Environmental optimization of electric vehicles slow-charging infrastructures through a life cycle management approach

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Abstract. Official reports about electromobility state that electric vehicles offer an environmentally friendly option with regard to conventional ones. However, environmental impacts on the public urban space related to installing charging infrastructures are poor known and assessed until now. The paper compares the contribution to the environmental impacts of two common types of charging systems installed on surface at the public urban space of Barcelona. Systems are representative of the models installed in other European cities for charging electric scooters. They are based on the conventional plugging to the grid (3.7 kWh). The research is completed with economic data to identify the best environmental and economic constructive solution. Results show that reductions of 65% of the environmental impacts and 26% of the economic investment could be achieved by installing charging stations instead of isolated charging stands.

1 Introduction

Many governments are promoting the electromobility as a renewed strategy to reduce pollutants emissions, safeguarding energy supply and promoting the economic growth. Electric vehicles (EVs) hold the promise, if widely adopted, to offer a secure, comprehensive, efficient and environmentally friendly energy option than conventional cars [1].

Although the introduction of EVs in cities is a strategic element to promote urban sustainability there are a number of limitations that must be overcome to truly mass market penetration. The deployment of charging infrastructures where batteries may be charged easily and quickly is considered to be one of the major challenges in customer acceptability of electric vehicles [2]. Charging the battery at home, overnight, is considered the cheapest, greenest and most convenient means of charging the EV when off-street parking is available. However, due to the limited driving range, long charging time of batteries and the lack of access to a private parking lot by some EVs´ users it will be essential to create pervasive public charging infrastructure that ensures reliable charging capability [3]. Therefore, governments are promoting the installation of public charging systems and have published several guidelines for their implementation in cities, i.e. [4], [5]. Guidelines specify a set of criteria that must be considered for installing charging points on the public urban space. But, they are mainly based on technical and economic aspects without incorporating environmental criteria related to the design and management of charging systems. Environmental impacts to the urban space by installing charging systems are little assessed in scientific literature, as well. Therefore, there is no comprehensive environmental data available to facilitate the ecodesign and life cycle management of charging infrastructures to minimize the environmental burden on the urban built space.

The paper aims to assess the environmental impact to the urban space of two slow-charging systems for electric scooters by means of a life cycle assessment methodology, which has been used as a tool for the assessment of other urban infrastructures [6], [7], [8], [9] in order to provide environmental criteria for contributing to urban sustainability.

2 Scope and justification

The research is focused on the Catalan Strategy of electromobility [10] in its pilot application to Barcelona, which is one of the most advanced Spanish cities in promoting charging points for EVs. The objective is to have 76,000 EVs on road and 91,200 charging points operating by 2015. Approximately, the 90% of charging points will be slow-charging systems based on the conventional plugging to the grid (3.7 kWh). At least the 20% of charging systems are expected to be placed in Barcelona, where municipal fleet vehicles, motorcycles and scooters have been identified as major segments to become electric in the short time [11]. Two-wheelers vehicles account for almost the 30% of the total private fleet vehicles of Barcelona [12], similar value to other metropolitan areas and European cities where there is a great tradition of using two-wheelers for daily commuting. Electric motorcycles/scooters fleet is more mature than electric cars and it is easier to implement and manage in the short-term. So, the Council is primarily promoting the installation of public surface charging systems for electric motorcycles and scooters. Currently, there are 129 public slow-charging points operating in the city and a total of 221 are expected to be installed by the end of 2011:

- 98 slow-charging points will be at underground public parking (mainly for electric cars)
- 123 points will be operating at the surface of the urban space:
  - 93 points exclusively for electric motorcycles and scooters
  - 25 points for mixed-use (motorcycle/scooter and electric cars)
  - 5 points exclusively for electric cars

Being the 95.9% public slow-charging points for charging two-wheelers at the public urban surface, the paper is focused on studying the environmental impacts of two common types of slow-charging systems implemented in the city for charging Electric Scooters.

