Data Analysis from Demonstrating Electric Mini – Buses in Portugal: Results and Conclusions

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Abstract

The growing need to evaluate mobility alternatives in Portugal emerged from the substantial increase of the car fleet, which occurred during the last decade, and of its negative effects.

Nowadays, the environmental pollution associated to the transport energy sub-sector, in Portugal, is affecting not only the population's quality of life, but is also putting at risk the conservation of the historic centres of the cities. The reversal of this tendency depends on the use of environmentally friendly vehicles, in which the electric vehicles play an important role.

The road electric vehicle, powered from the mains, presents the clear advantage of a zero local pollution rate. However, it should not be considered a zero emission vehicle, in a global perspective, since, depending on how the electricity is produced, it may or may not have produced pollutant emissions ("well to wheel analysis"). From this perspective, depending on the structure of the electricity production system, each country would realize the variable advantages and disadvantages related to the use of these vehicles.

In the sequence of a previous technical oriented analysis [1] [2], this paper aims to present the results of the social and operational monitoring performed during the last two and half years in 25 different cities (including one of the two which have already implemented a regular service), which allows to conclude on the real benefits related to the introduction of such vehicles in the Portuguese public transport fleets.

Keywords:

"Electric Vehicle", "Sustainable Mobility", "Demonstration", "Pollutant Emissions"

1. Introduction

The questions around pollutant emissions and greenhouse effects are no longer addressed as future problems; they are part of our present issues and require urgent solutions.

According to the "Portuguese Program for Climate Changes" (PNAC – Programa Nacional para as Alterações Climáticas) "the subject of climate changes constitutes a priority in the definition of sustainable development strategy, and it is one of its most important elements".

Since 1990, the energy utility sub-sector accounts for the highest contribution to the greenhouse gases, however, the transport sub-sector presents the greatest growth in the period between 1990 and 1999, see Figure 1.

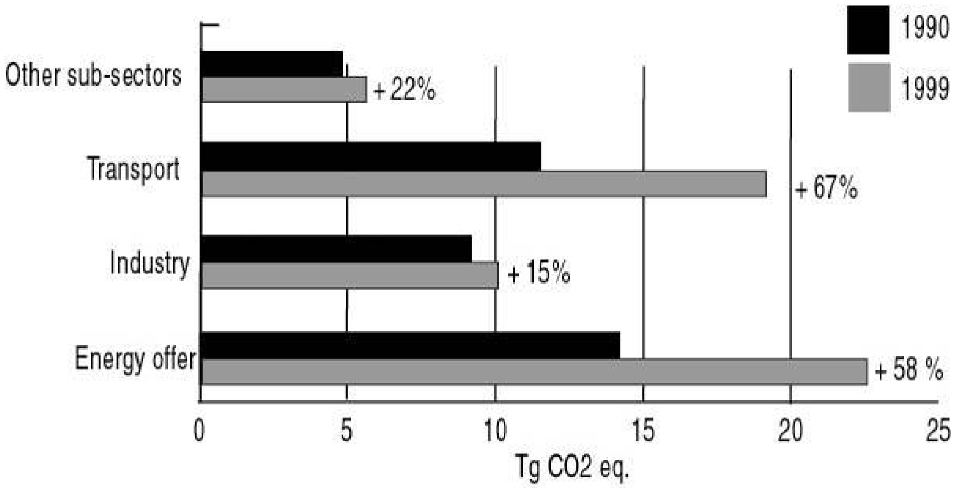

Figure 1 – Evolution of CO_{2eq} emissions in the energy sub-sectors from 1990 to 1999 [9].

In 2000, transports accounted for 29% of the total CO_2 emissions, between Industry that accounts for 26%, and Energy utilities accounting for 33% (figure 2). Because it is one of the major contributors to the emissions of greenhouse gases, the implementation of measures aimed at containing the associated negative impacts is considered urgent. In view of this, several measures were proposed in the Portuguese Program for Climate Changes, which strongly emphasizes the need to increase efficiency in the field of road transportation.

