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Integration of Renewable Energies for Trolleybus and Mini-Bus Lines in Coimbra

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Abstract

Trolleybuses and electric mini-buses in the Portuguese city of Coimbra are one of the main forms of daily transportation of its many citizens. As part of CIVITAS MODERN European Project – MObility, Development and Energy use ReductioN, one of its main objectives for Coimbra is the integration of clean production electricity system owned by the City Council, able to supply the energy to the trolleybus traction lines, plus electric energy to charge the batteries of the electric mini-buses fleet. This electric fleet is undergoing a significant expansion in the near future. A study was carried out in order to evaluate the potential of renewable energy production to supply the electric fleet public transportation in Coimbra, reducing the necessity of fossil fuels and associated emissions, therefore improving the air quality. The electricity source will be a low head hydro potential, using an already existing dam-bridge, where a group of turbine-generators units can be placed, with modest operation costs and reduced civil works with small environmental impact. The optimization of the renewable energy generation is also assessed as a function of the load profiles.

Keywords: Trolleybus lines, public transport, electric vehicles, energy consumption, emissions reduction, hydropower

1 Introduction

Environmental concerns regarding greenhouse effect, pollutant gas emissions and improvement of air quality inside cities are nowadays a priority. In order to reduce traffic congestion, accidents and improve air quality, the European Commission has been developing actions like the CIVITAS (*CIty, VITAlity, Sustainability*) program in order to reduce CO_2 emissions and oil consumption, as well as to improve mobility, in European cities.

The support of initiatives from the European Commission like CIVITAS will help cities to achieve a cleaner and energy efficient urban transportation system by implementing several measures as part of the concept of sustainable mobility. For the year of 2020, the European Commission has already established several key targets:

- Reduction of at least 20 per cent of greenhouse gases (GHG) emissions;
- 20 per cent share of renewable energies in the total European Union (EU) energy consumption;
- 20 per cent energy saving through energy efficiency improvements.

The CIVITAS program, "for better and cleaner transports in cities", promoted and co-financed by the European Union (EU), with 3 main phases, reached 59 European cities. Coimbra integrated the third phase of the program, called CIVITAS Plus, with MODERN (*MObility, Development and Energy use REductioN*) project.

Figure 1: View of Coimbra from river Mondego

As part of the MODERN project, several measures and objectives were established for the promotion of sustainable mobility in the city of Coimbra. One of the main measures is the integration of turbine-generators (feasibility study report) in an already existing dam-bridge in the river Mondego located in the northwest of the city. The main objective is the production of electric energy to supply Coimbra's electric vehicles in the public transport fleet. This document will further analyze the integration of energy from hydropower, with trolleybuses and electric mini-bus lines, in the city of Coimbra.

2 Portuguese GHGs emissions and electric production system

2.1 GHGs emissions by sectors

Under the Kyoto Protocol and in accordance with the EU burden-sharing commitment, Portugal accepted as an objective to limit the growth of greenhouse gases (GHGs) emissions to 27 per cent, in the first period of 2008-2012, compared to the 1990 levels. The EU, as a whole, agreed in a total 8 per cent reduction.

In 2006, Portuguese GHG emissions without land-use, land-use change and forestry (LULUCF) increased approximately 40.7 per cent compared to 1990 levels. The total GHG emissions in Portugal were estimated at about 83.2 Mton CO_2eq being the energy sector the most important source [1].

The evolution of pollutant emissions in the energy sector from 1990 to 2005 and the forecast scenario for 2010, according to the National Climate Change Program (NCCP or PNAC for "Programa Nacional para as Alterações Climáticas"), shows the greatest growth in pollutant emissions in the sub-sector of road transportation, see Fig.2 [2].

