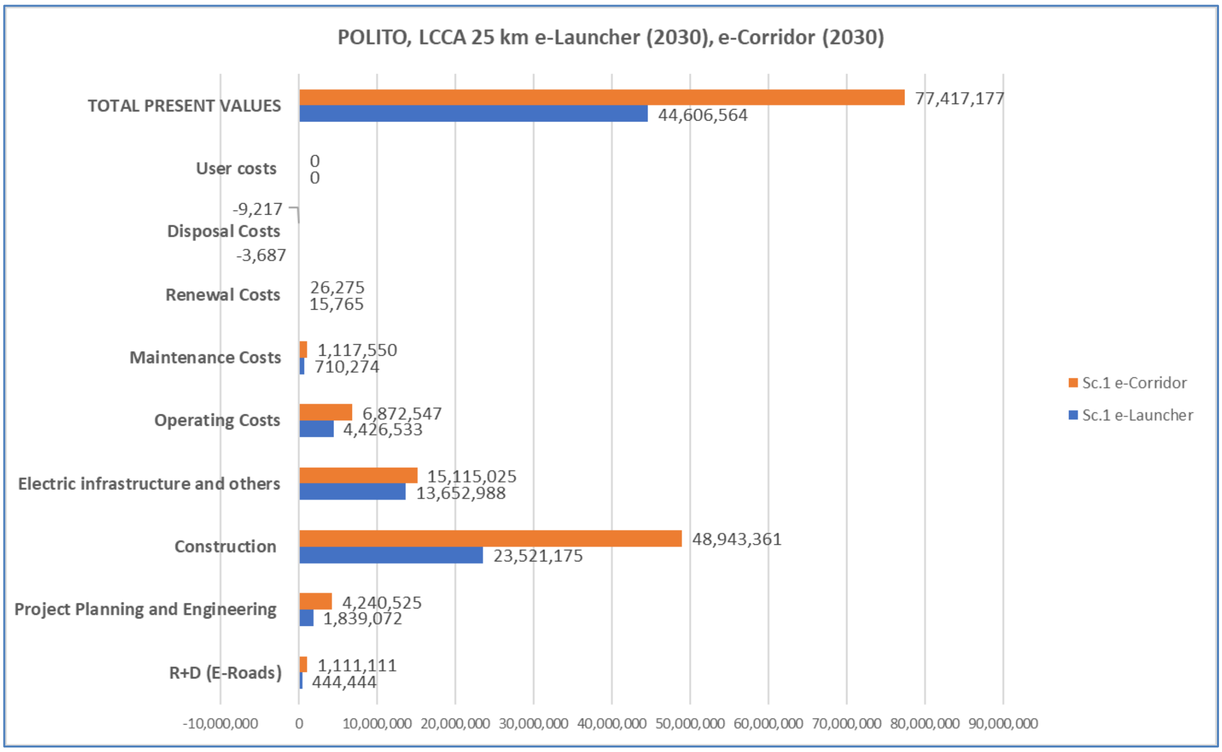


Figure 28. Breakdown of cost. Comparison e-Launcher /e-Corridor (2030)

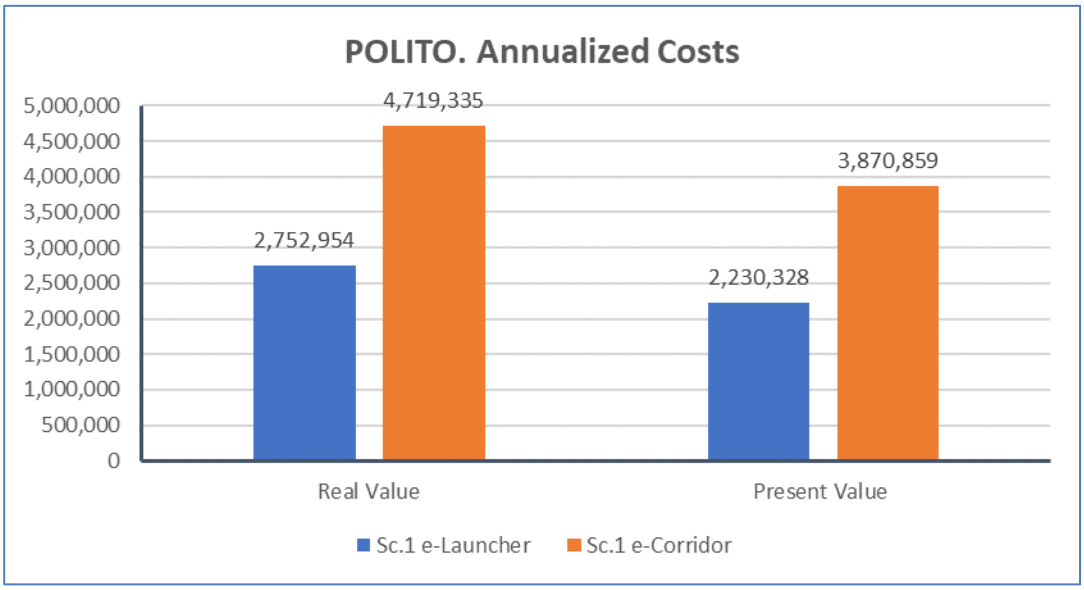


Figure 29. Annualized Cost (e-Launcher / e-Corridor)

Although 10 km length compared to 25 km represents the 40%, in economic terms, the e-Launcher is quite more expensive. Its cost represents the 57% of the cost of an e-Corridor. This is due to two main factors; the need to keep a similar power supply as the e-Trucks and e-Buses consumption is higher and the need to keep some fix costs for the operation and maintenance in the e-Launcher (so, there is not a direct proportional reduction on this concept because a basic structure is required).

3.9.3 Urban Scenario (e-buses)

The urban scenario has been defined in D5.4.1. This scenario considers the transformation of the whole public bus fleet of a city to electric and the incorporation of stationary and dynamic charging solutions in the whole fleet. Simulations in D5.4.1 have shown that no continuous dynamic corridor is needed, but some stationary charging at bus stops (10 m) plus a short dynamic track adding 15 m more to increase the charging capability. The concept is that the bus starts the route with the full storage and charging in every stop and during the small dynamic trenches, complete the whole daily trips (18 round trips) without the need of additional intermediate stationary charging at the garage. At night, the bus is recharged to its full capacity at the garage. This way, most of the

energy consumption for recharging is transferred to daylight hours, which facilitates direct consumption of solar power from the grid.

This scenario presents some advantages:

i) The users and the amortization of the infrastructure are known, permitting an easier business model analysis.
ii) Periodic charging where bus stops allows to reduce the battery size dramatically, modifying the conceptual approach to the model. Instead of a range extender, we reduce in this case the battery size, maintaining the same service to the public.
iii) Dedicated lanes for buses inside the city are already in place so it is not necessary to build new lanes.
iv) There will be some traffic affectation during the works but after them, the environmental advantages will flourish with the significant reduction of pollutants inside the city where the environmental problem is more acute.
v) Public authorities will be able to give example to the citizenship as early adopters promoting clean technologies.
vi) Recharging during daylight hours enables direct use of solar power present in the grid

Fundamental data and assumptions used in this scenario come from the EU Unplugged project, which investigated how the use of inductive charging of Electric Vehicles (EV) in urban environments improved the convenience and sustainability of car-based mobility.

To allow an easy comparison with the rest of scenarios, in D5.4.1 a practical exercise was done considering an average city with a population of around 700.000 inhabitants. This city might have 40 bus lines with 400 buses and an average length of the daily route of 9 km each. Every bus makes 18 round trips per day with a duration between of 1 h per round trip. This scenario can also be applied to larger cities, just increasing the number of routes, but maintaining the ration of 10 buses/route and 9 km/route. The bus consumption reaches 2 kWh/km. We must indicate that from our own market research, we found less energy consumption in some buses and trucks (below 1 kWh/km, according to the OEM's advertisements. UNPLUGGED data was taken from first-generation e-buses. In the

VICTORIA project, the small urban bus had already a consumption of 0.5 kWh/km. Therefore, declarations of consumption levels below 1 kWh per km should be treated with care.

Matlab/Octave programming was employed to do the calculations, in order to achieve a combination of the regenerative braking energy recovery and the complex driving cycles (SORT driving cycle was considered). Some of the results are presented hereinafter, while for further details please refer to deliverable D5.4.1.