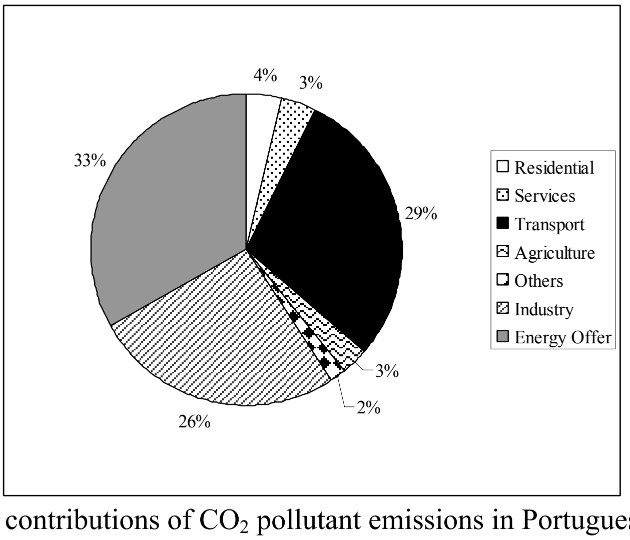

Figure 2 – Different contributions of CO_2 pollutant emissions in Portuguese sectors, 2000 [3].

Given the high efficiency of the electric motor, combined with the absence of local emissions, the electric vehicle appears once again as a logic alternative to conventional propulsion. The objective of this paper is to analyse the use of electric vehicles in real settings, over a significant period of time, in Portugal.

Figure 3 – Regular lines with Electric mini-bus in two Portuguese cities: Coimbra and Portalegre. Two more cities – Bragança and Viseu – are launching their lines now.

2. Demonstrating Electric Mini-Buses in Portugal - Background

The Directorate-General for Inland Transport and the Portuguese Electric Vehicle Association, developed the demonstration action “Introduction of Electric Buses in Public Transportation Fleets in Portugal”, not only to present alternative types of technologies in public transports, that are available today, but also to introduce new mobility concepts [8].

This closing action travelled to 24 Portuguese cities, over a period of two and a half years, allowing several municipalities, transport operators and all type of users to experience what this type of vehicles can offer.

This demonstration action was divided in two phases; the first, that included all the preparatory activities and preliminary tests, ran from September 2001 to February 2002. During this first phase, the “OREOS 55H” hybrid midi-bus, manufactured by Gépebus, was tested in several different places and settings, as well as the “GULLIVER” mini-buses, manufactured by Tecnobus.

Figure 4 – Hybrid Electric midi-bus “OREOS 55H”.

Figure 5 – Electric mini-bus “GULLIVER”.

During the second phase, which ran from June 2002 to January 2005, two electric “GULLIVER” mini-buses, manufactured by Tecnobus, were purchased and put into service in twenty four Portuguese cities, for periods of four to six weeks, having travelled more than 74.000 kilometres. Many of these cities adopted the operation system know as “blue line” (invented in Bordeaux), which means that the circuit is defined by a blue line painted on the pavement. There are no stops neither defined schedules, to enter or exit the bus. The passenger only needs to manifest this intention to the driver at any point of the “blue line” stretch. The gap between buses is approximately ten minutes which results on an average waiting time of five minutes (“forget the timetable frequency”).

As a result of this action, two Portuguese cities, Coimbra and Portalegre, have already implemented regular public transport services with electric mini-buses. Furthermore, until April 2005, two more cities, Viseu and Bragança, will also adopt this type of service.

3. Monitoring the Social Impact

Several tools were developed in order to assess the social impact, such as interviews with all the persons intervening in the bus service: drivers, mechanics, persons responsible for recharging; inquires to the passengers and monitoring of the variation in daily utilization. These surveys allowed to determinate the level of satisfaction with regard to the service provided by the two buses, from the perspective of the passenger and of the transport operator.

3.1 Inquiries to the Passengers

The inquiry allowed for assessing the public opinion towards the vehicle itself, the service provided and the use of alternative energies in public transports. The inquiry was made on board the bus, while in service, and was divided into four different parts:

- Opinion regarding the vehicle;
- Opinion regarding the circuit and the use of alternative energies in transports, in general;
- Use of public transport;
- Characterization of the passenger.

The following figure shows some of the results achieved.