3 Methodology

The environmental assessment is based on the LCA methodology [13]. The impact assessment method chosen is CML baseline 2001, v.2009 [14] being the midpoint impact categories considered: abiotic depletion potential of elements (ADP1 [kg Sb eq.]) and fossils (ADP2 [MJ]), acidification potential (AP[kg SO_2 eq.]), eutrophication potential (EP[kg PO_4^{3-} eq.]), global warming potential 100 years (GWP[kg CO_2 eq.]), human toxicity potential (HTP[kg DCB eq.]), ozone depletion potential (ODP[kg R-11 eq.]) and photochemical ozone creation potential (POCP[kg C_2H_4 eq.]) and the indicator of cumulative energy demand (CED). The software used is GaBi 4.4 with the ecoinvent v2.1 database [16].

3.1 Functional Unit

The functional unit (F.U.) provides a reference for the inputs and outputs associated with the system under study [13]. The F.U. is defined as the environmental impacts of using a charging point (= outlet) during 12 hours per day for recharging electric scooters over 15 years.

3.2 Description of the systems under study

The charging systems assessed are an Exterior Recharge Post with two outlets ERP2 (Fig. 1), and an Exterior Recharge Station equipped with 6 outlets, ERS6 both for recharging two-wheelers (Fig. 2). Charging systems are based on the conventional plugging to the grid (3.7 kWh per outlet).

3.2.1 Exterior Recharge Post with 2 outlets available (ERP2)

The ERP2 is one the most common systems being implementing in Barcelona and other European countries. It is based on a power post (stand) where two scooters can be recharged at the same time. Each outlet has a power and maximum current output of 230 V c.a. and 16 A. The stand is usually based on a stainless steel body that incorporates all the electronic technology needed to provide energy in a safe and controlled manner. The minimum power contracted must be 11.1 kW [16].

3.2.2 Exterior Recharge Station equipped with 6 outlets (ERS6)

There are five ERS6 planned to be installed in Barcelona. This system is an alternative infrastructure designed to cover up the needs of charging the battery of six 2-wheel electrical vehicles at the same time. The stand is based on a stainless steel body with has incorporated all the electronic technology for supplying electricity. Each outlet has a power output of 3.7 kWh. The minimum power to be contracted to the power supplier company is about 25.9 kW [16].

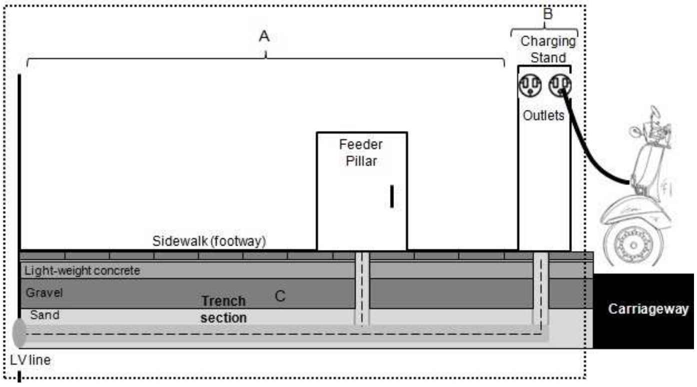

Fig.1: Structural infrastructure related to the system ERP2 (not scaled)

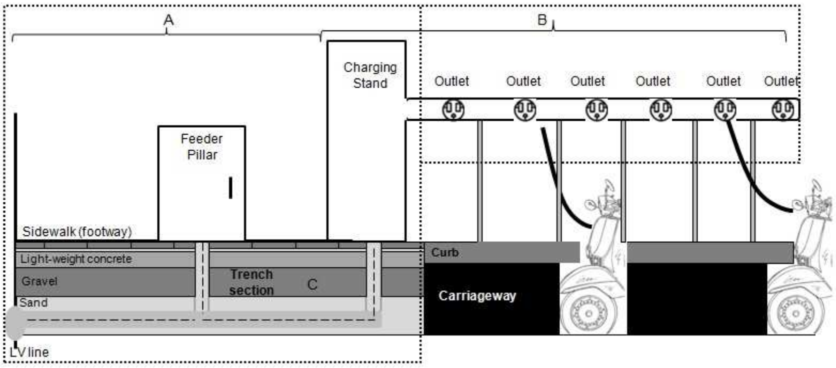

Fig.2: **Structural infrastructure related to the system ERS6 (not scaled)**

3.2.3 Common elements of the systems

- Connecting infrastructure (A)

