# Electric Mini-Buses in Portugal: Results and Conclusions

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This paper aims to present the results from operational monitoring, performed with electric mini-buses, during the last two and half years in 25 different Portuguese cities (including one of the three which have already implemented a regular service), concluding on the real benefits related to the introduction of electric vehicles in the Portuguese public transport fleets.

## 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.

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.

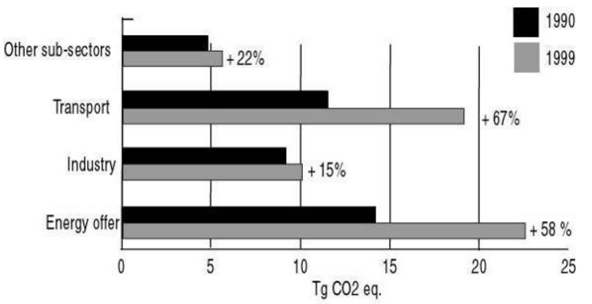



Figure 1: Evolution of $CO_{2eq}$ emissions in the energy sub-sectors from 1990 to 1999 [9].

In 2000, transports accounted for 29% of the total CO2 emissions, between Industry that accounts for 26%, and Energy utilities accounting for 33% (figure 2). Because transportation is one of the major contributors to greenhouse gases emissions, the implementation of measures is considered urgent. 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.

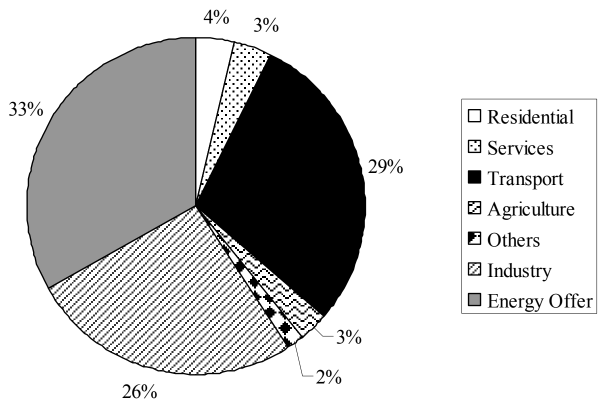



Figure 2: Different contributions of CO2 pollutant emissions in Portuguese sectors, 2000 [3].

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


Figure 3: Regular lines with electric mini-bus in three Portuguese cities: Coimbra Portalegre and Bragança. Two cities, Viseu and Viana do Castelo, decided also adopt this type of service.

## 2 DEMONSTRATING ELECTRIC MINI-BUSES IN PORTUGAL

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 demonstration action travelled to 25 Portuguese cities, over a period of two and a half years, allowing several municipalities, transport operators and all type of users to experience this type of vehicles.

The action was divided in two phases; the first, that included all the preparatory activities and preliminary tests, ran from September 2001 till February 2002. During this first phase, two buses were tested in several different places and conditions: the "OREOS 55H" hybrid midi-bus, manufactured by Gépebus, and the "GULLIVER" mini-bus, manufactured by Tecnobus.


Figure 4: Hybrid Electric midi-bus "OREOS 55H".

During the second phase, which ran from June 2002 till January 2005, two electric "GULLIVER" mini-buses, manufactured by Tecnobus, were purchased and put into service for periods of four to six weeks, in twenty four Portuguese cities, 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 intention to enter or exit the bus to the driver at any point of the "blue line". The time gap between buses is programmed to be approximately ten minutes which results on an average waiting time of five minutes ("forget the timetable frequency").


Figure 5: Electric mini-bus "GULLIVER".

As a result from this demonstration action, three Portuguese cities, Coimbra, Portalegre and Bragança, have already implemented regular public transport services in their historic centres, with electric mini-buses. Furthermore, two cities, Viseu and Viana do Castelo, decided also adopt this type of service.

## 3 MONITORING THE VEHICLES' PERFORMANCE

During the demonstration action, several monitoring tools were developed in order to assess the vehicles performance in different conditions, comprising several variables.