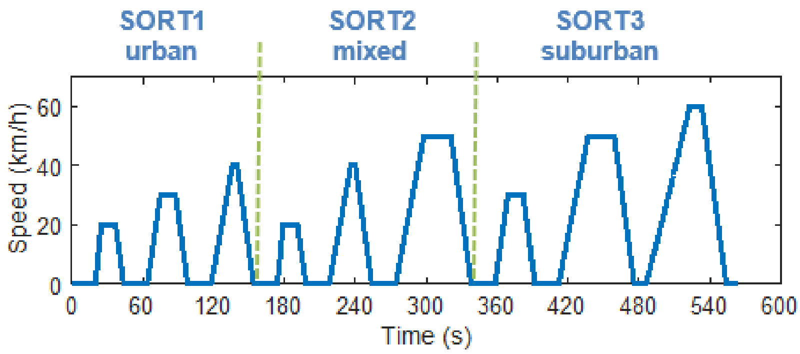


Figure 30: SORT cycle considered in UNPLUGGED project.

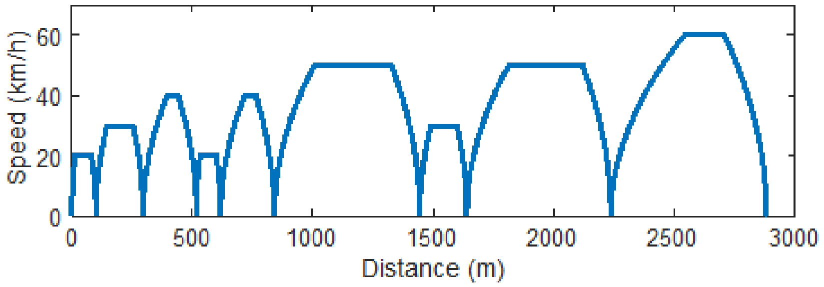


Figure 31: SORT cycle expressed in distance vs. speed.

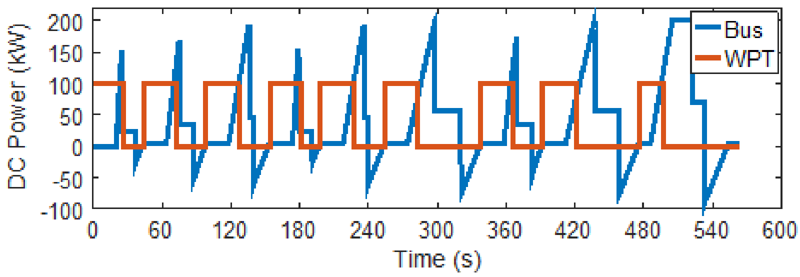


Figure 32: DC power at vehicle for 7700 Volvo Bus (Source: UNPLUGGED D3.2) and 25-m WPT tracks at each stop, recharging at 100 kW.

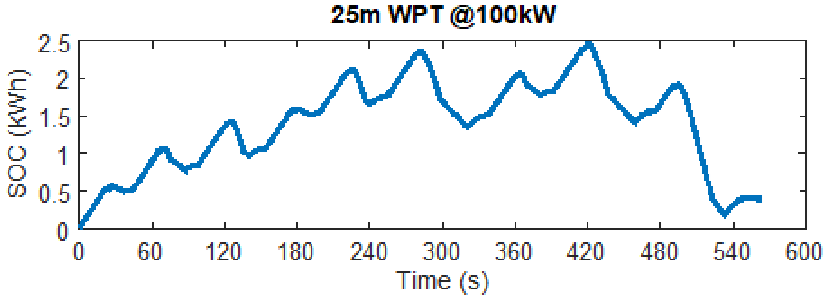


Figure 33: State of charge of vehicle battery assuming 100-kW recharge at each stop and 25 m of dynamic track and 90% battery efficiency.

The market information we gathered in relation to the most recent heavy e-vehicles is summarised below. This data will be used in the final deliverables to analyse the future business models related to the dynamic charging technology.

Table 45. Preliminary market information in relation to e-heavy vehicles (various sources not necessarily reliable from internet).

Market e-Buses				Market e-Trucks		
Hyunday Elec-city				**Tesla e-truck**		
	Length	12	m	Engine	760	kW
	Engine	240	kW	Capacity	625	kWh
	Capacity	256	kWh	Autonomy	500	km
	Autonomy	290	km	Consumption	1.25	kWh/km
	Consumption	0.88	kWh/km	Cost	210,000	€
Poterra Catalyst E2 series						
	Length	12	m	**Mitsubitsi E-Fuso Vision 1 Daimler**		
	Engine	377	kW	Engine	ND	kW
	Capacity	660	kWh	Capacity	300	kWh
	Autonomy	563	km	Autonomy	350	km
	Consumption	1.17	kWh/km	Consumption	0.86	kWh/km
Irizar Electric i2E						
	Length	12	m	ND. No data		
	Engine	180	kW			
	Capacity	376	kWh			
	Autonomy	200	km			
	Consumption	1.88	kWh/km			
BYD, New Flyer Electric Bus Utah Xcelsior						
	Length	18	m			
	Engine	160	kW			
	Capacity	818	kWh			
	Autonomy	418	km			
	Consumption	1.96	kWh/km			
Estandar urban bus Class I Diesel						
	Length	12	m			
	Engine	217.5	KW			
	Consuption	35	l Diesel/100 km			
	Cost urban bus	250,000	€			

Below, the main assumptions for the urban scenario are shown. Most data are related to each other, except for those in green colour that come from the Matlab/Octave simulation prepared by CIRCE/POLITO.

Table 46. Assumptions for the bus scenario. Example in a city with 700.000 inhabitants and 40 bus routes.

Urban Scenario, buses				
Number of buses	400			buses
Number of routes	40			routes
Driving cycle	SORT 1-1-2-2-3-3			
Average Daily route (km), 1 direction (half trip)	9			km
Number of stops per route	27			stops/route
Total number of stops	1,080			stops/city
Time for one route (round trip)	0.5 h (1 h)			
Service time (h) = nº of round trips	18			trips
Consumption bus on average	2			kWh/km
Energy required (one round trip)				
Per route / bus (kWh)	36.0			kWh
Fleet (MWh)	14.4			MWh
Energy required per day (18 h service)				
One bus (kWh)	648			kWh/bus
Fleet (MWh)	259.2			MWh/fleet
Dynamic and static Power transfer (kW)	50	100	150	kW
Total POWER required by fleet (MW) (32% simultaneously)	8	16	24	MW
Charging mode (from simulation in Otave)	Continuous	25 m at stop	10 m at stop	Matlab
km of e-corridor	360	27	11	km
Required on-board energy storage (kWh) (Matlab)	6	7.5	9	kWh
Required average charging time per stop (s)	48	24	16	s
Required charging time per bus and route (min)	21.6	10.8	7.2	min
Number of coils per route (2.5m/coil)	3600	270	108	coils/route
Total number of coils	144,000	10,800	4,320	total coils
Total number of MV/LV transformers	180x 315 kVA	180x 630 kVA	270x 630 kVA	Total Trafos
Total number of HV/MV transformers	1x 8 MVA	1x 16 MVA	1x 24 MVA	Total Trafos

After some common data, the table is divided in three columns, which demonstrates that assuming 2 kWh / km bus consumption (relatively high in our opinion, as we mentioned), with 50 kW power transfer capacity, the whole circuit (9 km per each of the 40 routes) shall require permanent dynamic charging considering a battery storage capacity of 6 kWh. But in case we assume 100 kW power transfer and 7.5 kWh storage capacity, 25 meters in and after the bus stops of static and dynamic charging will be enough to keep the fleet in operation. This is the base case that we will take as a reference in our LCCA. Finally,

assuming 150 kW power transfer and storage capacity of 9 kWh, the required e-trenches will be 10 m long at each bus stop (only static charging, in this case).

Table 47. Main differences between motorway scenario and bus scenario in economic terms to prepare the urban scenario LCCA.