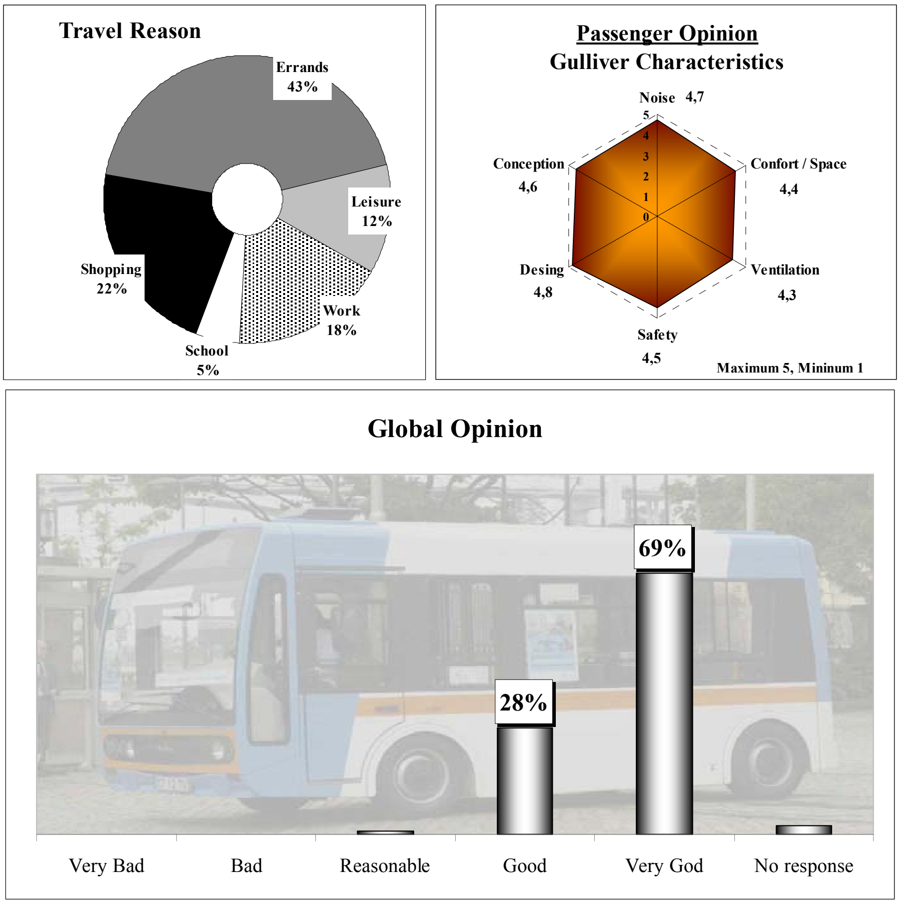

Figure 6 – Data resulting from the inquiries to passengers.

Figure 7 illustrates the summary of the average global opinion, considering the vehicle, the circuit, the type of service, schedules, etc. This indicator was analysed quantitatively, five of the answers corresponding to "very good" and one to "very bad". As this graph shows, all the values are above four, the mean value being 4.5, which means that the public global opinion towards this demonstration was very good.

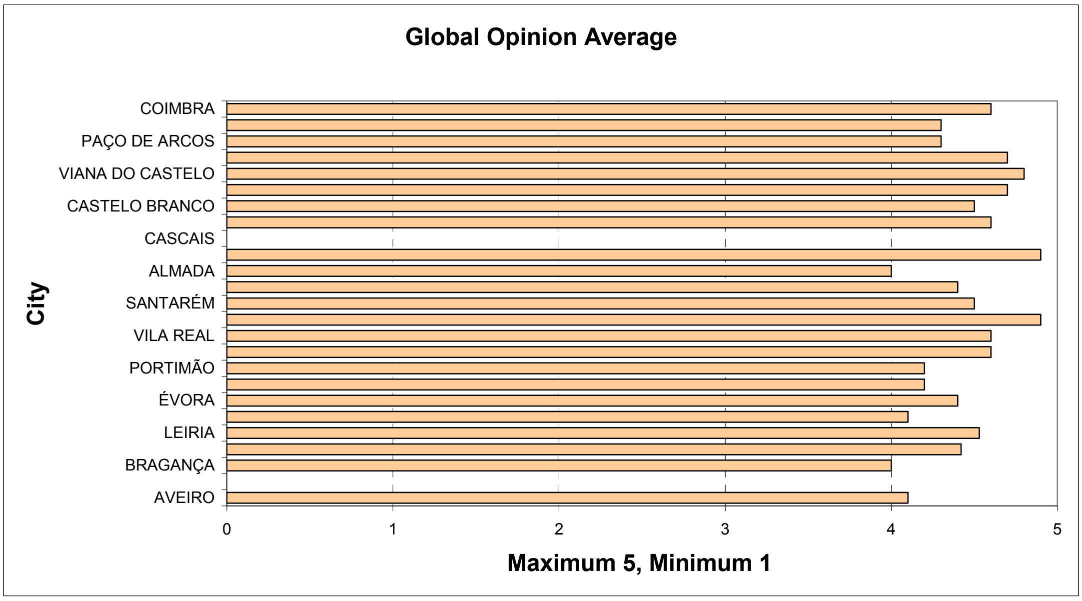

Figure 7 – Global Opinion Average in different cities.