### 3.1 Daily Consumption and Travelled Distance

Daily consumption and travelled distance are two values characterising the vehicles' performance on the road. Daily consumption depends on a large variety of factors, such as the driver's dynamic behaviour, speed, slopes and number of passengers.

### 3.2 Daily Mean Consumption

The two values mentioned above enable to calculate the daily mean energy consumption, where the efficiency of the recharging process is also taken into account (see point 3.3). Figure 6 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, indicating its strong relation with the slopes of the circuits. Taking into account all tested cities, the daily mean consumption of the two electric mini-buses corresponds to 76 kWh/100km.

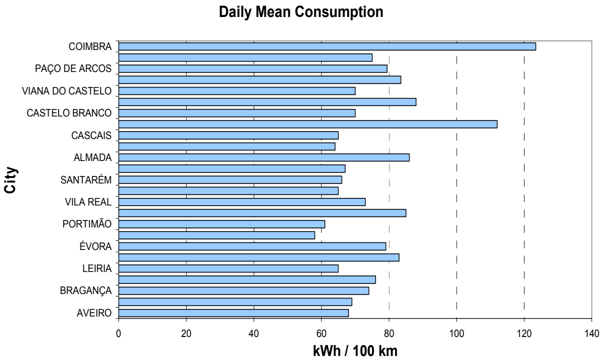



Figure 6: Daily Mean Consumption in the different cities (kWh/100 km).

### 3.3 Statistical Analysis of Energy Consumption

During the demonstration action two monitoring procedures were developed, which allowed the determination of the daily mean consumption of the two electric minibuses. One of these actions consisted in the monitoring of the battery recharging process, allowing the calculation the recharging process efficiency, see figure 7.

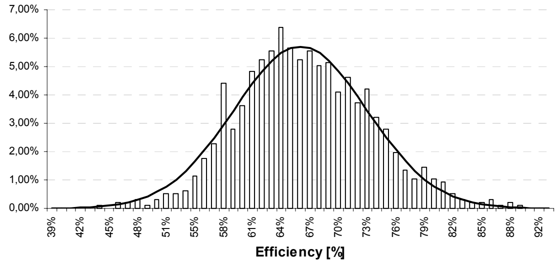



Figure 7: Probability Density Function of the efficiency corresponding to the batteries recharging process.

The values given in the previous figure represent a random variable and where submitted to the “random test” [10] and to the “goodness of fit test” [10], which allows to test whether a random sample corresponds to a specified, or partially specified, probability function. In this case, the group of values fit the normal distribution with a mean of 66% and a standard deviation of 6,7% meaning a coefficient of variability of 10%.

The same tests were performed in the total sample (corresponding to 24 cities) of daily energy consumption. However, this variable does not follow a normal distribution, figure 8.

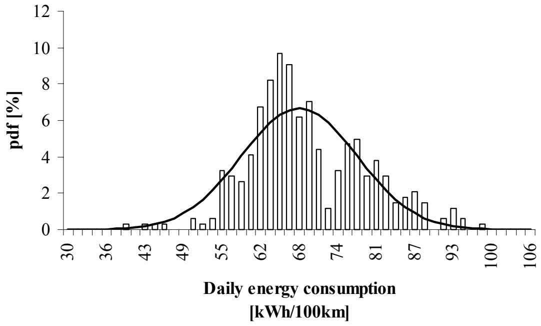



Figure 8: Probability Density Function of the daily energy consumption.

A careful observation of the previous figure indicates that there are two distinct normal distribution functions, corresponding each to the two groups of cities with higher and lower consumption values.

Separating the lower and the higher consumption cities, the following probability distribution and cumulative distribution functions were obtained.

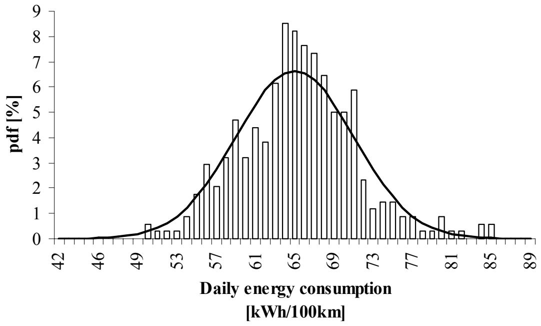



Figure 9: Probability Density Function of the daily energy consumption of the lower consumption cities.

