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Electric vehicle adopters in Lisbon: motivation, utilization patterns and environmental impacts

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The introduction of alternative vehicle technologies as a response to pressure regarding fossil fuel dependency in the transportation sector poses several questions regarding their impact on travel and driving behaviour and also on the environment. This project aims to assess electric vehicle users' motivations, daily patterns and vehicle operation and management. Promoted by EMEL – Lisbon's mobility and parking municipal company – the project was publicized among Lisbon's electric vehicle users, who were offered, as an incentive, a green permit which allowed them to park the vehicles for free on the street within the city's metropolitan central area.
Data were gathered over a period of one year from 25 users (private and fleet drivers) through interviews and on-board diaries, comprising a total of 5,132 trips, 49,785 km travelled and a total of 8,529 kWh charged related to 831 charges. The results indicate that environmental and economic (lower running costs) factors are the main drivers for electric vehicle adoption by private users, whereas fleet drivers mention their company's image as the motive behind the deployment of this technology in fleets. Private users' energy consumption and CO2 emissions were also estimated. When compared to conventional internal combustion engine vehicles running on gasoline or diesel, electric vehicles reveal considerable reductions in both energy consumption and CO2 emissions in a Well-to-Wheel life cycle approach. These decreases are between 35–43% for energy consumption and 58–63% for CO2 emissions.

Keywords: *Driver behaviour, electric vehicle, adaptation, mobility, environmental impacts.*

1. Introduction

The transportation sector has been facing the dilemma of how to address its dependence on fossil fuels over the last few decades. The use of fossil fuels conveys large environmental costs as it is responsible for contributing massively to global greenhouse gas emissions. Changes in fuel characteristics or the introduction of alternative energy pathways can lead to lower emissions. Replacing conventional gasoline and diesel fuel has been subject of discussion over several decades (Hensher and Button, 2003). Improvements in technology will not themselves be enough.

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Behavioural change stands out as a critical factor in meeting the challenges of reducing energy consumption and emissions. It is essential to educate people to choose more efficient vehicles, how to use them and to change their driving patterns (Taylor et al, 2009).

Considering the potential contribution of the electric vehicle (EV) to more sustainable mobility as well as the rapid growth of adopters worldwide, the main objective of this study is to assess early adopters' adaptation and use of EVs in the city of Lisbon. Aspects including driving behaviour, mobility patterns and charging routines were analysed through interviews with EV drivers. More specifically, this study analysed early adopters' motivation to acquire and use EVs, adaptation and expectations of the vehicles, advantages and disadvantages, among other aspects. All these factors were analysed considering two types of fleet: private fleets and business fleets. Estimations of energy consumption and CO2 emissions were also assessed based on a lifecycle approach (LCA), considering a Well-to-Wheel (WTW) analysis. A comparison between technologies was performed: EV, and conventional internal combustion engines running on gasoline (ICE Gas) and diesel (ICE Diesel).

The remainder of this article is organized as follows. In Section 2 a literature review concerning the introduction of EV on the market is presented addressing its benefits and downsides, early adopters' characterization and mobility patterns and what are the environmental impacts of adopting the EV. Section 3 and 4 overview the methodology and the results obtained in the study. Section 5 concludes with a summary of the main findings of the study.

2. Literature review

The development of alternative vehicle technologies as a way of responding to the transportation sector dependency on fossil fuels has risen considerably over the last few decades. The introduction of these technologies poses questions regarding their impact on people's driving behaviour, mobility patterns, and safety performance and on the environment. Adopting these vehicles will convey new challenges to the users as they require a new interaction with the vehicle, mainly in relation to the recharging routines and vehicle management. Therefore, it is essential to understand how and what will change in consumers' mobility and driving patterns.

Manufacturers have been investing in promoting and introducing these vehicles in their fleets (Lieven et al, 2011) and a small group of early adopters have already embraced them, even though they are still not the consumers' first choice. Nonetheless, mass commercialization will occur in the long term, which will require the existence of transportation systems capable of integrating and fostering this new technology (IEA, 2012). However, alternative vehicle technologies are only now being introduced in the market and remain in development and constant evolution. This will pose new challenges to research. Issues such as advances in vehicle technology and the potential new interaction with these vehicles will constantly have to be addressed. A number of countries, such as the United Kingdom (UK; Greater London Authority, 2009), the United States of America (USA; PlaNYC, 2010), France and China (IBM, 2011) have developed strategic plans concerning the adoption of alternative vehicles in their countries. Those plans are primarily focused on analysing potential consumers and their preferences regarding vehicles as well as potential mobility changes that will come with EV use. This investment will create electric vehicle-friendly eco-systems, helping to build the foundations for widespread adoption (IEA, 2012). One of the main objectives of the energy strategy of the Portuguese Government has been to promote the development of specific industry clusters in Portugal, such as wind power turbines, solar panels and battery industries. Consequently, a strong investment in EV has been observed, namely with the launch of the Electric Mobility Plan/'Plano de Mobilidade Eléctrica' (MEI, 2009). A public recharging infrastructure has been deployed in Portugal, with 1,300 slow and 50 fast public recharging points available across the country. In addition to the electricity cost, users are charged a fee of €0.07/kWh for slow charging and

€0.20/kWh for fast charging (Ministério da Economia da Inovação e do Desenvolvimento, 2011). A survey conducted in six European countries (France, Germany, Italy, Poland, Spain and UK) indicated that a large majority (84%) of the respondents considered government incentives to support the diffusion of electric vehicles essential. Also, 40% believed that the market share of electric vehicles would increase rapidly. Italy and Spain were the more optimistic countries in terms of the future (Thiel et al, 2012).