Route type	**Urban buses**	**Data for the Economic calculation**	**Urban Scenario (100 kW)**			**Motorway Scenario (50 kW)**		
Number of buses	400	Total number of charging events/day	194,400	events/day	Assured	12,000	Events/day	Estimated
Number of routes	40	Energy transfered / Charging event	0.67	kWh		13	kWh	
Driving cycle	SORT 1-1-2-2-3-3	Total energy transfered /whole fleet/day	129,600	kWh		150,000	kWh	
Average Daily route (km)	9	Total energy at grid level /day	162,000	kWh		187,500	kWh	
Number of stops per route	27	Approximate Total Power required	16.0	MW		23.4	MW	
Total number of stops	1,080	Aproximate cost of energy /day	0.119	€/kWh	19,278 €	0.119	€/kWh	22,313 €
Time for one route (round trip)	0.5 h (1 h)	Cost of energy per year (grid level)			7,036,470 €			8,144,063 €
Service time (h) = nº of round trips	18							
Energy required (one round trip)		Nº of Trafo MV/LV	180	units	3,016,440 €	25	units	665,000 €
Per route / bus (kWh)	36.0	Power Trafo MV/LV	630	KVA	16,758 €	1	MVA	26,600 €
Fleet (MWh)	14.4							
Energy required per day (18 h service)		AC/DC Converter	180	units	39,690 €	25	units	63,000 €
One bus (kWh)	648	Total AC/DC Converter			7,144,200 €			1,575,000 €
Fleet (MWh)	259.2							
Dynamic and static Power transfer (kW)	100							
Total POWER required by fleet (MW)	16	Nº of Trafo HV/MV	1	units		1	units	
Charging mode	25 m at stop	Power Trafo HV/MV	16	MVA	176,000 €	25	MVA	275,000 €
km of e-corridor	27							
Required on-board energy storage (kWh)	7.5	Nº of coils, cabling and capacitors (POLITO)	13,500	units	2,835,000 €	12,500	units	2,625,000 €
Required average charging time per stop (s)	24							
Required charging time per bus and route (min)	10.8	Nº Km	24			25	km	
Number of coils per route (2m/coil)	337.5							
Total number of coils	13,500	User costs			11,660,541 €			10,796,797 €
Number of LV transformers per route		Construction costs /only reconstruction			No			Yes
Total number of MV/LV transformers	180x 630 kVA	Property costs			No			Yes

(Note. In green colour those relevant different data used as entry data for the Urban LCCA)

In the previous table, we showed the main differences between the motorway scenario and the urban scenario, in preparation of the specific LCCA elaboration. The total length of the dynamic charging area is quite similar although in the urban scenario we will find small trenches of dynamic charging (e-trenches).

The analysis for the urban scenario, reflects that it is significantly more expensive than the motorway scenario (e-Corridor); approximately 30%. The reason for this major difference can be found in the following considerations:

- Electrification of the network is quite more expensive as we need 180 trafos (MV/LV, 630 kVA) instead of 25 trafos (1 MW) in the case of the motorway.
- In the urban scenario, we will affect the remaining lanes during works generating important user costs.
- Most concepts will rise by a factor of 27/25 as the affected km is slightly higher in the urban example.

By the contrary some factors will be lower.

- The operation activities will be simplified as less personnel will be required; for instance, no customer service, or no need to make major marketing activities.
- The equipment for billing, IT, Communication and traffic management will be simplified as there a single and unique client; the bus public company.

We must also highlight that the beneficial effects of the electric buses will be clearly perceived by the citizens living in the cities where the pollution is more acute and this factor must be considered by the authorities when taking the investment decisions. Besides, the strategy with the e-buses is to reduce the battery size but keeping the daily service as it is with the conventional buses whilst the e-corridors strategy pretends to extend the autonomy keeping the battery size in favour of such extension.

The comparable breakdown table (motorway against urban scenario) is depicted below.

Table 48. Table comparing e-Corridor and e-Urban scenarios (2030, CAPEX)

COMPARABLE TABLE (E-CORRIDOR, URBAN SCENARIOS) 2.030.									E-CORRIDOR	URBAN
(Calculation for 1 e-corridor 25 km length, 50 kW Power transfer)									25	27
0. PRELIMINARY R+D		R&D Inv	Nº Units			Nº E-corr	km E-cor	Cost /1 km	Cost /25 km	Cost /27 km
0.1. R+D on road works	VEDE	5,000,000 €	4	Devlpers		120	1,350	14,815 €	370,370 €	400,000 €
0.2. R+D on electric components design	VEDE	5,000,000 €	4	Devlpers				14,815 €	370,370 €	400,000 €
0.3 Future Research needs	VEDE	5,000,000 €	4	Devlpers				14,815 €	370,370 €	400,000 €
TOTAL PRELIMINARY R+D		60,000,000						44,444 €	1,111,111 €	1,200,000 €
	SOURCE	TYPE	Nº units	Unit	Cost/unit 2017	Cost/unit 2030	Unit	Cost /1 km	Cost /25 km	Cost /27 km
1. DESIGN AND ENGINEERING (ROAD RECONSTRUCTION)										
1.1. Planning and Design	QiE	Labour			2,578,176	2,578,176		103,127 €	2,578,176 €	2,784,431 €
1.2. Project management	QiE	Labour			948,597	948,597		37,944 €	948,597 €	1,024,484 €
1.3 Property	QiE	assets	25	acres	15,000	15,000	€/acre	0 €	0 €	0 €
1.4 Environmental analysis	QiE	Labour						28,550 €	713,752 €	770,852 €
TOTAL DESIGN AND ENGINEERING								169,621 €	4,240,525 €	4,579,767 €
2. INFRASTRUCTURE EXPENDITURE (E-CORRIDOR CONSTRUCTION)										
2.1 e-Corridor construction costs (pavement, All concepts)	POLITO	All			951,669	951,669		951,669 €	23,791,723 €	25,695,061 €
TOTAL Construction Costs								951,669 €	23,791,723 €	25,695,061 €
2.2 Electric Infrastruture		CALCULATION FOR 1 KM ROAD			2,017	2,030	year	Cost /1 km	Cost /25 km	Cost /27 km
221 Power Supply (HV/MV, Trafo 25 MVA, Trafo 16 MVA)	INGETEAM		1	units	11,000	11,000	€/unit	11,000 €	275,000 €	176,000 €
222 Power Supply (MV/LV, Trafo 1MVA, rectifier 400V AC to 650V DC)					128,700	90,090	€/unit	90,090 €	2,252,250 €	10,248,840 €
2211 Main Transformer (MV/DC, 1 MVA, 25- 630 kVA, 180)	INGETEAM	Equipment	1	units	38,000	26,600	€/unit	26,600 €	665,000 €	3,016,440 €
2212 Power metering (25,180)	POLIMI	Consumable	1	units	600	420	€/unit	420 €	10,500 €	75,600 €
2213 Protection and shunting circuits (25,180)	POLITO	Consumable	1	units	100	70	€/unit	70 €	1,750 €	12,600 €
2214 AC/DC Converter (400V AC to 650V DC, 25, 180)	POLITO	Equipment	1	units	90,000	63,000	€/unit	63,000 €	1,575,000 €	7,144,200 €
223 Distribution Shelter								85,552 €	2,138,800 €	2,309,904 €
2231 Shelter	TECNO	Equipment	10	units	2,036	1,425	€/unit	14,252 €	356,300 €	384,804 €
2232 Super-capacitors box	POLITO	Equipment	10	units	5,000	3,500	€/unit	35,000 €	875,000 €	945,000 €
2233 Control Power Supply	POLITO	Equipment	10	units	80	80	€/unit	800 €	20,000 €	21,600 €
2234 SBRio PE boxes management unit	POLITO	Equipment	10	units	100	50	€/unit	500 €	12,500 €	13,500 €
2235 Vehicule Communication unit	CRF	Equipment	10	units	1,000	700	€/unit	7,000 €	175,000 €	189,000 €
2236 CSCU	TUB	Equipment	10	units	4,000	2,800	€/unit	28,000 €	700,000 €	756,000 €
224 Power Electronics (DC/HF)								95,000 €	2,375,000 €	2,565,000 €
2241 Power Electronics board	POLITO	Equipment	500	coils	143	100	€/coil	50,000 €	1,250,000 €	1,350,000 €
2242 Active Bridge	POLITO	Equipment	500	coils	86	60	€/coil	30,000 €	750,000 €	810,000 €
2243 Housing	POLITO	Equipment	500	coils	29	20	€/coil	10,000 €	250,000 €	270,000 €
2244 Connectors	POLITO	Consumable	500	coils	14	10	€/coil	5,000 €	125,000 €	135,000 €
225 Coil, Cabling and Capacitors								105,000 €	2,625,000 €	2,835,000 €
2251 Coil	POLITO	Equip/Lab	500	coils	400	200	€/coil	100,000 €	2,500,000 €	2,700,000 €
2252 Connectors	POLITO	Consumable	500	coils	2	2.0	€/coil	1,000 €	25,000 €	27,000 €
2253 Capacitors	POLITO	Equipment	500	coils	11	8	€/coil	4,000 €	100,000 €	108,000 €
226 Distribution lines								51,250 €	1,281,250 €	1,383,750 €
2261 Manholes (Plastic box - 55x55cm)	QIE	Consumable	250	boxes	50	35	€/2 coils	8,750 €	218,750 €	236,250 €
2262 Distribution Pipes	QIE	Consumable	50,000	m	0.10	0.10	€/m	5,000 €	125,000 €	135,000 €
2263 650VDC Distribution cables with connectors	QIE	Consumable	50,000	m	0.25	0.25	€/m	12,500 €	312,500 €	337,500 €
2264 Signal communication cables and connectors	QIE	Consumable	50,000	m	0.30	0.30	€/m	15,000 €	375,000 €	405,000 €
2265 Signal power supply cables and connectors	QIE	Consumable	50,000	m	0.20	0.20	€/m	10,000 €	250,000 €	270,000 €
227 Monitoring								12,482 €	312,060 €	337,025 €
2271 Optical Fiber	QIE	Consumable	17,472	m	0.70	0.49	€/m	12,230 €	305,760 €	330,221 €
2272 Surface sensors (4/km)	QIE	Consumable	4	units	30	21	€/unit	84 €	2,100 €	2,268 €
2273 Data Processing Unit	QiE	Computer	2	units	3,000	2,100	€/unit	168 €	4,200 €	4,536 €
228 Labour & Outsourcing (Vehicles Rental)								7,109 €	191,255 €	206,555 €
2281 Labour (Electric)	QIE	Labour	20	month-h	2,750.00	2,750.00	€/month	4,406 €	110,147 €	118,959 €
2282 Outsourcing	QIE	HV Rental	15	veh	90.00	90.00	€/day	2,704 €	81,108 €	87,597 €
TOTAL Electric Infrastructure								457,484 €	11,450,615 €	20,062,074 €
TOTAL INFRASTRUCTURE EXPENDITURE								1,409,153 €	35,242,338 €	45,757,135 €
TOTAL CAPEX								1,578,774 €	39,482,863 €	50,336,902 €