Applying now the random and the goodness of fit tests, to these new values, the normal distribution fits with a mean of 65 kWh/100 km and a standard deviation of 6 kWh/100 km, which imply a coefficient of variability of 9%.

In figure 10, the normal distribution fit can be easily observed.

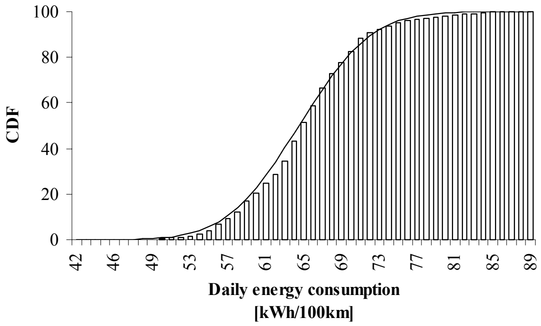



Figure 10: Cumulative Distribution Function of the daily energy consumption of the lower consumption cities.

The same process was applied to the higher consumption cities, which confirmed the normal distribution fit with a mean of 80 kWh/100 km and a standard deviation of 6 kWh/100 km, which imply a coefficient of variability of 7,5%. These set of values can be observed in figure 11 and 12.

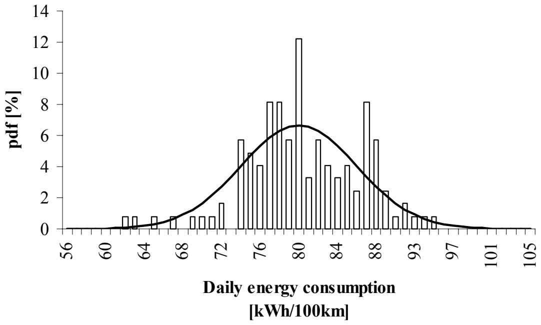



Figure 11: Probability Density Function of the daily energy consumption of the higher consumption cities.

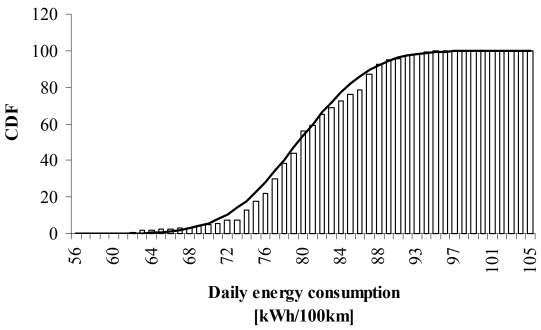



Figure 12: Cumulative Distribution Function of the daily energy consumption of the higher consumption cities.

## 4 PORTUGUESE ELECTRICITY PRODUCTION SYSTEM

### 4.1 Evolution

From a general point of view, the positive contribution of using electric vehicles depends strongly on the processes of electricity production. Figure 13 shows the installed capacity evolution of the Portuguese Electricity System (SEN) during the last twenty years.

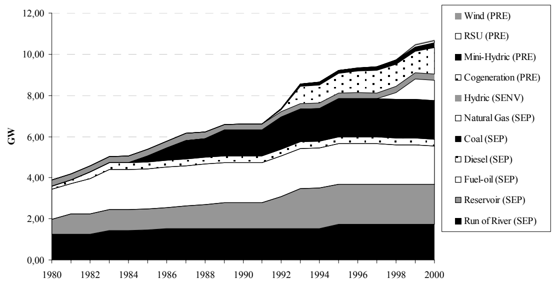



Figure 13: Evolution of the installed capacity of the SEN [11]

PRE – Special Regime Generation
SENV – Non – Binding Electricity System
RSU – Biomass Power Station
SEP – Public Service Electricity System

Hydroelectricity has been a tradition in Portugal. Electricity production from renewable energies - cogeneration and biomass - emerged only in the nineties and presently, represents nearly 15% of the total installed capacity of the SEN.