2.1 Electric vehicle benefits and downsides

EVs have several advantages in relation to becoming the transportation mode of the future. However, there are also a number of drawbacks, compelling consumers to make complex and balanced assessments when deciding if they should purchase an EV. An on-line survey developed in Portugal to assess plug-in vehicle acceptance revealed that of 852 respondents, 13% and 25% were willing to buy an EV and plug-in hybrid electric vehicle (PHEV), respectively. However, when information regarding fuel price was provided, willingness to buy increased to 57% and 67% for EV and PHEV, respectively (Baptista et al, 2012a). In the USA, the results of a survey conducted with 2,302 drivers revealed that only 35% would buy a PHEV. This could be an indicator that the interest in adopting such technologies is shaped predominantly by the perceptions of their disadvantages (Carley et al, 2013; Hjorthol, 2013).

A study with the participation of early PHEV adopters in North America analysed how drivers use and recharge PHEVs, their recommendations for future PHEV evolution and their opinions of the vehicles. Drivers were enthusiastic about the technology and believed in its potential; however, concerns were expressed about the state of technology, battery life expectancy, vehicle autonomy (km range allowed by the vehicle’s battery) and charging behaviour and infrastructure (Kurani et al, 2008). High acquisition costs, limited driving range and long recharging hours have been identified by early adopters and potential buyers as the main disadvantages of electric vehicles (BOSCH, 2012; Carley et al, 2013; Hjorthol, 2013; Thiel et al, 2012). High fuel economy and lower energy costs are acknowledged as the main advantages of adopting these types of vehicles, as well as environmental considerations (Carley et al, 2013).

Business companies are also starting to deploy EVs in their fleets due to the numerous benefits they convey. These benefits can be: environmental, due to lower levels of energy spent; financial (lower running costs and revenue growth); operational, associated with a more pleasant driving experience; image related, contributing to the reputation of the business (BOSCH, 2012; EV20, 2012). However, corporations will face new challenges with the adoption of the EV, mostly associated with the charging infrastructure and investment necessary to deploy it (Coulomb Technologies, 2011). Uncertainties associated with the commercial robustness of the vehicles, their life expectancy and the long-term costs involved are also aspects that companies will have to consider (Feng and Figliozzi, 2013). Challenges concerning vehicle characteristics will also arise, demanding that companies develop strategic plans and goals for EV adoption. The deployment of EVs in fleets will only be successful if the following considerations are acknowledged: types of trips, travelling routes, fleet requirements and the willingness of drivers and employers to accept the vehicles, as well as their expectations and adaptation to EVs (GE Capital, 2012).

2.2 EV adoption: user characterization and mobility patterns

Across countries, early adopters and consumers with the stated intent to purchase EVs share common social demographic characteristics. Users are mainly between the ages of 30 and 50, highly educated, with high incomes, environmentally sensitive, belong to households with more than one car, and live in or in the vicinities of large cities (Baptista et al, 2012a; Carley et al, 2013; Hjorthol, 2013).

A survey was conducted with 260 neighbourhood electric vehicle (NEV) owners in California to determine why, how and when vehicles were used in daily routines. Concerning the motivation for acquiring the vehicle, 'NEV fits my lifestyle' stands out as the main reason (71.6%), followed by economic (62.35%) and environmental (56.17%) motives (Green Car Institute, 2003). The results indicate that the vehicles were predominantly used as replacements for conventional vehicles, even though the users continued to own ICE vehicles. EVs were used for several types of trips (local errands, visiting family and friends, personal recreation, etc.), and users made an average daily number of 3.89 trips (Green Car Institute, 2003). Hjorthol (2013) found that in Norway, commuting from home to work is one of the main reasons for using EVs and users display adjustments in trip management and the adoption of a smoother driving style. A long-term study trial was developed in the USA to assess private EV users' adaptation, charging behaviours, initial attitudes, motivation and behavioural changes. The results show that private users are intrinsically motivated, develop a greater self-efficacy in overcoming difficulties, adapt completely to the car and that plugging-in times become a routine (Burgess and Harris, 2009–2011). The results of a Portuguese survey to assess plug-in vehicle acceptance and probable usage patterns indicate that 70% of potential buyers would preferably recharge the vehicle at home, and 70–73% would recharge during night time (Baptista et al, 2012a). Concerning improvements to EVs, European drivers' preferences include the possibility of increasing the range and decreasing the price (Thiel et al, 2012).

Smart Move Case Studies, developed in the UK in 2011 by Cenex, revealed that fleet drivers scored their driving experience as equivalent or better when compared to driving conventional vehicles, namely with regard to driving smoothness, environmental performance and braking and acceleration performance (EV20, 2012). The study developed in California with NEVs revealed that main reasons why companies adopt EVs were the need for a vehicle that would fit the company's travel needs, an environmentally-friendly mode of transport, more affordable fleet vehicles and fuel savings. Small fleets also reported that the main uses of EVs were to deliver goods, provide personal mobility at work and carry business clients and associates (Green Car Institute, 2003). The charging patterns for the five organizations that took part in the Cenex study reveal that only 11.6% of charging time is related to cheap night rates. This pattern is to be expected as fleet charging occurs essentially at charging points installed in the company, and vehicles are plugged in multiple times throughout the day for short periods of time (EV20, 2012).

