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Assessing CO_2 emissions of electric vehicles for e-sharing and home care. Two cases developed at Valencian region

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ABSTRACT

Assessing the environmental impact of transport has been an issue over the last decade. The general framework is established and the followings factors must be considered to obtain results as accurate as possible. Among others (a) the study should considered the entire life cycle if possible: building & materials, usage phase and waste treatment and (b) usage phase assessment must be developed under real conditions in addition to lab tests.
When the object of study is urban private transport, some extra lines can be taken into account considering the high impact that environmental initiatives makes in society. The information that local authorities and community receives about the initiative is as relevant as the environmental benefits obtain of the implementation of the project.
In this paper, we present the methodology developed to assess CO_2 emissions of electric vehicles intendent to car-sharing and home care; two projects developed at Valencian region. We deepen in the relevance and type of information obtain and manage for both studies with a life cycle vision.
As a result of usage phase assessment, field test proves to be revealing giving a more realistic vision of the benefits of the project. Theoretical assessments were useful to consider the implementation of a certain project and the necessary support complementing the entity of the study. Resources needed to develop field test might skew results by biasing the study. Attention need to be paid in order to manage resources to set up field tests and avoid setting up field tests due to available resources.
Bibliographic studies have shown building, materials and waste treatment depends on available data. Life cycle assessment seems to be the most adequate tool to obtain accurate results although the cost of the assessment is high and might not show significant differences between cars of similar characteristics.

1. INTRODUCTION

Urban mobility is the main cause of pollution in cities. The smog and emissions from private and public vehicles make urban air harmful to the environment and to humans.

European Union (EU) is working to raise awareness to the cities, citizens and government of the importance of an action plan on urban mobility (European Commission, 2009) in order to:

- Develop a competitive transport system,
- Respect the EU commitment in the fight against climate change, growth and employment, social cohesion, health and safety,
- Deal with the demographic evolution of urban centers and the social concern over mobility,
- Articulate the link between long-distance transport and mobility.

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Among the proposed actions, the EU commitment to promote greener vehicles and more sustainable urban transport. An example is the CIVITAS initiative (European Union, 2011). Electric vehicles are, today, a reality and an alternative to traditional vehicles. The traditional combustion engine, not only generates emissions that pollute the atmosphere and contribute to climate change, it also narrows the energy dependence on oil along with its consequences. There are three main reasons to implement electric vehicles in public and semi-public transport:

- significant amount of emissions is saved,
- noise in the city is reduced and
- the community is engaged with the solution by using a greener transport and seeing how it works in their own neighborhood.

Carbon Footprint is the benchmark indicator for assessing the environmental performance of different products and services. Mobility and transport are one of the areas where it is most widespread. Carbon Footprint measures the emissions of greenhouse gases produced by an activity or use. For vehicles emissions, Carbon Footprint is calculated in grams of carbon dioxide equivalent (CO_2e) per kilometer [gCO_2e/km]. A deeper description on how is calculated is given in Method section.

This work is motivated by the participation of authors in two different project that took place in Valencia region: a) the validation of the e-sharing system for Sagunto city and b) the implementation of electric vehicles for the hospitalization unit of Alcoy Hospital as part of the validation and optimization of e-sharing Valencia project. Both projects required an analysis of the Carbon Footprint of different electric cars. The e-sharing project allowed an experimental analysis while home care project was developed theoretically.

As a result, the Carbon Footprint of different electric vehicles were assessed with different methodologies according to the available information and resources. The objective of this paper is to analyze both results and methodologies discussing scopes and limitations.
In the following sections, a short description of each project is given as a general framework of the study. In the Methods section, the procedures used to assess each Carbon Footprint is described. Results are presented in Results and Discussion section including a comparison with traditional fuel vehicles. Conclusions and Acknowledgments close the present communication.

1.2 e-sharing project

In Valencia province, Spain, there are two areas, Sagunto city -down town- and Sagunto port -sea coast- with a high transport communication. Citizens of Sagunto city and Sagunto port bridge the 6 km gap between them several times a day for different reasons. The idea of this project (2011) was to implement a greener alternative to the traditional transport by a car-sharing system based on electric vehicles. MOVUS was the organization responsible for the implementation of this project. A detail description of the project can be seen in MOVUS webpage (MOVUS, 2016)

1.3 Home care unit project

Alcoy is a city located in the province of Alicante, Spain. Alcoy is the city of reference for small towns and villages in this mountainous area. Juan Sanz Hospital of Alcoy give domiciliary services to a wide area. In 2014, the ministry of health of Valencia region promote this project where MOVUS installed a whole fleet of electric cars with different

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capacities and autonomies to serve as transport for the home care unit of the hospital.