On the other hand, in 1999, a natural gas combined-cycle power-plant at Tapada do Outeiro has started operation. This power station, characterized by an efficiency of 54% and very low emission levels, seems to be the right approach concerning thermal production options.

For the most important pollutants, figure 14 to 17 show the evolution of the specific emissions (g/kWh) arising from the Portuguese thermal power-stations.

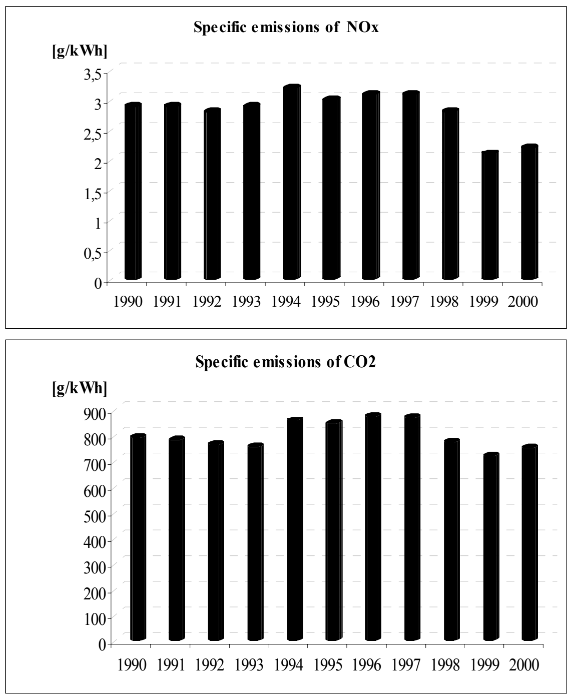



Figure 14 and 15: Evolution of the specific emissions of CO2 and NOx of the SEN [11]

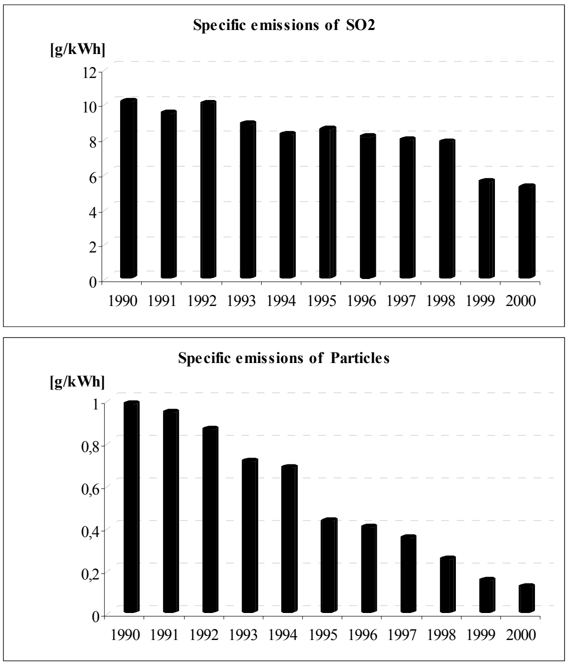



Figure 16 and 17: Evolution of the specific emissions of SO2 and Particles of the SEN [11]

### 4.2 Pollutant Emissions

A clear dependence of annual pollutant emission levels is related to the ratio between electricity production in thermal and hydroelectric power plants. Rain precipitation and other factors are essential for the definition of the electricity production annual "mix" and, consequently, for the emissions level definition of the Portuguese electricity production system.

Although electric vehicles (EV) are locally zero-emission vehicles, the electricity production to power them, presents environmental impacts. Those environmental issues are associated to all types of electricity production - for even, power-stations using renewable resources also cause disturbances in the surrounding ecosystems.