One of the main reasons for this success is related to the fact that these vehicles were mainly used in areas where a conventional vehicle would not be appropriated, such as historical centres. Because they are electric, these vehicles can also co-relate in perfect harmony with the pedestrian, as they do not pollute locally and their circulation produces a greatly reduced noise. Two good examples are the cities of Coimbra and Portalegre that have implemented regular services, connecting the cities' historic centres to other important points of the city, without neglecting pedestrian areas. Such type of service could never have been implemented with a conventional vehicle without causing damage to valuable monuments and disturbing the pedestrians.

Figure 8 – Electric mini-buses in pedestrian areas of Portuguese cities.

3.2 Variation of Daily Utilization

The number of passengers getting on and off the buses was taken into account in determined and separated areas of each circuit, in order to calculate the variation of the daily utilization of each mini-bus in the different cities.

The passengers/trip and number of passengers/equivalent day can be seen in Figure 9. Calculating the average for these indicators one achieves 9 passengers/trip and 360 passengers/day equivalent. Note that these buses have a maximum capacity of 22 passengers.

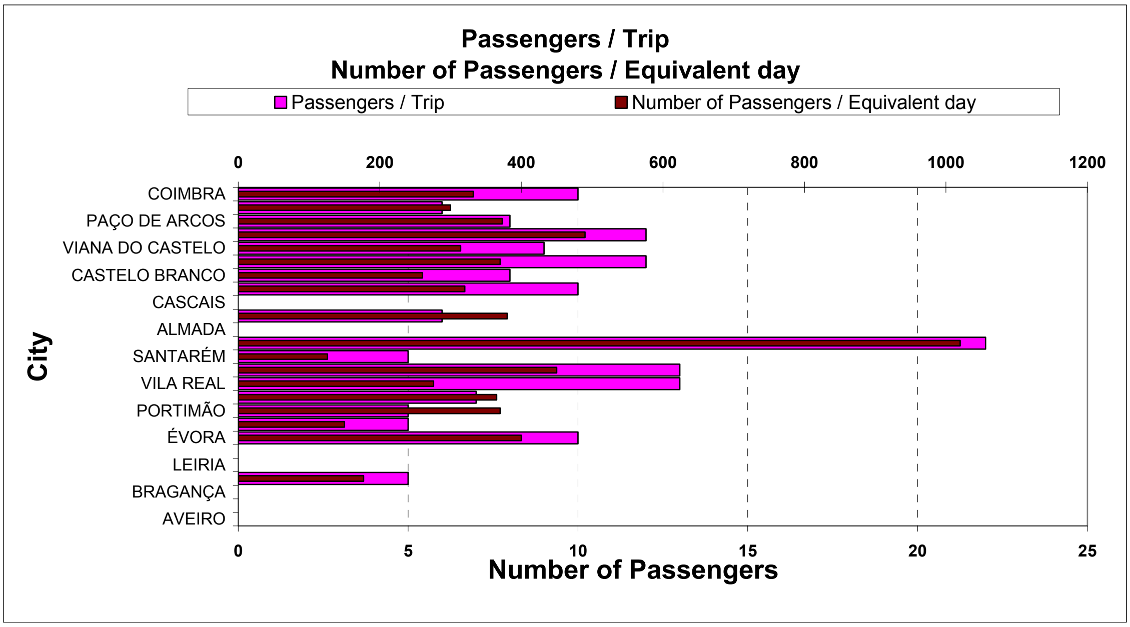

Figure 9 – Passengers/Trip and Passengers/Equivalent day in the different cities.

4. Monitoring the vehicles' performance

During the two and half years in which the second phase of the demonstration took place, several monitoring instruments were developed in order to assess the performance of the vehicles in different settings. The monitoring comprises several variables, in each of the aspects that we point out below.

4.1 Daily Consumption and Travelled Distance

These two values characterise the vehicles' performance on the road; the daily consumption depends on a large variety of factors, such as the driver's dynamic behaviour, slopes and number of passengers.