To operate a charging system, a connection from the local electricity network to a feeder pillar is required [16], [17]. This means that a charging system needs a "connecting infrastructure" between the general low voltage (LV) line and the charging stand (B). The connecting infrastructure is divided into three main elements: connection to LV line, feeder pillar and connection to charging stand.
The feeder pillar is considered to be the same for both charging systems, although output-cables from the feeder pillar to the charging place have different sections according to the power supplied.

- Building materials (C) and system installation

Installation (defined as D in Table 1) begins with the connection to the local LV network that supposes to excavate a trench of around 70-80 cm depth and 35-45 cm wide where cables are housed. The average distance in Barcelona from the LV line to the feeder pillar is about 12 m plus 3 m from the feeder pillar to the charging stand (due to technical concerns). Cables are placed in polyethylene tubes over a 5-cm layer of sand extended along the length of the trench (15 m). Tubes are covered up to 30 cm with a more sand. The trench is filled with a 30-cm layer of gravel. Once compacted, a 12-cm layer of light-weight concrete is poured over it. Finally, a standard pavement of concrete slabs of 4 cm wide for pedestrian and light weight traffic use [6] is fixed with a 2-cm cement mortar [18].
Materials and machinery required in installation are shown in Table 1.

- Materials transportation, system use, maintenance and system removal

Materials transportation (E) is based on a local market perspective. It is assumed, a usage rate of 83% during the operation time of the system, considering be operative 12h per day. This means that during 10h the system is constantly supplying energy for electric scooters. Another assumption is that there is an energy loss (F) of 0.5% of the total power contracted by the system when an EV is connected to the outlet, being 0.25% when there is no vehicle connected (almost 14h). Energy losses are considered in the form of heat.

There is a little maintenance of the charging system that (mainly related to repairs due to vandalism acts or accidents) so it is excluded from the environmental assessment. Finally, the stage of removal and waste management (G) is associated only with removing the electronic equipment. Building infrastructure (trench and underground cables) is considered to be maintained after 15 years.

4 Results and Discussion

4.1 Inventory data

Table 1 shows the inventory of the major materials and energy flows of the systems. Technical data comes from the City Council of Barcelona [18] and can be interpreted as an average of the slow-charging systems currently implemented in the city. Due to the high variety of alternatives related to the electronic components, they are aggregated in weight. The stage of use is related to using the infrastructure for charging the electric scooter. The impact of the electric energy consumption by batteries during the charging time is outside the limits of the study, as well as the parking lot occupied by the vehicle.

Tab.1: Life cycle inventory data for ERP2 and ERS6 systems

Life cycle stages	Flows	ERP2	ERS6
connecting infrastructure (A)			
Connection to LV line	Cable Al (4x50mm^2)	14 m	14 m
	PE tube (1x125mm)	13 m	13 m
Feeder pillar	Envelope $^{(a, b, c)}$ (1250x750x300mm)	30 kg	30 kg

	Plastic ABS	6.2 kg	6.2 kg
	PE tube (1x63mm)	1 m	1 m
	Electronics	15 kg	15 kg
	Cable Cu (various)	0.91 kg	0.91 kg
Connection to point	Cable Cu (3x10mm^2)	4 m	-
	Cable Cu (3x16mm^2)	-	5 m
	PE tube (1x63mm)	4 m	4 m
Charging stand (B)	Envelope (stainless steel)	40 kg	257.5 kg
	Iron supports	-	9.92 kg
	Electronics	4 kg	13 kg
	Laptop	1 pc.	1 pc.
	Cable Cu (various)	0.6 kg	1.6 kg
Building materials - Trench (C)	Sand	2,796 kg	2,796 kg
	Gravel	3,334 kg	3,334 kg
	Light Concrete	1,293 kg	1,293 kg
	Cement Mortar	167 kg	162 kg
	Concrete slabs	617 kg	598 kg
	PEBD sheet	12 kg	12 kg
	PEBD film	0.64 kg	0.64 kg
Transportation (D)	Electrical equipment: Van <3.5 t	15 km	15 km
	Building materials: Lorry 3.5-16 t	30 km	30 km
	Wastes, Van <3.5 t	30 km	30 km
Infrastructure installation (E)	Diesel (machinery)	639.8 MJ	639.8 MJ
	Electricity, low volt.	12.4 MJ	13.7 MJ
Infrastructure use (energy losses) (F)	Electricity, low volt.	18,597 MJ	48,496 MJ
Removal and waste management (G)	Electronics	19 kg	28 kg
	Cables	1.5 kg	2.5 kg
	Plastic ABS(*)	9.5 kg	9.5 kg
	PE tube	0.63 kg	0.63 kg
	Steel and Iron	66 kg	293.4 kg
	Laptop	1 pc.	1 pc.