A thermal power-station produces pollutant emissions of sulphur oxide ($SO_x$), essentially sulphur dioxide ($SO_2$), carbon dioxide ($CO_2$), carbon monoxide (CO), and Particles (PM). These pollutant emissions have several consequences as acidification incidents, mainly produced by the two mentioned oxides, the increase greenhouse effect caused by the emissions of $CO_2$, and as the health damage associated to disturbances at the local ecosystems due to emissions of particles.

When an EV is recharging, it is not possible to determine which specific power-station is supplying the electricity, being possible to assume several recharging scenarios. In this paper we assumed that the vehicle is being fed by a combination of all power-stations of the Portuguese Electricity System. For that, the production "mix" of electricity needs to be calculated and the year 2000 "mix", represented in figure 18, was used.

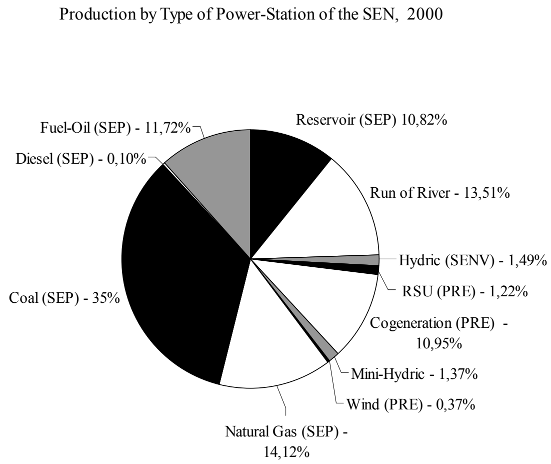



Figure 18: Production of Electricity of the SEN, 2000 [11]

Knowing the specific emissions [12] [13] [14] from each power-station, and considering the previous "mix", the pollutant emissions for an EV in Portugal can be determined (Table 1).

| | Specific Pollutant Emissions [g/kWh] |
|---|---|
| $SO_2$ | 3,14 |
| $NO_x$ | 1,32 |
| $CO_2$ | 442 |
| CO | 0,01 |
| Particles | 0,1 |

Table 1: Specific pollutant emissions of an EV concerning the production "mix" of 2000

### 4.3 Future Perspectives on Electricity Production in Portugal

A permanent effort to reduce the particles emission (reduction to one tenth in the last ten years period) and a diminution of $SO_2$ and $NO_x$ associated to the begining of electricity production at the Tapada do Outeiro power station was verified.

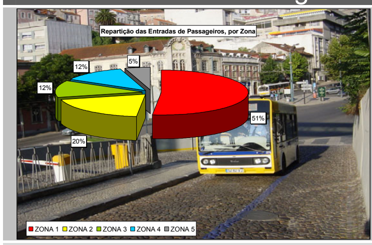
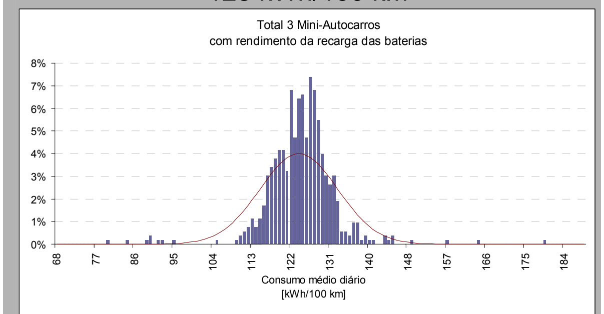
This trend is expected to improve with the foreseen investment in renewable energies and with the production contribution of a new natural gas combined-cycle power-station at Carregado, which is characterized by a higher efficiency when compared to Tapada do Outeiro.

The progress of the electricity production systems, associated to the fact that pollutant emissions originated by thermal production are confined to a specific location (making it easier to be solved), enhances the EV as an interesting alternative to its internal combustion alternative. Not only by the effective reduction of pollutant emissions but also by its removal from city centres.

## 5 PERMANENT LINES: CASE STUDY COIMBRA

The SMTUC – Municipality Services of Urban Transports of Coimbra has been exploring a "blue line" service, with three electric mini-buses since September 2003.