In red colour the column representing the urban scenario comparable with the motorway one (central column). The CAPEX for the urban scenario is almost 30% higher than the motorway scenario for just two additional km (27 over 25).

The second part of the table for the O&M activities is depicted below.

Table 49. Urban Scenario and a comparison with motorway scenario, in terms of O&M activities, pavement renewal and disposal costs.

COMPARABLE TABLE (E-CORRIDOR, URBAN SCENARIOS) 2.030. OPEX								E-CORRIDOR	E-CORRIDOR	URBAN	
3. OPERATION E-CORRIDOR, E-TRENCHES								**1 year**	**20 years**	**20 years**	Lifetime
3.1. Labor								**405,000 €**	**8,100,000 €**	**5,075,000 €**	
311 Head of service (24 h)	QiE	Labour	3	units/y	30,000	30,000	€/year	90,000 €	1,800,000 €	1,350,000 €	1
312 Traffic management labour (24 h)	QiE	Labour	5	units/y	18,000	18,000	€/year	90,000 €	1,800,000 €	1,350,000 €	1
313 Metering and billing administration (24 h)	QiE	Labour	5	units/y	25,000	25,000	€/year	125,000 €	2,500,000 €	1,875,000 €	1
314 Customer service (24 h)	QiE	Labour	5	units/y	20,000	20,000	€/year	100,000 €	2,000,000 €	500,000 €	1
3.2. Consumables								**36,000 €**	**720,000 €**	**360,000 €**	
321 Advertising and marketing	QiE	Consumable	1	un.	20,000	20,000	€/year	20,000 €	400,000 €	40,000 €	1
322 Software and data bases	QiE	Consumable	1	un.	16,000	16,000	€/year	16,000 €	320,000 €	320,000 €	1
3.3 Equipments								**64,800 €**	**239,760 €**	**119,880 €**	
331 Billing Equipment	QiE	Equipment	1	un.	30,000	24,000	€	24,000 €	88,800 €	44,400 €	5
332 IT Equipment	QiE	Equipment	1	un.	18,000	14,400	€	14,400 €	53,280 €	26,640 €	5
333 Communication Equipment	QiE	Equipment	1	un.	18,000	14,400	€	14,400 €	53,280 €	26,640 €	5
334 Traffic management equipment	QiE	Equipment	1	un.	15,000	12,000	€	12,000 €	44,400 €	22,200 €	5
3.4 Overtime and outsource								**45,540 €**	**910,800 €**	**983,664 €**	
341 Labour overtime (% Labour costs)	POLIMI	Labour	5.0%	Labour	20,250	20,250	€/year	20,250 €	405,000 €	437,400 €	1
342 Outsource (external services) (% Direct Costs)	POLIMI	External	5.0%	Direct Cost	25,290	25,290	€/year	25,290 €	505,800 €	546,264 €	1
3.4 Other operating costs								**5,513 €**	**110,268 €**	**119,089 €**	
341 Other operating costs (% of direct costs)	POLIMI	Consumable	1.0%	Direct Cost	2,555	5,513	€/year	5,513 €	110,268 €	119,089 €	1
TOTAL OPERATION								**556,853 €**	**10,080,828 €**	**10,887,294 €**	
4. MAINTENANCE OF E-CORRIDOR (ADDED MAINTENANCE OVER A CONVENTIONAL ROAD)								**1 year**	**20 years**	**20 years**	Lifetime
4.1. Preventive maintenance								**64,841 €**	**1,296,815 €**	**1,400,560 €**	
411 DWPT system inspection and testing	POLIMI	Labour	365	days		150	€/day	54,750 €	1,095,000 €	1,182,600 €	1
412 Small Repairs (2% Equipment/Consumable)	QIE	Equip/Consum				10,091	€/year	10,091 €	201,815 €	217,960 €	1
4.2. Corrective maintenance								**18,733 €**	**374,657 €**	**404,630 €**	
421 DWTP System umplanned repairs (25% Prevent. Maint.)	POLIMI	Equip/Cons/lab	1	per year		16,210	€/year	16,210 €	324,204 €	350,140 €	1
422 Small Repairs (25% of Repairs Preventive Maintenance)	QIE	Equip/Consum				2,523	€/year	2,523 €	50,454 €	54,490 €	1
TOTAL MAINTENANCE								**83,574 €**	**1,671,472 €**	**1,805,190 €**	
5. RENEWAL COSTS OF E-CORRIDOR, E-TRENCHES (ADDED RENEWED ASSETS IN THE E-CORRIDOR)								**Initial CAPEX**	**Rest CAPEX (20 y)**	**Initial CAPEX**	**Rest CAPEX (20 y)**
ELECTRIC EQUIPMENT RENEWAL								**E-CORRIDOR**	**E-CORRIDOR**	**URBAN**	**URBAN**
5.1. Major electric equipment repairs											
511 Power Supply (HV/MV, Trafo 25 MVA, Trafo 16 MVA)	QIE							275,000 €	0 €	176,000 €	0 €
512 Power Supply (MV/LV, Trafo 1MVA, rectifier 400V AC to 650V D	QIE							2,252,250 €	0 €	10,248,840 €	0 €
513 Distribution Shelter	QIE							2,138,800 €	0 €	2,309,904 €	0 €
514 Power Electronics (DC/HF)	QIE	Cost reduction		10%	100%	Substituted		2,375,000 €	2,137,500 €	2,565,000 €	2,308,500 €
515 Coil, Cabling and Capacitors	QIE	Cost copper increased		5%	30%	Deteriorated		2,625,000 €	826,875 €	2,835,000 €	893,025 €
516 Distribution lines	QIE							1,281,250 €	0 €	1,383,750 €	0 €
517 Monitoring	QIE	Cost reduction		5%	Every five years			312,060 €	842,562 €	337,025 €	909,967 €
518 Labour & Outsourcing (Vehicles Rental)	QIE							191,255 €	64,666 €	206,555 €	42,772 €
TOTAL MAJOR ELECTRIC REPAIRS								**11,450,615 €**	**3,871,603 €**	**20,062,074 €**	**4,181,331 €**
PAVEMENT RENEWAL											
5.2. T-Road preventive Rehabilitation (years 5 and 15)								**10,810,800 €**	**19,459,440 €**	**11,675,664 €**	**21,016,195 €**
521 Asphalt wear (years 5 and 15)	QIE							10,810,800 €	19,459,440 €	11,675,664 €	21,016,195 €
5.3 E-Road Rehabilitation (year 10)								**19,273,773 €**	**17,346,396 €**	**20,815,675 €**	**18,734,108 €**
531 Bituminous coating (emulsion and sealing)	QIE							5,828 €	5,245 €	6,294 €	5,665 €
532 Asphalt wear and binder	QIE							19,091,545 €	17,182,391 €	20,618,869 €	18,556,982 €
533 Concrete binder (area of coils)	QIE							176,400 €	158,760 €	190,512 €	171,461 €
TOTAL PAVEMENT RENEWAL									**36,805,836 €**		**39,750,303 €**
TOTAL MAJOR PAVEMENT REFURBISHMENT									**36,805,836 €**		**39,750,303 €**
5.4 Refurbisment in major repairs											
541 Repainting road surface and signs	QIE	Consumable, vehicle leasing and labour						**12,800 €**	**38,400 €**	**13,824 €**	**41,472 €**
		(years 5,10,15)	16	h	3	800	€/h	12,800 €	38,400 €	13,824 €	41,472 €
TOTAL PAVEMENT REFURBISMENT									**38,400 €**		**41,472 €**
6. DISPOSAL COSTS											**0 €**
6.1. Cost of assets disposal											
611 Removal of asphalt wear and take our coils	QIE							1,081,080 €	864,864 €	1,167,566 €	934,053 €
6.2. Residual value									**885,060 €**		**955,865 €**
621 Copper recovery	QiE	Consumable	5.50	€/kg		160,920	kg		885,060 €		955,865 €
TOTAL COPPER RECOVERED									**885,060 €**		**955,865 €**