4.2 Daily Mean Consumption

The two values mentioned above enable to calculate the daily mean energy consumption, for which the efficiency of the recharging process was taken into account (see point 4.3). Figure 10 illustrates the different consumptions recorded for each city.

As the chart shows, the daily mean consumption presents a significant variation from one city to the other, which indicates its strong relation to the slopes of the circuits. The daily mean consumption – taking in account all cities – corresponds to 76 kWh/100km.

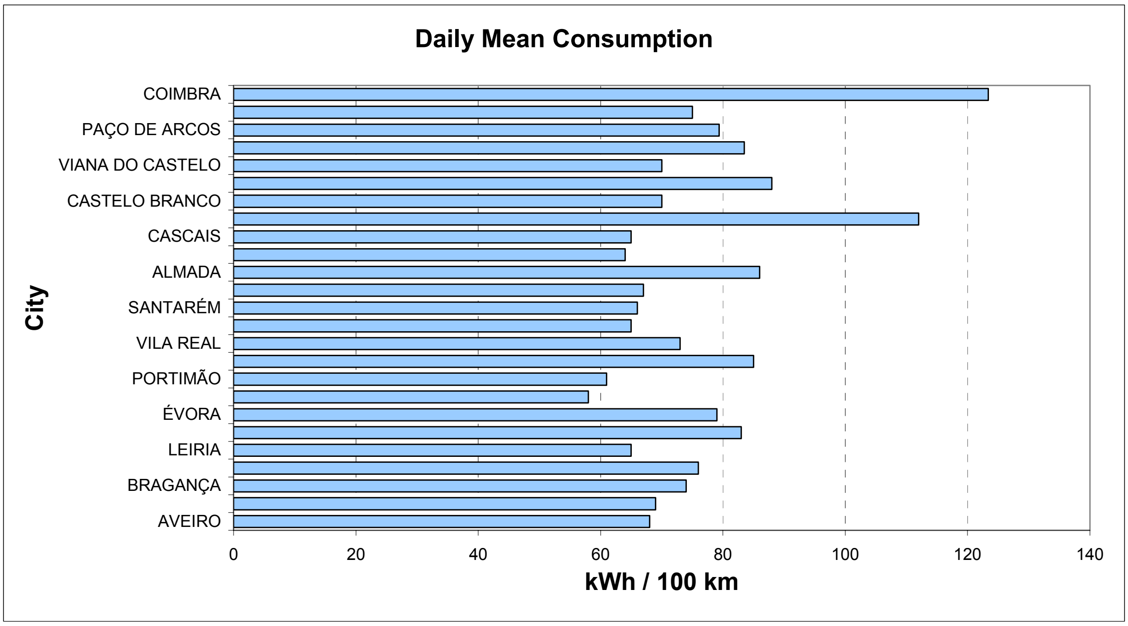

Figure 10 – Daily Mean Consumption in the different cities (kWh/100 km).

4.3 Battery Recharging

In order to determine the actual vehicle consumption, the efficiency of the recharging process was monitored and assessed. (Wall to Wheel). The resulting 65% efficiency is represented in the following scheme:

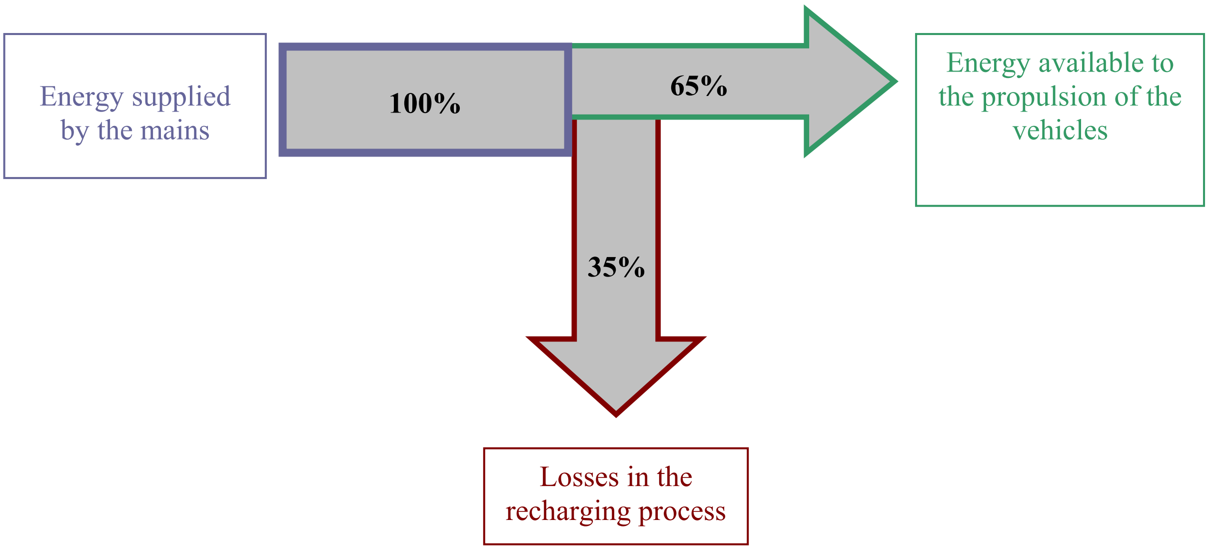

Figure 11 – Scheme of the recharging process efficiency.

5. Conclusions

The following figures represent the summary of the major variables monitored during the demonstration action, in terms of maximum, minimum and average values. From these we can characterize the average service provided by the two vehicles over the past two and a half years:

VARIABLE		ADJUSTED AVERAGE (1)	MIN/ MAX
Type of line (2)	Circular	23	
	Diametrical	2	
Average extension (km)		4	2,5/14
Type of operation	"Blue Line" (no stops)	14	
	With stops	12	
	Average No of stops	14	8/40
Average waiting time	"Blue Line" (min)	6,12	5/18
	With stops (min)	7,4	30
Average load	Per Day (No of passengers)	360	126/1020
	Per Trip (No of passengers)	9	5/22
Average daily travel (km/Bus) (3)		81,4	37/129
Average Energy consumption (kWh/100 km)		74,2	58/123,4
Energy cost	Electricity (4) (€ / 100 km)	5	
	Diesel equivalent (5) (€ / 100 km)	17	
Average global opinion of passengers on the experience (scale 1=min 5=max)		4,4	4/4,9
CO2	locally	0	0
	Production site (6) (g CO 2 eq / km)	390 (7)	
Tariff	Average single ticket (€)	0,5	0,20/1,25
	Free (experimental)	9	5/22

(1) Eliminating extreme or atypical values
(2) 20 out of 25 lines were newly designed, no existing lines having been found suitable
(3) Normally with 1 battery change
(4) bi-tariff (2/3 night - 1/3 day charging)
(5) 20 liter diesel / 100 km at 0,85 € / liter
(6) Resulting from year 2000 Portuguese production mix
(7) 525 in the case of an equivalent diesel bus

	City	Circulation Type		Blue Line / Stops				Extension	Gap Between Buses	Average Waiting Time	Passengers / Trip	Number of passengers / equivalent day	Fare	Daily Mean Consumption	Global Opinion Average	Kilometres / day
		Radial		10 S	Number fo Stops			= 1 km	= 3 min	= 3 min	= 2 passengers	= 60 passengers	= 10 cent	= 20 kWh/100km	= 1	= 20 km
		Diametrical		BL	Blue Line											
		Circular		NS	New Service			› 6 km	› 18 min	› 18 min	› 12 passengers	› 360 passengers	› 60 cent			› 120 km
				ES	Existing Service								F FREE			
1	AVEIRO	Circular		15 S			ES		20 - 40							
2	VISEU	Circular		12 S		NS							F			
3	BRAGANÇA	Diametrical	Diametrical	40 S			ES	14	60	30			1 €			
4	BRAGA	Circular		8 S		NS										
5	LEIRIA	Circular		9 S		NS										
6	BEJA	Circular		39 S			ES	9	20							
7	ÉVORA	Circular		12 S	BL	NS						400	F			130
8	SETÚBAL	Circular		19 S		NS			20							
9	PORTIMÃO	Circular		14 S		NS						370				
10	PORTALEGRE	Circular			BL	NS										
11	VILA REAL	Circular		15 S		NS			20		13		F			
12	MIRANDELA	Circular	Circular		BL	NS					13	450	F			
Maximum		Radial	0	S	12			14	60	30	22	1020	1,25	123,4	4,9	129
Minimum		Diametrical	2	BL	14			2,5	8	4	5	126	0,2	58	4	37
Average		Circular	23	NS	20	ES	5	4,6	16	8,1	9	360	0,5	76,2	4,5	79,9

Figure 12 – Summary of the major variables monitored during the demonstration action.