[a] stainless steel (26kg), [b] polycarbonate (3kg), [c] epoxy resin (1kg)

[*] including polycarbonate and epoxy resin

4.2 Life Cycle Impact Assessment (LCIA)

4.2.1 Exterior Recharge Post (ERP2)

Table 2 shows the total impacts of the life cycle of the ERP2 system.

Tab.2: Life cycle environmental impacts of ERP2 system

Impacts	Total	A%	B%	C%	D%	E%	F%	G%
ADP1	**5.49E-01**	33.15	19.33	**46.46**	0.06	0.01	1.00	0.00
ADP2	**8.75E+05**	1.17	0.78	**92.84**	0.15	0.09	4.96	0.01
EP	**3.53E+02**	1.54	0.90	**88.92**	0.14	0.13	8.36	0.01
AP	**6.04E+01**	1.49	1.08	**94.23**	0.20	0.19	2.75	0.05
GWP	**1.65E+05**	0.43	0.58	**96.88**	0.06	0.04	1.99	0.04
HTP	**2.08E+04**	15.35	16.22	**63.83**	0.04	0.02	3.86	0.68
ODP	**6.74E-03**	0.77	2.96	**93.24**	0.21	0.11	2.70	0.01
POCP	**4.14E+01**	1.26	0.70	**94.00**	0.19	0.16	3.67	0.02
CED	**1.19E+06**	1.13	0.77	**92.37**	0.12	0.07	5.54	0.01

A: Connecting infrastructure B: Charging stand; C: Building materials; D: Transport; E: Infrastructure installation; F: Infrastructure use; G: Removal and management

Building materials are the highest contributors to the environmental impact. They account almost the 90% of total impacts and energy requirements of the system life cycle. The concrete is the material which contributes the most to the impact, over 90% of the total input by building materials. Even its low contribution to the final impact, energy losses of using the system over 15 years is the second highest-impact stage. This is remarkable, since is considered as inefficiency.

4.2.2 Exterior Recharge Station (ERS6)

Table 3 shows the total impacts of the life cycle of the ERS6 system.

Tab.3: Life cycle environmental impacts of ERS6 system

Impacts	Total	A%	B%	C%	D%	E%	F%	G%
ADP1	**6.93E-01**	26.42	34.80	**36.76**	0.06	0.01	1.94	0.01
ADP2	**9.66E+05**	1.08	2.82	**84.15**	0.17	0.09	11.67	0.03
EP	**4.14E+02**	1.36	4.03	**75.82**	0.13	0.11	18.51	0.04

AP	**6.44E+01**	1.41	2.93	**88.47**	0.21	0.18	6.70	0.10
GWP	**1.72E+05**	0.41	1.41	**93.06**	0.07	0.04	4.97	0.05
HTP	**4.00E+04**	8.24	52.82	**33.25**	0.03	0.01	5.22	0.42
ODP	**7.12E-03**	0.73	4.04	**88.22**	0.24	0.10	6.63	0.03
POCP	**4.49E+01**	1.19	2.90	**86.70**	0.22	0.15	8.79	0.05
CED	**1.32E+06**	1.03	2.71	**83.11**	0.14	0.07	12.93	0.02

The LCIA shows a similar trend to the ERP2 system, where building materials are the highest contributor to the environmental impact. In this case, building materials slightly reduced their relative contribution due to an increase of the input by the charging stand and system use, higher than the ERP2 system.