2.3 EV adoption: environmental impacts

There is no question that alternative vehicle technologies have the potential to reduce fuel dependency and reduce CO2 emissions. Alternative vehicle technologies might have an impact on users' driving patterns, which will influence individual fuel consumption and emissions. In relation to their performance and range capacity, it is possible to assert that EVs are better suited to urban driving contexts. There they achieve larger reductions in CO2 and other tailpipe emissions per km travelled. A study of the benefits of the introduction of EVs in Ireland concluded that in an urban context it is possible to achieve a reduction in CO2 emissions of 25–40%. This pattern can also be observed in the UK and USA (Smith, 2010). An analysis of the potential impacts of EVs in Adelaide and Sydney indicate that this technology can affect daily journeys of a 100 km charge range. As most daily journeys undertaken using conventional vehicles are within this range, each city could reduce its CO2 emissions by 5% (Taylor et al, 2009). Brady and O'Mahony (2011) used COPERT 4 to assess the potential reduction in emissions in relation to commuting. Within the different EV market penetration scenarios, the one most likely to occur in the following years is the low scenario, indicating a reduction of 3% in CO2 emissions. Doucette and McCulloch (2011) modelled the CO2 emissions of EVs and PHEVs, comparing them with reference values of CO2 emissions from ICE using New European Drive Cycle data. For low and medium CO2 charging intensity, EVs stand out as the best option over the entire driving range. However, for high CO2 charging intensity, the results indicate that PHEVs emit less over the entire driving range (Doucette and McCulloch, 2011).

A study performed for the Portuguese fleet, presenting a full lifecycle vehicle technologies and energy pathways analysis, concluded that vehicles powered with hydrogen and electricity present considerably lower WTW results in relation to both energy consumption and CO2 emissions. However, when considering only Well-to-Tank (WTT) efficiency, both alternative technologies show higher values than those of gasoline and diesel (Baptista et al, 2010). Another study that evaluated future energy consumption and emission scenarios for the Portuguese road transportation sector reveals that the introduction of alternative vehicle technologies could lead in the long term (2050) to energy consumption reductions of 2–66% and 7–73% for CO2 emissions. However, in the short term, it is essential to focus not only on the challenges and opportunities of each technology but also on the development of taxation and policies to promote public transportation use (Baptista et al, 2012b). Penetration scenarios for PHEVs and EVs show that by 2020, the introduction of these technologies will still be scarce. By 2030, a limited impact on CO2 emissions will be observed (Hawkins et al, 2012).

Although EVs present lower lifecycle CO2 emissions, this difference will depend on the carbon intensity of the marginal electricity production used to charge the vehicles (Crist, 2012). It is necessary to ensure that the demand for electricity that will come from the penetration of EVs in fleets will be met through renewable electricity (Hawkins et al, 2012). Model estimations comparing the costs and performance of EVs with ICEs reveal that the socio-economic viability of EVs is lower than that of ICEs. Even taking into consideration the cost of local pollutants and noise caused by conventional vehicles, EVs still present worse results. Besides the gains in CO2 emissions, an EV will cost the consumer an additional €12,000 and society an additional €15,000over its lifetime in comparison with conventional technology vehicles (Prud'homme and Koning, 2012). A comparison of the lifetime costs of EVs and ICEs indicate that for most scenarios, the marginal CO2 reduction costs of replacing conventional vehicles with EVs are still high. Even though EVs emit approximately 18 to 50 tonnes less CO2 over their lifetime, the cost to society, considering their actual features, is €7,000 to €12,000 more than that of ICEs (Crist, 2012). For these excess costs to be reduced, making the EV a more successful solution, several changes must occur: a reduction in purchase and battery costs, an increase in electric efficiency and an increase in oil costs. If these changes do not occur in the short term, massive subsidies will be needed to make EVs a viable socio-economic solution (Prud'homme and Koning, 2012).

3. Methodology

Promoted by EMEL (Lisbon's mobility and parking municipal company) and developed in collaboration with IDMEC (the Mechanical Engineering Institute of the Technical University of Lisbon), this research aimed to evaluate the adaptation to EV technology by private and fleet users by reaching a sample of up to 25 EV users. EMEL publicized the project among private users of electric vehicles as well as companies with EVs in their fleets. All the participants agreed to take part in interviews and private users agreed to have their mobility patterns monitored on a daily basis for one year. Both private and fleet users were given a green permit – an incentive created by EMEL – allowing them to park for free in the Lisbon metropolitan area for the duration of the project. Regarding private users, 13 drivers (10 male, three female) and 12 fleet drivers (11 male, one female) with an average age of 49.2 and 36.7 years, respectively, agreed to take part in the project. Regarding private drivers, the three female participants were the wives of three drivers, and were interviewed as they used the vehicle on a daily basis. The fleet drivers were from three Portuguese companies. On average, private users had 29.9 years of driving experience and fleet users had 19.6 years. At the beginning of the project, private users had owned their vehicle for an average of 5.7 months, using it seven days a week, and also owned at least one conventional vehicle. Fleet users only used the EV as a work instrument. They could use the vehicle every weekday or only when they needed to travel outside their workplace.

In the initial part of the project, each participant took part in an interview, composed of 28 open-ended questions for private users and 20 open-ended questions for fleet users. Drivers were questioned on aspects such as their motivation to acquire and use the vehicle and its advantages and disadvantages. Other traits, such as impacts on driving behaviour, mobility management and charging routines, were also discussed. Participants were also encouraged to suggest improvements to the vehicle and to articulate their expectations of the future. The interviews were taped and subsequently transcribed.