This table reflects that the operation and maintenance activities and the renewal of equipment and pavement is very similar with the exception of the small difference in extension between both scenarios (27 km over 25 km).

Finally, a summary of the LCCA for the urban scenario is documented in next table.

Table 50. Summary of the LCCA for the urban scenario.

PRESENT VALUES POLITO	URBAN 2030	MW 2030
R+D (E-Roads)	1,200,000	1,111,111
Project Planning and Engineering	4,579,767	4,240,525
Construction	52,858,830	48,943,361
Electric infrastructure and others	24,016,142	15,115,025
Operating Costs	6,590,737	6,872,547
Maintenance Costs	1,206,954	1,117,550
Renewal Costs	28,377	26,275
Disposal Costs	-9,955	-9,217
User costs	11,660,541	0
TOTAL PRESENT VALUES	**102,131,394**	**77,417,177**
TOTAL PRESENT VALUES /km	**3,782,644**	**3,096,687**
ANNUALIZED COST (20 years lifetime)	**URBAN 2030**	**MW 2030**
Real Value	6,004,187	4,719,335
Present Value	5,106,570	3,870,859

The urban scenario is approximately a 22% more expensive than the motorway scenario by constructed km. This is due to the more complex electric architecture and the generated used costs in the busy cities due to the congested daily traffic. In the next table, we show the comparison between the motorway (e-Corridors) and Urban scenarios where these conclusions are seen.

Table 51. Comparison e-Corridor and e-Trenches (urban buses) in 2030.

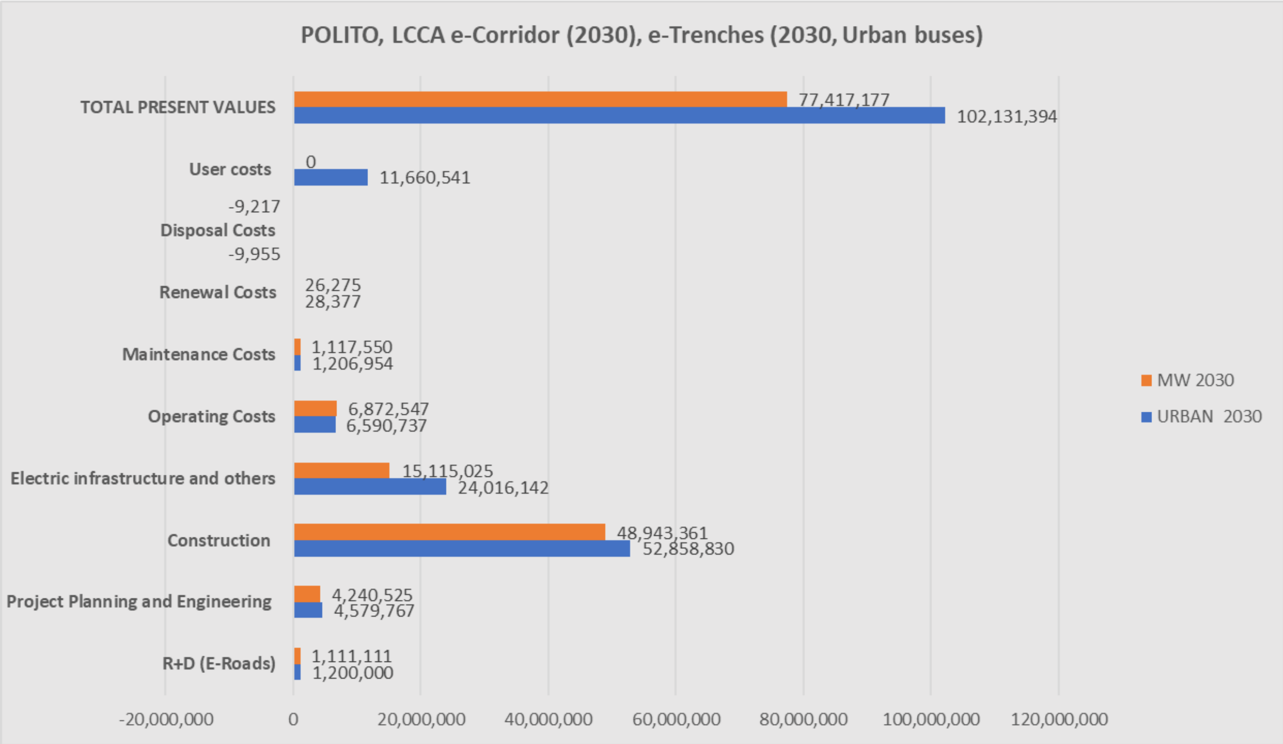
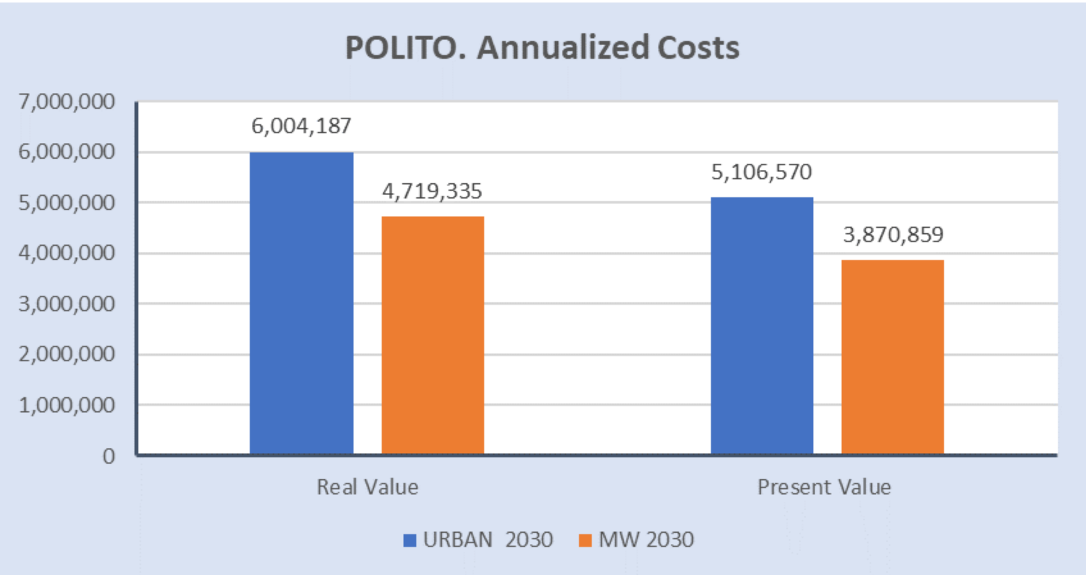


Table 52. Annualized costs for the e-Corridor and e-Trenches scenarios in 2030.