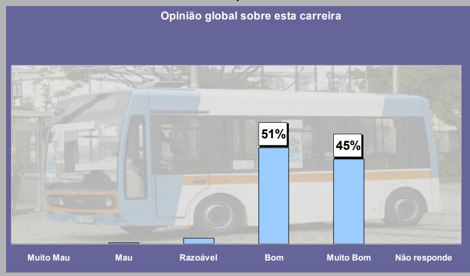
This chapter resumes some of the social and operational monitoring performed in Coimbra during the first eleven months of service.

| Type of line | |
|---|---|
| Circular "Blue Line" |  |
| Extension | 3 km |
| Average Waiting Time | 5 min |
| **Average Load** | |
|  | 10 passengers/trip |
| | 330 passengers/day |
| Average daily travel | 45 km/bus |
| **Average Energy Consumption** | |
| 123 kWh/100 km | |
|  | |







| Average global opinion of passengers on the experience (scale 1=min 5=max) |
|---|
| 4,6 |
|  |



## 6 CONCLUSIONS

With the consumption and the production "mix", referred to previously, the pollutant emissions for an electric mini-bus can be determined and compared to the standard limits for its internal combustion equivalent (Figure 19).

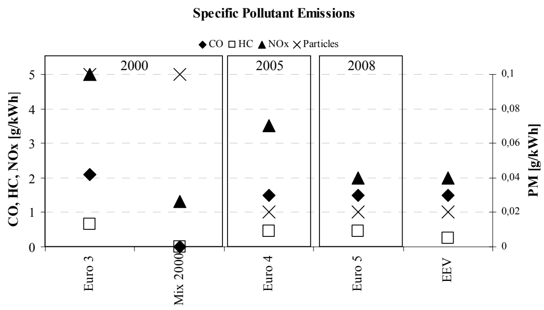



Figure 19: Comparison of specific emissions related to electric and internal combustion mini-buses

It can be verified that the use of electric vehicles causes a significant reduction of pollutant emissions, with exception for the particles. The value of particles pollutant emissions correspondent to a mini-bus electric vehicle circulating in Portugal, considering the production "mix" of 2000, is respecting the limits for EURO 3, being superior to the values referred on EURO 4 and EURO 5. However, the values of the other pollutant gases are bellow all the restrictions mentioned, being even lower than the values corresponding to an Enhanced Environmentally Friendly Vehicle.

The values calculated for particles emission are expected to be considerably reduced by the foreseen evolution of the Portuguese Electricity System, since the natural gas combined-cycle power-stations do not release this type of emissions.

The following table represents the summary of the major variables monitored during the demonstration action, in terms of maximum, minimum and average values. From these values, we can characterize the average service provided by the 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 |
| $CO_2$ | 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

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## 8 AUTHORS

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**Jorge Esteves** [(1)(3)(4]), jesteves@deea.isel.ipl.pt, graduated and got his M.Sc. and Ph.D. degrees in Electrical Engineering from Instituto Superior Técnico, Lisboa, Portugal, in 1983, 1986, and 1992, respectively. Since 2004, he is Coordinator Professor of the Department of Electrical and Automation Engineering at Instituto Superior de Engenharia de Lisboa. He is also a researcher at the Centro de Automática da Universidade Técnica de Lisboa and Director of Dispatch and Networks at the Portuguese Energy Regulator Authority (ERSE). His main research interests are electrical machines modelling, variable speed electrical drive and generator systems and applications of electric and electronic systems to the transport domain. He is Chairman of the Board of the Portuguese Electric Vehicle Association.

**Manuel de Oliveira** (2), smtuc@webside.pt, from 1971 to 1973 was an acting partner on the transport company "Oliveiras, Transportes e Turismo". Always connected to the automobile business, in 1983 was elected town councillor for the city hall of Coimbra, where performed functions in the traffic area, economical development for two years, and in 1990 as president of the directors board of SMTUC. From 1990 to 2001 was connected to a fuel industry (IDEMITSU) as director of network development. Since February 2002 is the General Manager of SMTUC – Serviços Municipalizados de Transportes Urbanos de Coimbra.

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