Private users were also asked to complete a daily on-board diary. This diary collected information including the day of the month, the number of trips made on that day, the number of kilometres travelled that day and the energy recharged (kWh) on that day. This information allowed assessment of vehicle operation and charging management. The information in the on-board diaries was collected monthly during the course of one year and relates to seven vehicles as the remaining participants failed to collect data as initially agreed. The assessment of the energy and environmental impact of the technology was undertaken using the lifecycle analysis (LCA) approach, considering the Well-to-Wheel (WTW) stage. This approach includes the Tank-to-Wheel stage (TTW), referring to fuel consumption and emissions resulting from moving the vehicle during the driving cycle. Data gathering through on-board diaries enabled assessment of users' energy consumption and CO2 emissions in the TTW stage. The Well-to-Tank (WTT) stage was also taken into consideration to allow a fair comparison between technologies. This stage accounts for the fuel production (Baptista et al, 2010). Reference values for WTT energy consumption and CO2 emissions for Portugal were used for electricity, gasoline and diesel (Baptista et al, 2010).

4. Results

4.1 Users' interview analysis

One of the main aspects to take into consideration when analysing users' profiles is to establish what motivates them to buy and use this alternative technology. Table 1 and Table 2 present results related to the factors influencing EV purchase. Private users mention environmental and economic (energy cost and running costs) factors as the main motives for purchasing the EV (62%), as shown in Table 1. Even though the majority of fleet users consider the environmental factor important (75%), 33% of fleet users consider that companies invest in EV to improve their image status (Table 2). Fleet users also mention the economic factor as influencing the purchase by companies (25%), as well as the types of trips for which the vehicle will be used (25%). The 8% of private users who state that there were no factors influencing the purchase corresponds to the responses of the wives of some of the drivers, indicating that they had no part in the decision.

Table 1 Factors influencing the EV purchase decision for private users (percentage of participants)

Factors influencing purchase	Private users (%)
Environmental	62
Economic	62
Professional	8
Changes in personal life	8
Interest in the technology	8
None	8

Table 2 Factors influencing companies' EV purchase decision according to fleet users (percentage of participants)

Factors influencing purchase	Fleet users (%)
Environmental	75
Image status	33
Economic	25
Type of trips	25

In terms of the main advantages of EVs, private users mention economic (85%), driving comfort (77%) and environmental (46%) factors, as seen in Table 3. Other aspects mentioned with less emphasis are fossil fuel independence (23%), vehicle design (8%) and safety (8%). In contrast, for fleet users, the vehicle's main advantages are the environmental factor (67%) and driving comfort (50%). In comparison with private users, fleet drivers disregard the economic factor as an advantage (Table 3). Both private and fleet users consider the vehicle's autonomy as its main disadvantage (77% and 83%, respectively), as seen in Table 3. The charging infrastructure is also considered a negative aspect by both private (15%) and fleet (25%) users. Fleet users mention the vehicle's acquisition cost as a disadvantage (33%), but only 15% of private users mention this aspect, as seen in Table 3.

Table 3 EV advantages and disadvantages according to private and fleet users (percentage of participants)

Advantages of EV	Private users (%)	Fleet users (%)	Disadvantages of EV	Private users (%)	Fleet users (%)
Economic	85	8	Autonomy	77	83
Driving comfort	77	50	Charging infrastructure	15	25
Environmental	46	67	Purchase cost	15	33
Fossil fuel independence	23	0	Vehicle design	15	0
Vehicle design	8	33	Vehicle safety	8	8
Safety	8	0	Vehicle speed	0	17
Vehicle Power	0	25	Absence of vehicle noise	0	17
			None	8	8

The majority of private users (75%) consider that the lower energy cost outweighs the vehicle's high acquisition cost, while 8% think the opposite and 17% have no view on this matter. Fleet drivers consider that low energy costs can overshadow the initial high investment when buying the EV (45%). However, 45% think the contrary and 9% still have no perception. All participants from both groups of drivers mention an immediate adaptation to the vehicle, even though 62% of private users and 8% of fleet users state they anticipated problems adapting to EV use in relation to aspects such as the vehicle autonomy and the charging infrastructure.

For private users, the main differences between driving an EV and an ICE are related to the fact that there is no need to make trips to a petrol station (31%) and the existence of the estimated available autonomy alert (31%) shown on the vehicle dashboard. These factors are followed by driving smoothness (23%) and vehicle power (23%), as seen in Table 4. Fleet drivers either mention driving smoothness (33%) and the lack of trips to petrol stations (25%). However, 33% of fleet users mention that there are no differences between driving both technologies, although also indicating that they use the vehicle for short periods of time (Table 4).

Autonomy stands out as the main concern for both private and fleet drivers when driving the EV, at 85% and 50%, respectively. Concerns for pedestrians, safety and speed are also mentioned but with less emphasis (Table 5). Regarding concerns when driving ICEs, 58% of fleet drivers reveal having none and 25% indicate concerns regarding fuel cost and speed. In contrast, as presented in Table 5, private drivers state that they have concerns about using fossil fuels (31%) when driving ICEs, followed by concerns for the environment (15%) and safety issues (15%). Private drivers also mention having no concerns when driving ICEs (23%).