2. METHODS

As described in the introduction, this paper combined the results of two projects: (1) an experimental analysis to assess the real energy efficiency of the electric vehicles used in the car-sharing project (e-sharing project) and (2) a theoretical analysis over the fleet (two electric and a traditional car model) installed to cover the needs of home care unit project.

Projects differs in the way energy consumption is obtained. The assessment of the Carbon Footprint is the same for both cases. Particularities of each project are described below following by the methodology used to assessed Carbon Footprint.

3.1 Project 1: e-Sharing project

This analysis consisted on driving experiences where different variables were considered. A first set of variables define the state of the experience (**¡Error! No se encuentra el origen de la referencia.**).

Variable	Unit	Method	Type
Test time	Minutes	Direct	Quantitative
Distance traveled	Km	Direct	Quantitative
Route type	-	Direct	Qualitative convert by pairs. See Table 2.
Average speed	Km/h	Indirect	Quantitative

Table 1. Definition of the experience

Route type	P1	P2
Urban	1	0
Interurban	0	1
Mixed	0	0

Table 2. Route type binary relation.

Average speed (as) was calculated as the relation between the distance traveled and the time of the test (Equation 1).

$$as\left[\frac{km}{h}\right] = \frac{Distance\ traveled\ [km]}{Test\ time\ [h]} \quad (1)$$

A set of complementary variables were defined in order to assess the influence in the energy consumption of using certain instruments as lights, air conditioning, stereo, etc. (Table 3). Qualitative variables were converted to quantitative information by binary assignation depending of possible answers. When three answers where possible, as rout type variable, a pair binary system was defined converting the variable in the combination of two binary variables.

Variable	Unit	Method	Type
Occupants	-	Direct	Quantitative: only driver (0) / driver and passenger (1)
Use of air conditioning	-	Direct	Qualitative: on (1) / off (0)
Use of stereo	-	Direct	Qualitative: on (1) / off (0)

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Windows position	-	Direct	Qualitative: open (1) / closed (0)
Use of wiper	-	Direct	Qualitative: on (1) / off (0)

Table 3. Complementary variables

Regarding to the variables chosen some limitations must be considered. Qualitative variables convert into quantitative responses by binary assignation skews information. I.e., use of wiper is considered as on (1) or off (0) but the speed is not taken under consideration. Although it might influence in the consumption of the care, it is considered to be insignificant. Occupants were restricted to one or two even though the model of the car used, Th!nk, has 4 seats. Test time was fixed to 30 minutes, 1 hour and 1 hour and 30 minutes.

Experiences were carried out with the help of selected students trained in the subject. A description of the experience was handle to each driver together with a short questionnaire that collected the necessary data. Information collected was overturned on a spreadsheet to be analyzed. *Statgraphic Plus 5.1* software was used to apply multiple regression technique for a statistical analysis.

An algorithm to calculate the real consumption of energy was obtained taking under consideration the significance of each variable. The algorithm allowed the assessment of Carbon Footprint of this specific car for different scenarios where the number of occupants, the use of air conditioning and the type of rout is considered. Results are presented in Results and Discussion section.

3.2 Project 2: Home care project

Objectives, resources and time available for this project conditioned the analysis to a theoretical assessment. The fleet was composed by 3 electric car models (Peugeot ION, Renault Fluence Z.E and Th!nk City) and a Renault Megan III powered by diesel. Calculation for the electric vehicles was carried out using the energy consumption information provided by the manufacturer except for Th!nk model that was already analyzed in the previous project. Renault Megan III emissions data was taken from the specifications report. An additional car powered by diesel, Smart for two, was considered with comparison purposes due to it similarity in performance to the smaller vehicles used in the project as Renault Megan III has similar performance to the biggest one (Renault Fluence Z.E).