The calculations for the present value has been made with a WACC of 4%, the same figure considered in all the exercise.

3.9.4 Conclusions of LCCA results

Finally, we summarise in a single table the conclusions of the LCCAs.

Table 53. Summary table for the LCCAs.

FABRIC PROJECT LCCA Summary	MOTORWAY SCENARIO				PERIURBAN	URBAN
	POLITO		SAET		POLITO	POLITO
	2030-25 km	2050-25 km	2030-25 km	2050-25 km	2030-10 km	2030-27 km
	e-Corridor	e-Road	e-Corridor	e-Road	e-Launcher	e-Trenches
REAL VALUES	**94,386,690**	**85,033,400**	**96,166,679**	**88,324,135**	**55,059,071**	**120,083,742**
NET PRESENT VALUES (NPV)						
R+D (E-Roads)	1,111,111	292,398	1,111,111	220,588	444,444	1,200,000
Project Planning and Engineering	4,240,525	1,989,153	4,206,505	1,993,236	1,839,072	4,579,767
Construction	48,943,361	31,402,003	49,083,694	31,458,095	23,521,175	52,858,830
Electric infrastructure and others	15,115,025	13,514,818	16,813,682	16,783,949	13,652,988	24,016,142
Operating Costs	6,872,547	6,872,547	6,369,498	6,369,498	4,426,533	6,590,737
Maintenance Costs	1,117,550	1,117,550	1,131,900	1,131,900	710,274	1,206,954
Renewal Costs	26,275	26,275	26,275	26,275	15,765	28,377
Disposal Costs	-9,217	2,514,124	2,452	2,525,793	-3,687	-9,955
User costs	0	10,796,797	0	10,818,966	0	11,660,541
TOTAL NET PRESENT VALUES	**77,417,177**	**68,525,665**	**78,745,118**	**71,328,301**	**44,606,564**	**102,131,394**
NPV/YEAR	3,870,859	3,426,283	3,937,256	3,566,415	2,230,328	5,106,570
NPV/KM	3,096,687	2,741,027	3,149,805	2,853,132	4,460,656	3,782,644
NPV/KM YEAR	154,834	137,051	157,490	142,657	223,033	189,132
DWPT-EV ESTIMATIONS (End Users)	1,000	12,000	1,000	12,000	3,600	400
NPV / KM YEAR EV	155	11	157	12	62	473
Type of vehicles	88% e-DWPT light Vehicles and 12% e-Heavy vehicles				100% HV/Vans	100% Buses

In the table above the LCCA main results are summarised. Although DWPT-EVs traffic in the different scenarios will be fully described in deliverable D5.5.2 “Business models and cost-benefit analysis, we advance here an estimation of most likely traffic by type of e-Corridor deriving in some figures representing the relative costs among different options.

Be aware of the following results:

- The most expensive construction option per year is the urban scenario and the cheapest the e-Roads in 2050.
- However, by km, the most expensive is the peri-urban scenario followed by the urban, being again the cheapest the e-Roads (motorway) in 2050.
- If we consider the most likely number of users (light and heavy vehicles equipped with DWPT system), we can conclude that the Net Present Value / km year and EV, clearly identifies the motorways as the best option for 2050 when a sufficient critical

mass of DWPT-EV will be in the roads. However, the urban scenario, due to the low level of buses charging in the e-Trenches, derives in a higher amount per user, €473. The option to charge in the bus lane other heavy vehicles could increase the productivity of the e-Trenches.

- Finally, we will like to mention that the figures between 2030 and 2050 looks very similar as the savings generated by the process optimization and the economy of scale are offset by the user costs generated in the works. Of course, the savings are something predictable but the user costs can vary a lot depending on the traffic congestions and the period of works (summer time, at night, etc). An intelligent planning of the works could then unbalance the calculation in clear favour of 2050 figures. In addition, the cost of the land has not been considered in the comparison, by two reasons; in one hand because the cost variation could be high depending, for instance, on the distance to populations or the construction density in the selected area, etc. On average we could fix 15.000 €/km for the space needed for e-Corridors of 7 m width., so the total costs for the 25 km might reach 375.000 € in addition to the other costs. Normally, the cost of such terrain in the e-Launchers will be higher as they are planned to be set in the surrounding area of crowded cities. Secondly, if the e-corridor investor is different to the motorway owner (for example an administration), maybe the owner might charge a rental fee for the use of the conventional lane and in that case these extra costs could compensate the investment done in the external dedicated road matching the investment figures.

4 CONCLUSIONS

The work in D5.3.4 is to make a systematic evaluation over the life cycle performances of e-Road infrastructure, mainly in terms of environmental impacts and economic costs. It is essentially one of the major outcomes of the years' work that has been performed in WP45 & WP53, being as well one of the important pillars for the final assessment in SP5 at system level. Taking the developed WPT solutions from POLITO and SAET as a technology basis, a series of LCA/LCCA calculations and analyses for e-Road infrastructure have been carried out throughout this deliverable, integrating as well with the inputs from the structural performance analyses, the construction, maintenance & operation experiences obtained from the FABRIC test sites, and some literature collections. A summary of the LCA/LCCA results are drawn as follow:

1) The main conclusions from LCA assessment of e-Road infrastructure are:
    - The two solutions analysed herein (POLITO and SAET), do not show significant differences in cumulative energy demand, fossil fuel consumption and climate change impact categories.
    - In the construction phase the most relevant components, in terms of impacts are the WPT components, even though they represent only the 1% of the total amount of materials in the e-Corridor. This leads to the conclusion that further studies should focus on these elements. Whether further empirical data should demonstrate that the lifetime of these components is lower than expected (20 years), the overall impacts will increase significantly.
    - For what concerns traditional construction materials, the most relevant share is still covered by asphalt: various studies suggest the use of warm or cold mix asphalts, rather than HMA. The use of recycled asphalt, a possible solution suggested for the reduction of environmental pressure, has to be more deeply investigated for this type of application: in some cases, it had required thicker layer to ensure the same performances as the virgin asphalt.
    - Maintenance accounts for almost 50% of the impacts in all the three categories. The impacts of this phase are thus related to the frequency of the operation rather than to the operation itself.

- Transports did not show a relevant impact in the construction and maintenance phases.
- Further studies should focus on the frequencies of the maintenance operations and WPT components should be investigated more in details: in particular only 4 components account for more than 90% of the total impacts in the POLITO solution, namely the coils, power electronic boards, the main transformer and the super capacitors.
- Further analysis should check better information on those components, taking into consideration to create an ad hoc dataset.

2) In terms of the LCCA calculations, three representative scenarios were considered: i) *Motorways* with dual traffic of e-light vehicles and e-trucks and e-buses, ii) *Peri-urban scenario* with e-trucks and e-buses, and iii) *Urban scenario* with e-buses in cities. In the meanwhile, for each of the technological options (POLITO and SAET), two possible construction alternatives were considered in the calculation of the costs: i) the manufacture of a new separated dedicated lane (e-Corridor, foreseen in 2030) and II) the re-construction of an existing lane from a traditional road (e-Road, foreseen in 2050) The costs calculated for specific cases, based on two different market entry times i.e. 2030 and 2050, have been documented accordingly. In the next deliverables D5.5.2 and D5.5.4, the real market options for these technologies will be analysed. The greatest threats do not come from the development of technology itself (e.g., the development of superfast chargers), but from the advancement of competing options as we will see in depth in said deliverables. Other types of installation will be also revised (trench-base, micro-trench base…).

These LCA/LCCA calculation results and analyses have succeeded in gaining some important insights into the life cycle performance of the e-Road infrastructure. In the next step of work, the corresponding results in this deliverable D5.3.4 will be further integrated into the final comprehensive assessment of the life cycle performances of the reviewed charging solutions at system-level, i.e. w.r.t not only the roads, but also the vehicles, electricity production etc.

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APPENDIX I DESCRIPTIONS OF WPT CONFIGURATIONS

WPT configuration of POLITO solution

The POLITO solution is based on dynamic wireless resonant inductive coupling principle. It was developed as part of the FP7 project eCo-FEV (efficient Cooperative infrastructure for Fully Electric Vehicles).

The primary coils collect the power from the low-voltage three-phase connection point, and the road-side system converts the AC voltage to DC and then to a 600V 100 kHz rectangular waveform in order to transfer the power through the air gap to the secondary coil. As this system is still under development, specifications are preliminary and subject to minor changes.