Table 4 Perceived differences between driving an EV and ICE according to private and fleet users (percentage of participants)

Differences between driving an EV and ICE	Private users (%)	Fleet users (%)
No trips to petrol station	31	25
Alert of estimated available autonomy on EV dashboard	31	8
EV's driving smoothness	23	33
EV's higher vehicle power	23	8
No gear changes in the EV	15	8
EV's lower running costs	15	0
EV does not use fossil fuels	8	0
EV's smaller size	8	0
Different trip management with EV	0	17
Need to search for a charging station with EV	0	8
None	0	33

Table 5 Perceived concerns when driving an EV and an ICE according to private and fleet users (percentage of participants)

Concerns driving an EV	Private users (%)	Fleet users (%)	Concerns driving an ICE	Private users (%)	Fleet users (%)
Autonomy	85	50	Fossil fuel use	31	0
Pedestrians	15	25	Environment	15	0
Safety	15	0	Safety	15	0
Speed	0	8	Noise	8	0
None	8	25	Fuel cost	8	25
			Speed	8	25
			Engine instrumentation	8	0
			None	23	58

Users' expectations concerning the future of the EV in Portugal indicate that 46% of private drivers and 33% of fleet drivers consider that the vehicle is the car of the future. Both types of drivers also believe that the market will start rising (42% and 23%, respectively). However, private users mention that there are no buying incentives (31%) and that there is still no market available in the country (8%). Fleet drivers indicate they would recommend the deployment of EVs in other fleets, mentioning that the types of trips (50%) and applications (8%) made with the EV should be taken into consideration.

Table 6 presents the results regarding the expected improvements considered necessary by participants to enhance the EV experience. As can be seen, autonomy (77%) is mentioned as the main improvement by both groups (77% and 67%), followed by enhancements to the charging infrastructure (69% and 33%). Fleet drivers also target vehicle design (25%) and purchase cost (25%) as issues in need of further improvement. Issues such as vehicle performance (17%) and vehicle management (8%) and promotion (8%) are also mentioned by fleet drivers (Table 6).

Table 6 Expected EV improvements according to private and fleet users (percentage of participants)

Improvements	Private users (%)	Fleet users (%)
Autonomy	77	67
Charging infrastructure	69	33
Design	8	25
Purchase cost	8	25
Vehicle performance	0	17
Vehicle management	0	8
Vehicle promotion	0	8

Of the private users, 54% consider that the adoption of the EV has had no impact on their daily mobility routines. However, 46% mention that after starting to use the vehicle their mobility routines changed (Table 7): the drivers report making more trips in the EV (67%) and undertaking different trip management (50%). Drivers also started using different types of roads (50%) and driving with more people on board the vehicle (17%), as seen in Table 7. The fleet drivers who consider that their mobility routines change when they use the EV (50%) also mention that they have to employ different trip management (100%).

When questioned about the impact of the EV on their driving style (Table 7), 69% of private drivers consider that their driving style has changed. They speed less (78%), are less aggressive (22%) and have a more efficient driving style (17%). As far as fleet drivers are concerned, 67% have noticed changes in their driving style. However, unlike private users, 38% consider that their driving style becomes more aggressive when driving the EV (Table 7).

Table 7 Impact on everyday mobility routines and driving style (percentage of participants)

Impact on everyday mobility routines	Private users (%)	Fleet users (%)	Impact on driving style	Private users (%)	Fleet users (%)
No	54	50	No	31	33
Yes	46	50	Yes	69	67
Changes observed in mobility routines			Changes observed in driving style		
More trips with the EV	67	0	Lower speed	78	17
Different type of road	50	0	Less aggressive driving	22	25
Different trip management	50	100	More efficient driving	17	25
Greater number of persons on board	17	0	More aggressive driving	0	38

The majority of private drivers (85%) use the vehicle to commute to work or drop their children at school and 62% to run small errands (Table 8). Concerning the driving context, 62% drive mainly in urban areas, while 38% commute using inter-urban routes. In fleets, all drivers use the EV for short trips (0–15 km) and occasionally some drivers (8%) use it for medium length trips (16–40km). These trips are mainly within an urban context (92%) and for periods of one day per week (83%) or several days per week (42%), as seen in Table 8.

Table 8 Private and fleet users' mobility patterns (percentage of participants)

Mobility patterns	Private users (%)	Mobility patterns	Fleet users (%)
Commute to work/school	85	Short trips (0–15km)	100
Errands	54	Medium trips (16–40 km)	8
Urban	62	Urban	92
Inter-urban	38	Inter-urban	17
Seven days a week	100	One day per week	83
		Several days per week	42

Concerning charging routines, private drivers charge their vehicles at home (92%) and on the street (38%), as shown in Table 9. At home, all drivers charge the vehicle during the night (100%) due to a special fee from the Portuguese electricity supplier (Table 10). However, some drivers also charge during the day (17%). The vehicle is charged at home every day (seven days a week) by 33% of the participants, twice a week by 17% and four times a week by 42%. When charging in the street, private drivers do so during the day (100%) and at night (20%). Both slow (80%) and fast charging (40%) points are used. On the street, 60% charge the vehicle seven days a week and 20% twice a week, as seen in Table 10. All private participants had to make changes to their home electrical systems to be able to charge their vehicles at home and 73% of the users mention that these charging routines match their initial expectations.