3.3 Carbon Footprint assessment

Carbon Footprint of the use-phase of each car model was obtained by calculation CO_2 equivalent emissions (CO_2e) from the average energy consumption. The functional unit used was kilometer route. Experimental analysis allowed us to evaluate different scenarios considering the significant variables and all three route types where average speed was obtained from the analysis of the experiences. The average energy consumption for the theoretical project was obtained from the specifications report and respond to a mixed route (urban and interurban).

The conversion from energy consumption (measured in kWh/km) into CO_2e emissions (measured in gCO_2e/km) was made by applying the corresponding conversion factor; the Spanish electric energy conversion factor for year of study (2014). The conversion factor is obtained considering the emissions of greenhouse gasses released during the production of the electric energy needed to charge the vehicles. It has to be considered the different procedures and technologies used to produce the electric energy of the country where vehicles are charged. The electric mix is the parameter that takes these particularities under

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consideration. Main greenhouse gases emitted are CO_2 and NOx. NOx emissions are converted to CO_2e by the Global Warming Potential (GWP) (UNEP, 2007) where:

$GWP_{CO2} = 1$
$GWP_{NOX}=298$

The conversion factor for electric energy (CFee) is define in Equation 2.

$$CFee\ \left[\frac{gCO_2e}{kWh}\right] = CO_2emissions \cdot GWP_{CO2} + NO_xemissions \cdot GWP_{NOx} \quad (2)$$

The Carbon Footprint (CF) for electric vehicles is obtain by Equation 3.

$$CF\ \left[\frac{gCO_2e}{km}\right] = electric\ consumption \left[\frac{kWh}{km}\right] \cdot CFee \left[\frac{gCO_2e}{kWh}\right] \quad (3)$$

4. RESULTS AND DISCUSSION

The data analysis of Th!nk city experiences revealed if variables considered contribute significantly to the electric consumption of the car. Summary of results is shown in Table 4:

Variable	Contribution to electric consumption
Distance traveled	Significant
Average speed	Significant
Route type	Significant
Use of air conditioning	Significant
Occupants	Significant
Use of lights	Insignificant
Use of stereo	Insignificant
Windows position	Insignificant
Use of wiper	Insignificant

Table 4. Contribution of variables to electric consumption

The algorithm obtained for the electric consumption of Th!nk city is shown in Equation 4.

$$el.consumption\ \left[\frac{kWh}{km}\right] = 2.08301 + 1.76046 \cdot C + 0.218371 \cdot D - 1.56994 \cdot P1 - 1.35825 \cdot P2 + 1.44441 \cdot O - 0.01054 \cdot as \quad (4)$$

where *el. consumption* represents the electric consumption, C is the variable that represents the use of air conditioning (binary), D represents the distance traveled in kilometers, O represents the number of occupants and as the average speed in km/h. P1 and P2 are the variables that represents the route type (binary pair) according to Table 2. The R^2 parameter for the algorithm is 0.9030 indicating that the model explains the 90.30% of the electric consumption variation.

In order to assess the Carbon Footprint for Th!nk City, four scenarios were designed considering the significant variables using a kilometer route as functional unit. Each scenario was evaluated for all three type routes: urban, mixed and interurban where their average speed based on the experiences was 37 km/h, 53 km/h and 76 km/h, respectively. Table 5 shows the combination of variables used.

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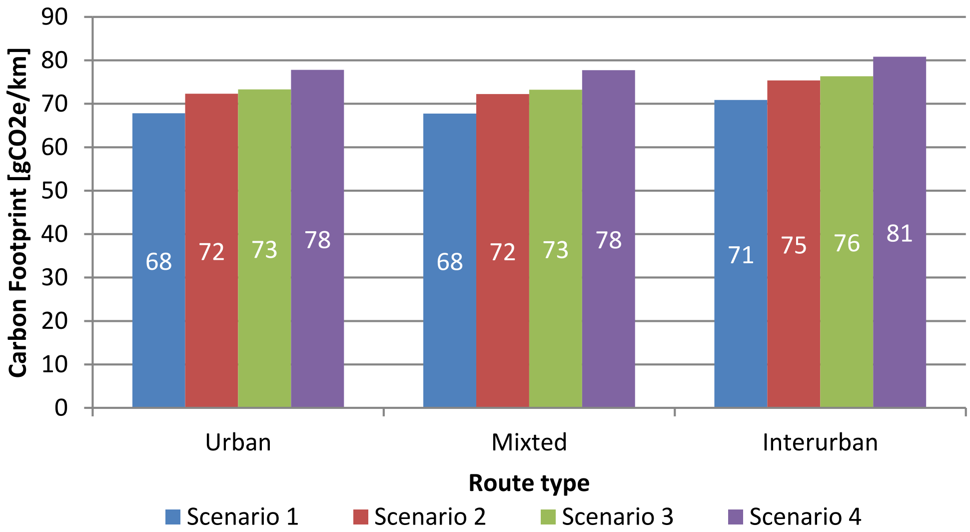
Scenario	C, air conditioning	O, occupants
1	0, off	1, only driver
2	0, off	2
3	1, on	1, only driver
4	1, on	2