4.2.3 Comparative environmental balance and cost analysis per functional unit (1 outlet)

- Environmental balance per F.U.

Table 4 shows the environmental impact contribution per F.U. of the systems under study

Tab.4: Comparison of the environmental impact contribution by systems F.U.

Impacts	ERP2 (1 outlet)	ERS6 (1 outlet)	% ERS6 vs. ERP2
ADP1	2.74E-01	1.16E-01	**- 57.88**
ADP2	4.38E+05	1.61E+05	**- 63.23**
EP	1.76E+02	6.90E+01	**- 60.91**
AP	3.02E+01	1.07E+01	**- 64.49**
GWP	8.26E+04	2.87E+04	**- 65.30**
HTP	1.04E+04	6.67E+03	**- 36.02**
ODP	3.37E-03	1.19E-03	**- 64.77**
POCP	2.07E+01	7.48E+00	**- 63.86**
CED	5.93E+05	2.20E+05	**- 62.95**

Charging electrics scooter at the ERS6 system means over 60% lower impact than charging at ERP2, because impacts by building materials are 3 times lower than ERP2 due to it optimize the use of the urban space (minimum urban intervention)

- Cost analysis

Table 4 shows a cost investment comparison between systems. Costs are related to building and installing the infrastructure; using it for charging and removing of the electronic equipment.

Tab.4: Comparison of investment cost between ERP2 and ERS6 systems and F.U.

Concepts	ERP2	ERP2 (1 outlet)	ERS6	ERS6 (1 outlet)
Items				
Connecting infrastructure (€)	726	363	755	126
Charging stand (€)	3,500	1750	9,000	1,500
Building materials (€)	480	240	480	80
Infrastructure installation (€)	250	125	350	60
Infrastructure use (€)	1,535	775	4,000	670
Removal (€)	250	125	350	60
Total cost € (approximated)	6,740	**3,370**	14,940	**2,490**
Energy sales				
Daily electricity sales (kWh)	73.60	36.80	220.80	36.80
Daily electricity sales* (€)	22	11	66	11
Amortization time (days)	308	**154**	228	**38**

*considering the current kWh price (0.2969€) [19] and assuming a constantly charging of 10 hours per day

Data is extracted from ITeC [20] and personal communication [18]. Cost analysis is based on the current commercial market prices and it shows the minimum economic investment required per system. It does not incorporate costs related to renting, building permits or interests. Results show that total cost per F.U. is 26% lower in ERS6 than ERP2 system.

5 Conclusions

Electric vehicles are means an environmentally promising alternative for private mobility but its implementation into the cities is complex. The deployment of an extensive charging network is required and it must be environmentally-planned from the early stages of decision-making for contributing to urban sustainability and increase the environmental value of EVs.

Results show that by maximizing the use of the urban space by implementing ERS6 against ERP2 systems the environmental impacts can be reduced over 60%, being one of the major savings the CO_2 emissions avoided (over 65%). Results also show that the ERS6 not only ensures better environmental benefits, also interesting cost savings, almost 30% of the total economic investment.

While the installation process of charging systems may seem relatively straightforward it has an important environmental burden to the urban system. The magnitude of the work required for installing the infrastructure - trench, connection to the general low voltage line, back-fill excavation, etc - highly determines the environmental impact of the charging systems.

On the other hand, benefits of slow-charging systems located on public urban surface are relatively low, especially due to the limited parking time and cost. So, to concentrate charging outlets, as ERS6 systems, at specific points of maximum use (hotspots), considering traffic flow and parking places, and minimize the spread of isolated charging points through the city may be an alternative solution.

Thus, a comprehensive study of charging systems and building solutions requirements is important to better know the best urban alternatives for implementing different types of charging infrastructures throughout the city. A comparative environmental study with fast and rapid charging systems could provide information about the better solutions by means of maximizing the use of the infrastructure by reducing the time required for charging the battery.

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