Table 9 Private users' charging locations (percentage of participants)

Charging location (%)	
Home	92
Street	38

Table 10 Private users' charging routines (percentage of participants)

Home charging routines (%)		Street charging routines (%)	
Day time	17	Day time	100
Night time	100	Night time	20
Seven days a week	33	Slow charging points	80
Twice a week	17	Fast charging points	40
Four times a week	42	Seven days a week	60
		Twice a week	20

Regarding fleet drivers, 42% do not charge the vehicle after using it, as presented in Table 11. When such behaviour occurs, it is done in the vicinity of the workplace by drivers who use the vehicle several days a week (42%) and by those who use the vehicle only one day a week (33%). Fleet drivers also charge in the street (25%) at slow-charging points (100%) and fast charging points (67%), as seen in Table 11.

Table 11 Fleet users charging patterns (percentage of participants)

Charging patterns (%)	
Do not charge the EV after using it	42
Work (one day per week use)	33
Work (use the EV several days a week)	42
Home (use the EV several days a week)	17
Street	25
Slow charge	100
Fast charge	67

4.2 On-board diary data

During the course of the project, seven private users completed an on-board diary. Overall, 1,243 days of driving were monitored, corresponding to 5,132 trips and 49,785 km travelled. Users made a total of 831 charges amounting to 8,529 kWh (Table 12).

Table 12 Total sample electric mobility profile

Days	km	Trips	Charges	kWh
1243	49786	5132	831	8529

As seen in Table 12, users made 3.5 trips per day and travelled 39.9 km per day. Charging routines show that users made 0.6 charges daily, consuming 6.3 kWh, which corresponds to 10.3 kWh consumed per charge and 0.157 kWh per km. Due to the small size of the sample (seven drivers) and its heterogeneity, the results reveal high standard deviations (STDEV) for most of the variables, indicating that a larger sample is necessary to obtain more statistically significant results. A confidence level analysis reveals that for a level of confidence of 90% and a deviation level of 20%, only two indicators (kWh/km and kWh/charge) have the necessary sample size to present robust results (between five and six drivers). For the remaining indicators, a sample of eight to 24 participants would be necessary to achieve more significant results (Table 13).

Table 13 Users' electric mobility profile, deviation and level of confidence

	km/day	Trips/day	Charges/day	kWh/day	kWh/km	kWh/trip	kWh/charge
Average EV	39.9	3.5	0.6	6.3	0.157	2.2	10.3
STDEV EV	24.4	2.3	0.2	3.1	0.1	1.2	3.3
Sample (90% CL, 20% Deviation)	21.05	24.58	8.19	13.87	6.42	16.66	5.71

4.3 Environmental impacts

The assessment of the energy and environmental impact of the technology was undertaken using the LCA approach, taking into consideration the WTW stage. A comparison between technologies was performed: EV, and conventional internal combustion engines running on gasoline (ICE Gas) and diesel (ICE Diesel).

Table 14 WTW energy consumption (MJ/km) and CO2 emissions (g/km): comparison between technologies (Baptista et al, 2010)

	TTW	WTT	TTW	WTT	WTW	
	Energy consumption		CO2 emissions		Energy consumption	CO2 emissions
	(MJ/km)	(MJ/km)	(g/km)	(g/km)	(MJ/km)	(g/km)
EV	0.62	0.65	0	62	1.27	62
ICE Gas	1.96	0.27	143	25	2.23	168
ICE Diesel	1.67	0.27	124	24	1.94	148

Energy consumption and CO2 emission reference values for Portugal were used for standard ICE Gas, ICE Diesel and electricity (Baptista et al, 2010). In relation to energy consumption, the results show that for the EV, TTW makes a smaller contribution (0.62 MJ/km) than ICE Gas and ICE Diesel, at 1.96 MJ/km and 1.67 MJ/km, respectively (Table 14). The opposite is observed when considering the WTT stage, as shown in Table 14. Overall, the EV presents lower WTW results, with an energy consumption of 1.27 MJ/km, while ICE Gas presents higher consumption results of 2.23 MJ/km. Concerning CO2 emissions, in TTW the electricity input is zero, but in WTT the electricity contribution is substantially higher (62 g/km) than that of fossil fuels. Globally, the EV exhibits reductions of between 35% and 43% in energy consumption and between 58% and 63% in CO2 emissions.

5. Discussion and conclusions

This study presents the results of a long-term project that followed both EV private drivers and fleet drivers. The aim of the project was to assess users' satisfaction and adaptation to an alternative vehicle technology, in this case fully electric vehicles. An initial interview was conducted with the participants to address aspects such as driving behaviour, mobility patterns, and charging routines, among others. Private drivers highlighted the economic and environmental aspects associated with the vehicle as the main reasons to purchase an EV. These motives follow the trend already found in other studies in which lifestyle, environmental and economic factors (energy and running costs) stand out as reasons to adopt an EV (Carley et al, 2013; Green Car Institute, 2003). Fleet drivers consider the environmental factor the main reason for deploying EVs in fleets. However, they also mention that investing in EVs will impact the company's image status. This is in accordance with other studies (BOSCH, 2012; EV20, 2012).

The results reveal that drivers adapt very well to the vehicle and that any concerns they may have in the beginning, whether related to the functioning of the vehicle, autonomy or charging infrastructure, are rapidly overcome. Private users mention that they make more trips and use different roads when using the EV. Fleet drivers state that different trip management is necessary when driving the vehicle. Overall, most drivers consider that the use of the EV has had an impact on their driving style. While private users report that they speed less, are less aggressive and adopt a more efficient driving style, fleet users indicate that their driving style becomes more aggressive. This might be explained by the novelty of the vehicle and the fact that fleet drivers tend to use the vehicle sporadically, leading them to test the vehicle in terms of its performance when using it.