The POLITO solution at the test site consists of 2 branches of 25 coils individually fed by DC/HF converters. Each coil has a DC/HF converter and the distribution is at 600 VDC. The feeder can be connected in parallel on the same cable.

In addition, a super capacitor solution will be provided to balance the possible load variations.

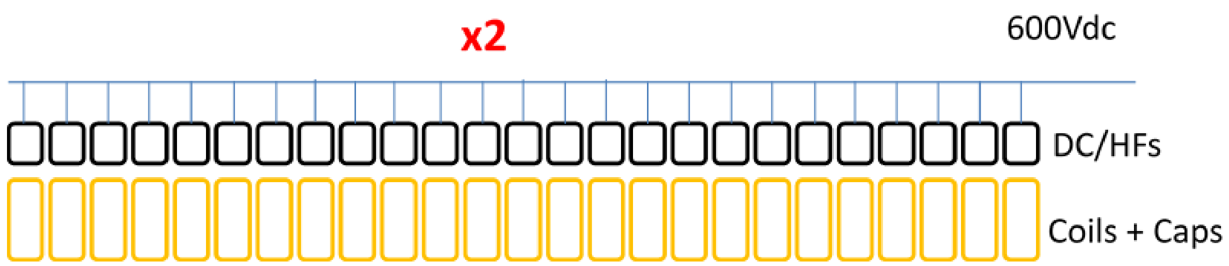

Figure 34: POLITO system test site layout.

The operating frequency of the power electronic can be anywhere in the 20-200 kHz range, although it is essential that the primary and secondary circuits operate at the same frequency, the 85kHz frequency reference was adopted.

The CWD system operates as a constant current secondary, which means that power control can be done at the secondary side without any additional controller. This also means that it is easier to transfer power back to the network, anyway, in the developed solution, no power back to the grid was implemented.

The power transfer rate is quoted as 20 kW. Secondary voltage can span from 0 to 400V, for a full rate power transfer from 300 to 400V. Primary input voltage will be 600-700V dc.

The current solutions are connected to three-phase 400V AC substation feeder points. However, the current solutions are primarily experimental and mainly used in controlled environments where the installation is used by a small number of vehicles. However, as the solutions become more commercial and installed at large scale other forms of connections must be considered due to the higher demand levels, stepping up from kW to MW range. A similar approach to rail is proposed where the connection point is at MV (medium voltage) or even HV (high voltage) feeders. This approach would also isolate the in-road power transfer infrastructure from the domestic supply. A possible adaptation of the POLITO solution to motorway application is reported in Figure 35.

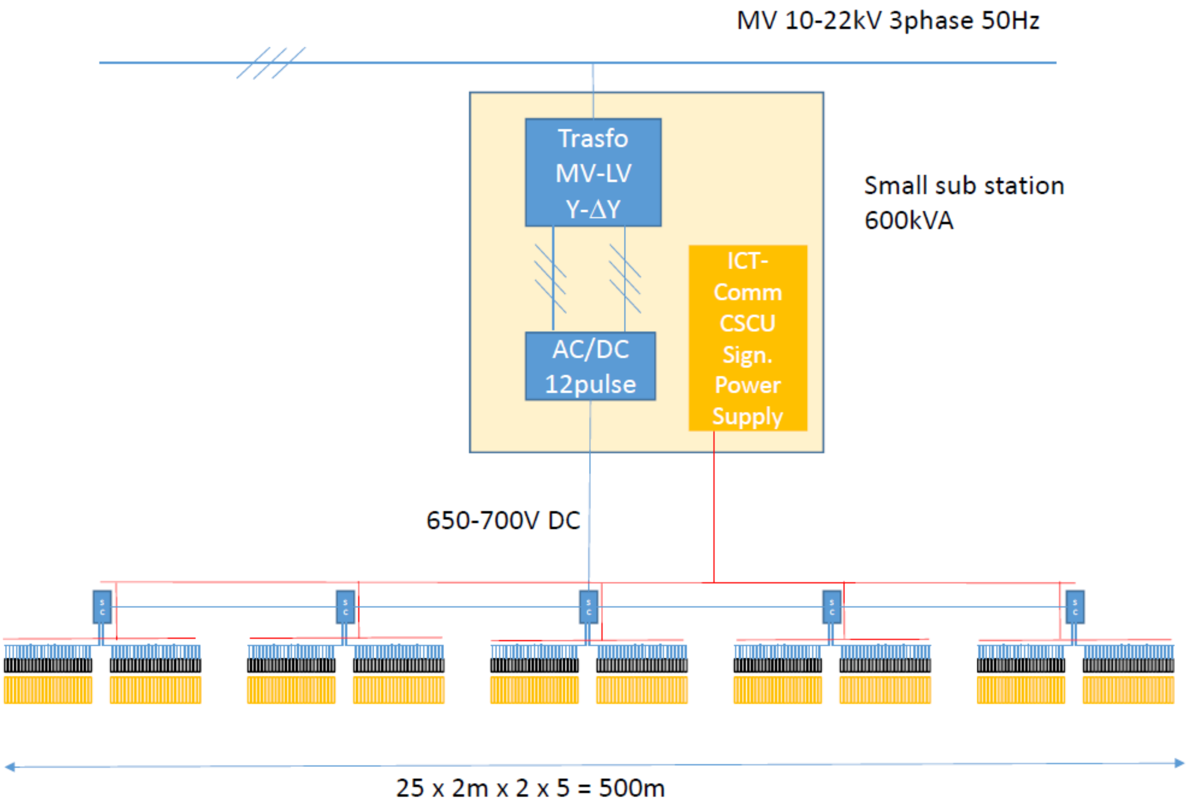

Figure 35: Possible adaptation of the POLITO solution

In real world applications, all charging coils will be embedded in the road surface to a depth of 6~7 cm, while the power electronics and control equipment are placed in plastic

manholes at the track sides. The loops will be embedded in a filling materials that still has to be defined, according to the results from the FEA analysis.

The coils used in the POLITO solution consist of 10 concentric windings, with rectangular shape, with the external dimensions of 1.6 m x 0.6 m. the diameter of the coils is 0.4 cm.

1. The tail of the loops which have to be connected to the power control equipment was placed in a PVC pipe.
2. The power electronics and control equipment are placed in the manholes at the track sides.
3. The PE are connected to a shelter (1 shelter every 50 PE, 25 per side), which receives power from a AC/DC converter which will grant the power supply to the charging area by a 2x16mm FG7R / FG7OR 0.6/1kV cable.
4. The main power and data transmission networks were connected to grid infrastructure (Figure 36) by a cable pipe that put in connection all the manholes and ran beside (but OUTSIDE) of the charging lane.

A substation is equipped with a MV/LV transformer and an AC/DC converter, conveying a low voltage direct current (650-700V DC) to the segments.

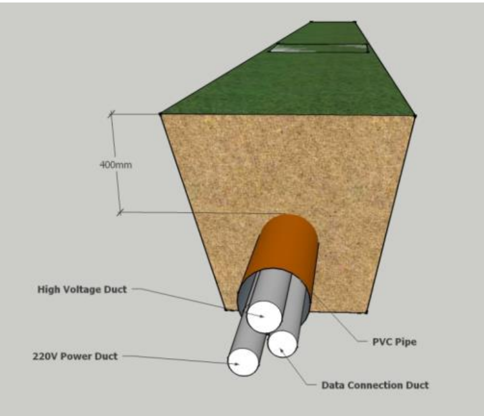

Figure 36: PVC pipe including the power and data cable

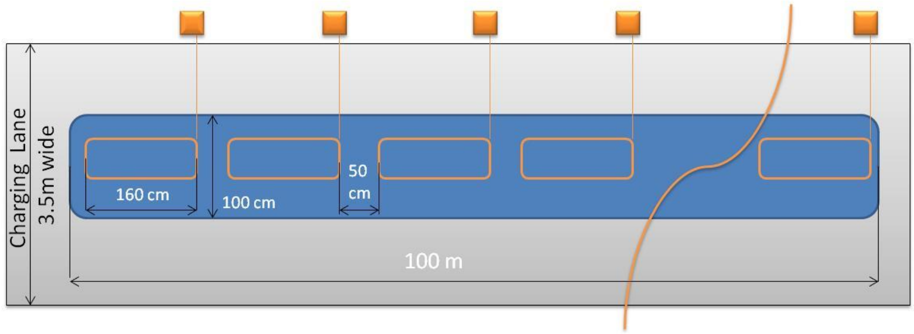

Figure 37: Layout of the installation of the POLITO coils

Here is the list of the components, provided by POLITO, sorted by function:

- In-road equipment
  - Coil
  - Connectors
  - Capacitors
- Road side equipment
  - Power Supply
    - Main Transformer 120 KVA
    - Power metering
    - Protection and shunting circuits
    - AC/DC Converter
  - Distribution Shelter
    - Shelter
    - Super-capacitors box
    - Control Power Supply
    - SBRio PE boxes management unit
    - Vehicle Communication unit
    - CSCU
  - Coil, Cabling and Capacitors
    - Coil
    - Connectors
    - Capacitors
  - Power Electronics (DC/HF)
    - Power Electronics board
    - Active Bridge
    - Housing
    - Connectors
  - Distribution lines
    - Manholes
    - Distribution Pipes
    - 650VDC Distribution cables with connectors

- Signal communication cables and connectors
- Signal power supply cables and connectors

WPT configuration of SAET solution

The development of SAET solution is closely related to the CWD system used in the POLITO solution, and they share the same secondary coil and the vehicle used for testing. Because the IPV system is designed to be interoperable with the CWD system, it uses the same communications system as the CWD system. The dimensions for the ground coils are currently 1.92m wide by 0.55 m long, they consist of a single winding and are currently designed to be installed 5cm below the road surface. The coils will be closely spaced and installed in 25m segments. The system normally operates at 85 kHz, but can operate in the range 60-150kHz for interoperability.

While designed to be interoperable with the CWD system, the IPV system has a different architecture to the CWD in that the secondary is expected to operate in a constant current mode, with power transfer controlled by the primary. This means that the secondary will need to be able to switch between operating modes, making the communications element of the system crucial to successful operation. The maximum power transfer rate is quoted as 100 kW, although it is expected to operate at 30-50 kW in FABRIC.

Differently from the POLITO configuration, in the SAET solution the AC/DC converter is placed in the shelter by the roadside, and the resonant capacitors are placed in the PE rather than beneath the road surface with the coils. In the same PE is also placed the HF transformer.

The SAET SPA system is designed to operate at 80 km/h (22.2 m/s), and only one vehicle at one time can collect power from the segment, therefore the minimum time gap between two vehicles should be at least 1.125 seconds.

Figure 38 shows the test site layout for the SAET IPV system. In this system, each segment (shown in red) is a loop coil (shown in orange), and each loop is connected to the 400VAC. A single feeder point provides power to a single segment which consists of 20 coils. The coil only switches on when there is a vehicle over it, so the feeder supplies power to approximately 2-3 coils at a time, each coil is rated at 40kW. The roadside equipment is housed in two cabinets; the physical dimension of a cabinet is 1 x 0.75 x 2 m

(HxWxD). The distance between the feeder transformer and the roadside inverter is approximately 100 m.

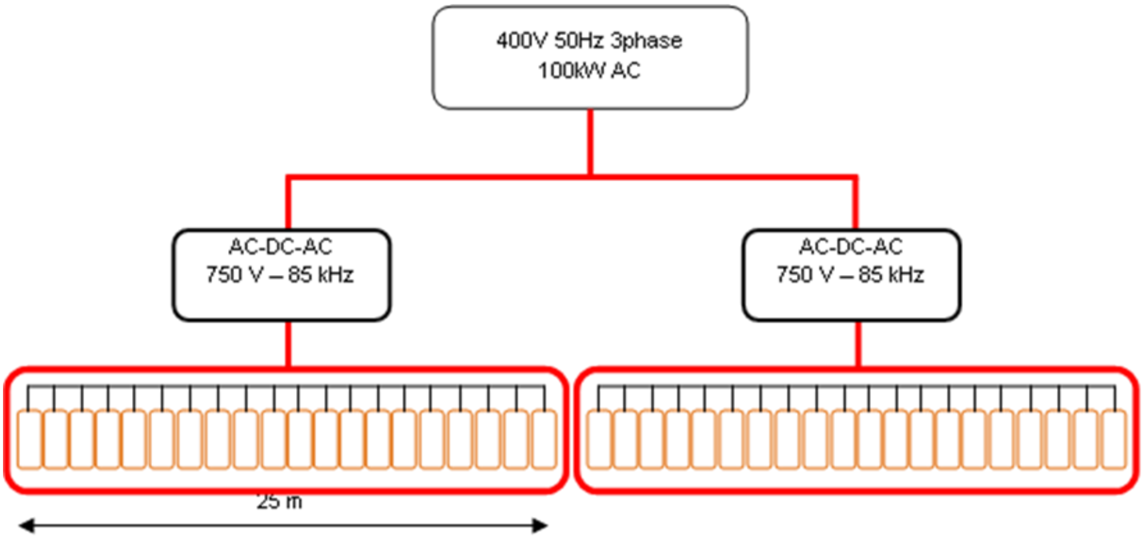

Figure 38: Test site layout for SAET SPA system.

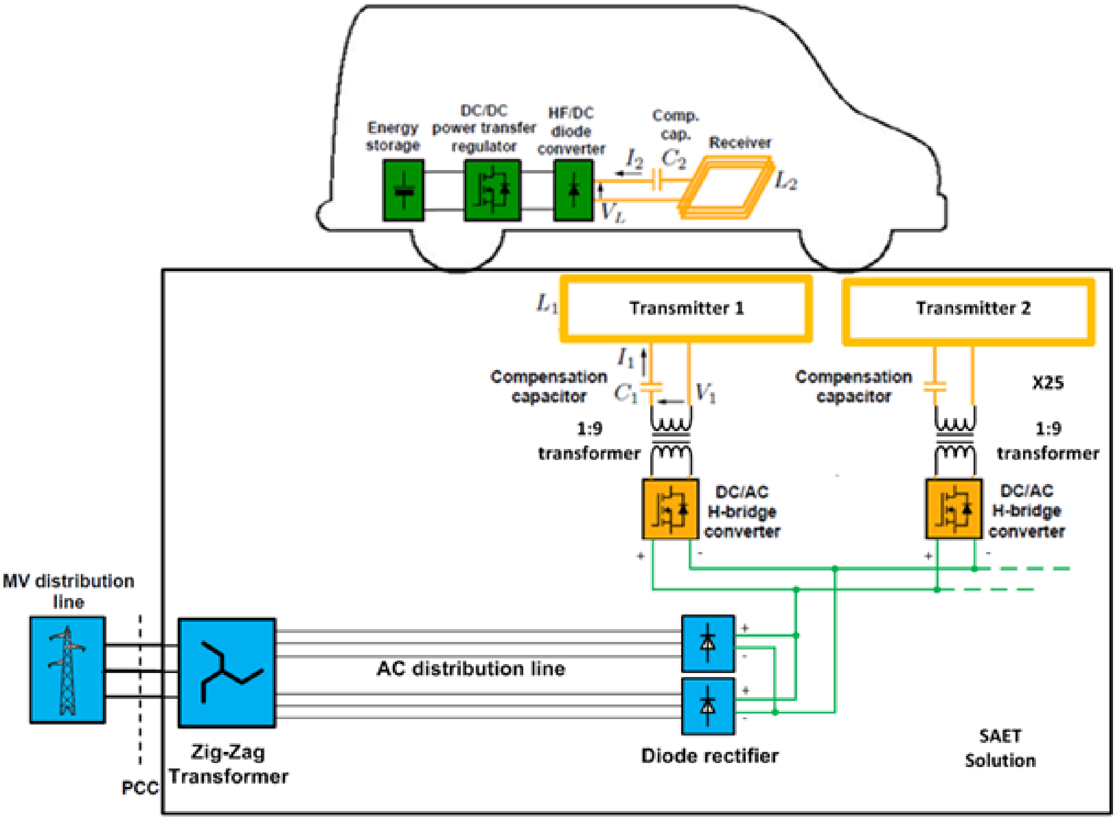

Figure 39 Power supply configuration of the SAET solution.

In the actual configuration of the SAET solution, shown in Figure 39, the shelter receives the double three-phase supply from the main power house; a twelve-pulse bridge and a filter are used to obtain the DC main line supply. In the manhole the SiC VFI and the control system are co-designed to give the 85kHz power supply, a specific custom-designed transformer reduces 1:10 the voltage; the series resonance capacitor matches the primary coil inductor impedance. In this configuration the coupling effects with ground are strongly reduced, since the self-inductance is really small and moves the resonance to a really high frequency >> 85 kHz.