	City	Circulation Type	Blue Line / Stops				Extension	Gap Between Buses	Average Waiting Time	Passengers / Trip	Number of passengers / equivalent day	Fare	Daily Mean Consumption	Global Opinion Average	Kilometres / day
		Radial	10 S	Number fo Stops			= 1 km	= 3 min	= 3 min	= 2 passengers	= 60 passengers	= 10 cent	= 20 kWh/100km	= 1	= 20 km
		Diametrical	BL	Blue Line			› 6 km	› 18 min	› 18 min	› 12 passengers	› 360 passengers	› 60 cent			› 120 km
		Circular	NS	New Service								F FREE			
			ES	Existing Service											
13	SANTARÉM	Circular		BL	NS										
14	ENTRONCAMENTO	Circular		BL	NS					22	1020	F			130
15	ALMADA	Diametrical	17 S			CE		15 - 20							
16	VILA FRANCA DE XIRA	Circular		BL	NS						380	F			
17	CASCAIS	Circular	17 S			CE						0,7 €			
18	ABRANTES	Circular		BL	NS							F			
19	CASTELO BRANCO	Circular		BL	NS							F			
20	GOUVEIA	Circular		BL	NS						370	F			
21	VIANA DO CASTELO	Circular		BL	NS										
22	S JOÃO DA MADEIRA	Circular		BL	NS						490	F			
23	PAÇO DE ARCOS	Circular		BL	NS						373	F			
24	OEIRAS	Circular		BL	NS							F			
C	COIMBRA	Circular		BL	NS										
	Maximum	Radial 0	S	12			14	60	30	22	1020	1,25	123,4	4,9	129
	Minimum	Diametrical 2	BL	14			2,5	8	4	5	126	0,2	58	4	37
	Average	Circular 23	NS	20	ES	5	4,6	16	8,1	9	360	0,5	76,2	4,5	79,9

Figure 13 – Summary of the major variables monitored during the demonstration action (cont.).

8. References

[1] I. Santos, J. Esteves, M. J. Resende, R. Stüssi, ***Improvement on Environment by Using EV's. The Portuguese Perspective***, Proceedings of 2004EET – European ELE-DRIVE TRASNPORTATION Conference & Exhibition, Estoril, Portugal, 2004.

[2] I. Santos, J. Esteves, M. J. Resende, R. Stüssi, ***EV's Contribution for a Sustainable Mobility Case Study for Portugal***, Proceedings of EVS 20 – International Electric Vehicles Symposium, Long Beach, California, 2003.

[3] Direcção Geral do Ambiente, ***Programa Nacional para as Alterações Climáticas – Medidas Adicionais Taxa sobre o Carbono para Discussão Pública***, 2003. Comissão das Alterações Climáticas, Portugal, 2003.

[4] Instituto do Ambiente, Centro de Estudos em Economia da Energia, dos Transportes e do Ambiente, Departamento de Ciências e Engenharia do Ambiente, FCT/UNL, ***PNAC Volume 4 – TRANSPORTES - CENÁRIO DE REFERÊNCIA 2000-2010***, Portugal, 2003.

[5] Instituto do Ambiente, Centro de Estudos em Economia da Energia, dos Transportes e do Ambiente, Departamento de Ciências e Engenharia do Ambiente, FCT/UNL, ***PNAC Volume 5 - Oferta de Energia - CENÁRIO DE REFERÊNCIA 2000-2010***, Portugal, 2003.

[6] J. Esteves, F. Vale, N. Teixeira, I. Santos, P. Matos, T. Farias, R. Stüssi, ***Hybrid Electric Buses: Dimensioning the Intermediate Electric Storage Stage***, Proceedings of 7th International Conference of ELECTRIMACS, Montreal, Canada, 2002.

[7] J. Esteves, R. Stussi, ***Introduction of Electric Buses in Portuguese Public Transportation Fleets*****, Proceedings of EVS 19** - International Electrical Vehicles Symposium, Busan, Korea, 2002.

[8] APVE*,* ***Demonstração de Autocarros Eléctricos Amigos do Ambiente Urbano****, Report on the test and vehicle selection phase*, 2002.

[9] Direcção Geral do Ambiente, ***Programa Nacional para as Alterações Climáticas*****, 2001**. DGA, Portugal, 2001.

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