Private drivers use the vehicle as a replacement for their conventional everyday vehicle, even though they still own at least one ICE. They use the EV for commuting and running errands, mainly in urban contexts. Their socio-demographic characteristics are in accordance with descriptions found in the literature: relatively young, environmentally aware, living in metropolitan areas (Baptista et al, 2012a; Carley et al, 2013). Mobility patterns reveal that users make an average of 3.5 trips and travel an average of 40 km per day. These findings are consistent with those found in the study developed in California with NEV adopters (Green Car Institute, 2003). Private users focused mainly on three positive aspects of the vehicle – economic, comfort and environmental – mentioning as the main disadvantages of the vehicle its autonomy and the infrastructure associated with it. These results are in accordance with other findings (Carley et al, 2013; IBM, 2011; Skippon and Garwood, 2011; Thiel et al, 2012; Hjorthol, 2013).

Private users charge at home and have made changes to their home electric systems for that purpose; a lower number of participants charge on the street. These results are consistent with findings of other studies that indicate that potential customers would consider recharging to be an overnight activity rather than an opportunity activity (Baptista et al, 2012a; Skippon and Garwood, 2011). The results found in this study are also indicators that these early adopters prefer to plan their trips ahead and determine a charging routine rather than take advantage of ad hoc recharging opportunities. This finding is in accordance with those found in studies developed in the USA (Burgess and Harris, 2009–2011). In fleets, the EV is used primarily for short trips and work-related mobility requirements (meetings, goods delivery). The vehicle is charged during the day, mostly at the company's premises. These patterns were also identified in the Cenex study and the Green Car Institute report (EV20, 2012; Green Car Institute, 2003). Private users apparently understand that the EV requires a more substantial initial investment than an ICE, but they consider it much cheaper to run, stating that the lower energy costs outweigh the higher acquisition costs. Fleet drivers would advise the deployment of EVs in other companies, but state that the types of trips and services should be taken into consideration. Such statements reveal the need to create strategic plans for the adoption of the EV in fleets, also mentioned in other studies (Coulomb Technologies, 2011; Feng and Figliozzi, 2013; GE Capital, 2012).

Concerning environmental performance, when compared to conventional technology, the LCA reveals that EVs represent considerable reductions in both energy consumption and CO2 emissions (35–43% and 58–63% respectively). The results are consonant with other findings that indicate potential CO2 emission reductions of 25–40% in urban contexts (Smith, 2010).

This research gives an inside look into early adopters' motivations for the adoption of and expectations of EVs, their adaptation process and routines associated with EV usage. This enables understanding of the barriers and advantages of this alternative technology in two distinct contexts: private users and business fleets. It is possible to assert that private drivers and fleet drivers make different uses of these vehicles and the overall system that surrounds them. This aspect should be taken into consideration when cities develop their strategic plans concerning the adoption of EV technology. Bearing in mind that private drivers prefer to charge at home and fleet drivers in the street or at the company's facilities, the allocation of charging points throughout the city should be determined accordingly. Charging points should be distributed in line with potential buyers' and early adopters' preferences, mainly near residential areas and company car parks.

Drivers consider that the lack of incentives in Portugal is one the reasons that is limiting the purchase of EVs. This suggests that governments should invest more in promoting the introduction of these vehicles in their fleets, for example by providing rebates or tax incentives for vehicle purchase, exemption from vehicle registration taxes or license fees, discounts on tolls and parking tariffs. In addition to financial incentives, other measures could be applied. In Portugal, EVs already have preferential parking places in some car parks and street parking areas. This measure could be augmented by giving access to restricted circulation lanes on urban roads or highways. However, these incentives must take into account the rebound effect that these vehicles might have on congestion rates. In the long term, when the adoption of EV is more widespread, EVs might contribute to higher levels of congestion in cities as drivers appear to make more trips using these vehicles. Therefore, policies such as pay- as-you drive measures could be outlined and applied not only to drivers of conventional technologies, but also to alternative vehicle technologies.

When used as low-mileage urban vehicle, and considering its advantages and disadvantages, the EV has proven to have sufficient potential to be integrated into fleets. However, they must be employed in areas where they will bring the most benefit. Business fleets must develop operational plans that take into account which aspects of the EV will work for their specific fleet. Also, companies should promote workshops to educate employers and fleet executives about the several applications that the EV can have within the company, from light-duty vehicles to heavy-duty and passenger transit vehicles. Training tools could also be developed in companies, focusing on concerns related to autonomy and charging routines. The deployment of EVs in business fleets could contribute to an uptake in the private consumer market. The positive experiences with EVs in fleets are expected to build greater confidence among other users.

Further information regarding fleet daily routines in terms of mobility and charging practices would allow a more profound understanding of the usage patterns of EVs in companies. Collecting information such as the state of charge, use of external applications (air conditioning, radio, etc.) and the frequency of use of these applications is also essential to assess the energy consumption of the EV as well as its environmental performance.

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References

Baptista, P., Tomás, T. and Silva, C. (2010). Plug-in hybrid fuel cell vehicles market penetration scenarios. *International Journal of Hydrogen Energy*, 35, 10024-10030.

Baptista, P., Rolim, C. and Silva, C. (2012a). Plug-in vehicle acceptance and probable utilization behaviour. *Journal of Transportation Technologies*, 2, 67-74.