Table 5. Scenarios for Carbon Footprint assessment for Th!nk City.

Spanish electric mix for the year of analysis, 2010, report 0.166 $kgCO_2/kWh$ and 2.17 10^{-4} kg NOx/kWh (Red Eléctrica Española, 2010). Carbon Footprint in grams of CO_2e by kilometers for each route type and scenario are shown in Figure 1.

Figure 1. Carbon Footprint of Th!nk City



As expected, two occupants with the air conditioning on have a highest Carbon Footprint. Urban and mixed routes have the same Carbon Footprint with no significant differences. Interurban routes rise the Carbon Footprint on a 4% on average. A deeper analysis of results is made further in this section when results of other vehicles are compared. The value chosen with comparison purposes for Th!nk City is the result of scenario 4 for mixed route.

Table 6 summarize the relevant technical specifications provided by the manufacturer for each model used in project 2 with an additional vehicle, Smart for Two. This car was added to the analysis in order to have a traditional motorization alternative for the less powered cars for comparison purposes.

Characteristics	**Th!nk city**	**Peugeot ION**	**Smart for Two**	**Renault Fluence Z.E**	**Renault Megan III**
Year	2010	2011	2015	2013	2014
Motorization	Electric	Electric	Petrol	Electric	Diesel
Power [kW]	30	49	52	70	70
Carbon Footprint [g CO_2e/km]	78	35	93	86	106
Source	Project 1	Based on official characteristi	Official characteristi cs report	Based on Official characteris	Official characteris tics report

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		cs report		tics report	

Table 6. Carbon Footprint of assessed vehicles

Smart for Two is the most similar vehicle with traditional engine in power and characteristics. The emission savings by using Th!nk City instead of Smart for Two is only a 16%. It has to be taken under consideration that the technology of this model is not the most recent. When comparing with a newer technology vehicle as Peugeot ION, the saving in emissions rises to a 62%. The savings between Fluence Z.E and Megan III is a 19%. Both vehicles with the latest technology and more power than the previous compared.

However, the highest benefit is not the emission savings but the source of the emission. The emissions from the generation of electricity are focused on the generation plant allowing a direct capture of CO_2. A deeper analysis can be made over available technology for CO_2 capturing in further researches. Traditional engines powered by petrol or diesel emits along all the planet as they are being used.

Results have certain limitations that need to be considered. The present analysis only focus on the use phase of the vehicles; the environmental impact and emissions of batteries and other components are not considered either in the manufacturing phase or the end of life phase. Likewise, the emissions coming from the production of petrol and diesel were not considered and would increase significantly the emissions of traditional vehicles. Finally, sources for this study are diverse and assumptions have been made both in the experimental and the theoretical analysis; the results of this study are only indicative of trends.

Other aspect to consider is the impact on society of these projects. In both cases, cars are in direct contact with the community. Reducing Carbon Footprint on this services not only avoid a high amount of CO_2e emissions, it also reduces noise in the city and give a cleaner perspective of the transport itself.

4. CONCLUSIONS

Two main benefits must be described for the use of electric cars in public fleets for services either open to citizens as Sagunto project or restricted to certain personnel as Home Care project: (a) CO_2 emissions are less on electric than on traditional vehicles, so is it Carbon Footprint. The balance is better when small cars are used. (b) Local source of emissions have alternative solutions and can be captured while traditional cars emit along their ride.

There are still many improvements needed and opportunities in this field, but applying and showing the community more efficient alternatives has significant impact on society.

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