Baptista, P., Silva, C., Farias, T. and Heywood, J. (2012b). Energy and environmental impacts of alternative pathways for the Portuguese road transportation sector. *Journal of Energy Policy*, 51, 802-815.

BOSCH (2012). *The Solution for Electric Vehicles in Commercial Fleets*. Bosch Software Innovation.

Brady, J. and O'Mahony, M. (2011). Travel to work in Dublin. The potential impacts of electric vehicles on climate change and urban air quality. *Transportation Research Part D*, 16, 188-193.

Burgess, M. and Harris, M. (2009-2011). *Behavioural Studies and Electric Vehicles. Ultra Low Carbon Vehicle Demonstrator Programme*. MINI E Project, UK.

Carley, S., Krause, R.M., Lane, B.W. and Gragam, J.D. (2013). Intent to purchase a plug-in electric vehicle: A survey of early impressions in large US cities. *Transportation Research Part D*, 18, 39-45.

Coulomb Technologies (2011). *Electric Vehicle Charging Solutions for Fleets*. Charge Point by Coulomb Technologies. Available from: http://www.verdek.com/pdf/Fleet-WhitePaper.pdf [Accessed April 2012].

Crist, P. (2012). Electric vehicles revisited: costs, subsidies and prospects. Discussion paper No 2012-13. *International Transport Forum*, OECD, Paris, France.

Doucette, R. and McCulloch, M. (2011). Modeling the prospects of plug-in hybrid electric vehicles to reduce CO2 emissions. *Applied Energy*, 88, 2315-2323.

EV20 Initiative (2012). *Plugged-In Fleets. A Guide to Deploying Electric Vehicles in Fleets*. The Climate Group.

Feng, W. and Figliozzi, M. (2013). An economic and technological analysis of the key factors affecting the competitiveness of electric commercial vehicles: A case study from the USA market. *Transportation Research Part C*, 26, 135-145.

GE Capital (2012). *Electric Vehicles: The Future is Now*. Deb Frodl, chief strategy officer for GE Capital, Fleet Services and global EV leader for GE. Available from: http://www.americas.gecapital.com/GECA/documents/EVs-the-future-is-now-FINAL.pdf [Accessed April 2012].

Greater London Authority (2009). *Turning London Electric. London's Electric Vehicle Infrastructure Strategy*. Technical Report, Greater London Authority, London, UK.

Green Car Institute (2003). *Study of NEV User Behavior in California*. Green Car Institute, San Louis Obispo, CA, USA.

Hawkins, R.T., Singh, B., Majeau-Bettez, G. and Strømman, H.A. (2012). Comparative environmental life cycle assessment of conventional and electric vehicles. *Journal of Industrial Ecology*, 17(1), 53-64.

Hensher, David A. and Button, Kenneth J. (2003) *Handbook of Transport and the Environment* Handbooks in Transport, vol. 4, Chapter 8, 2003.

Hjorthol, R. (2013). *Attitudes, Ownership and Use of Electric Vehicles – A Review of Literature*. TØI, Institute of Transport Economics, Norwegian Center for Transport Research. Report 1261/2013.

IBM (2011). *The Shift to Electric Vehicles. Putting Consumers in the Driver's Seat*. IBM Global Business Services, Executive Report.

IEA (2012). *EV City Casebook: A Look at the Global Electric Vehicle Movement 2012*.

Kurani, K.S., Heffner, R.R. and Turrentine, T.S. (2008). *Driving Plug-In Hybrid Electric Vehicles: Reports from US Drivers of HEVs Converted to PHEVs, circa 2006-07*. Institute of Transportation Studies, University of California, Davis. Research Report UCD-ITS-RR-08-24.

Lieven, T., Mühmlmeier, S., Henkel, S. and Waller, J.F (2011). Who will buy electric cars? An empirical study in Germany. *Transportation Research Part D*, 16, 236-243.

MEI (2009). *Mobilidade Eléctrica 'Portugal – Pioneiro na definição de um modelo nacional'*. Ministério da Economia e da Inovação, Lisbon, Portugal.

Ministério da Economia e da Inovação e do desenvolvimento (2011). *Regime económico –financeiro da actividade de operação de pontos de carregamento*. Portaria n.º 180/2011 de 2 de Maio.

PlaNYC (2010). *Exploring Electric Vehicle Adoption in New York City*. Technical Report. The City of New York, New York City, USA.

Prud'homme, R. and Koning, M. (2012). Electric vehicles: A tentative economic and environmental evaluation. *Transport Policy*, 23, 60-69.

Skippon, S. and Garwood, M. (2011). Responses to battery electric vehicles: UK consumer attitudes and attributions of symbolic meaning following direct experience to reduce psychological distance. *Transportation Research Part D*, 16, 525-531.

Smith, W.J. (2010). Can EV (electric vehicles) address Ireland's CO2 emissions from transport? *Energy*, 4514-4521.

Taylor, M., Pudney, P., Zito, R., Holyoak, N., Albrecht,A. and Raicu, R. (2009). *Planning for Electric Vehicles in Australia – Can We Match Environmental Requirements, Technology and Travel Demand?* Institute for Sustainable Systems and Technologies, University of South Australia, Adelaide, Australia.

Thiel, C., Alemanno, A., Scarcella, G., Zubaryeva, A. and Pasaoglu, G. (2012). *Attitude of European Car Drivers towards Electric Vehicles: A Survey.* JRC Scientific and Policy Reports. European Commission. Report EUR 25597 EN.