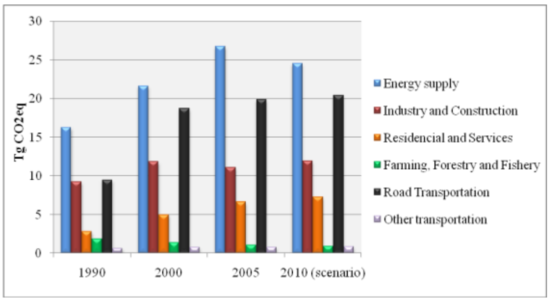

Figure 2: Evolution of CO_2eq emissions and 2010 scenario in the energy sub-sectors

From 1990 to 2005, pollutant emissions in the energy supply sub-sector raised about 65 per cent and in transportation 110 per cent. Energy industries and transportation sectors represented respectively 26.8 per cent and 24.2 per cent of total emissions in Portugal in 2006 (see Fig.3). This situation reflects the high dependence on fossil fuels (coal, natural gas and oil) for transportation and electricity generation.

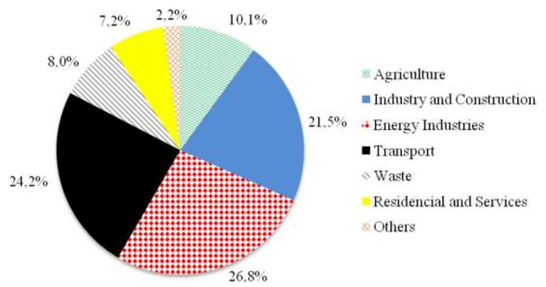

Figure 3: GHGs emissions in Portugal by sectors, 2006

In 2005, the transport in passenger cars was responsible for more than half of the energy consumption and GHGs emissions in the transportation sector. About 60% of these values were made in urban and suburban travels [2].

It is essential the development of measures to improve energy efficiency and GHGs reduction in the sectors of energy and transportation. Electric vehicles, with a better efficiency and lower emissions than combustion engines are seen as the future in order to achieve sustainable transportation.

2.2 Electric production system

2.2.1 Evolution

In order to evaluate pollutant emissions from the operation of electric vehicles in Portugal, an analysis of the Portuguese electric production system must be carried out. It is not possible to determine the source of the electricity used to supply or recharge the electric vehicle. It is assumed the electricity required is provided by the combination of different sources and power stations. Fig.4 represents the evolution of the electricity generation from different sources in Portugal [3] [4].

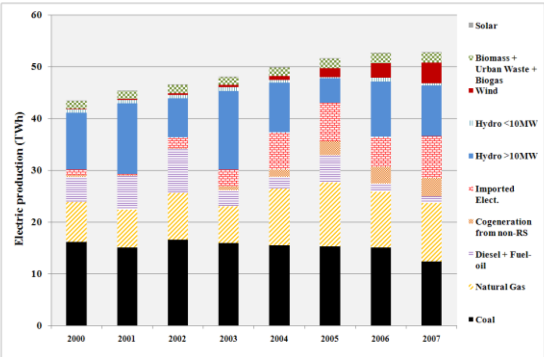

Figure 4: Evolution of electric production from different sources in Portugal

From 2000 until 2007, the electric production raised 22 per cent in the Portuguese electric system. The most important sources in the "mix" are the coal, natural gas and hydropower, strongly dependent of rain precipitation.

Electric production from coal power plants has been reduced in the last few years in order to reduce pollutant emissions. Natural gas utilities, with less pollutant emissions than coal, but still dependent of imported fossil fuel, represent an important share of electric production, especially after the integration of the natural gas combined-cycle power plant of Ribatejo in 2003. The amount of imported electricity has increased in the last years and represented about 15 per cent in 2007 in the production "mix", see Fig.5.

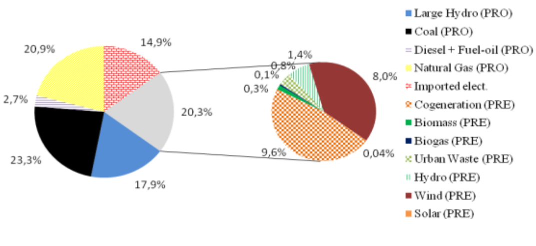

Figure 5: Portuguese electric production "mix", 2007

In 2007, the share of renewable energies represented 30.8 per cent in the production "mix". Portugal is still 8.2 per cent below the objective of 39 per cent share of renewable sources established in the European Directive 2001/77/CE.

Renewable energies are free of emissions, but not free of environmental impacts, because there are always impacts in the surrounding ecosystems. However, impacts are relatively small compared to traditional thermal power plants. Fig.6 represents the evolution of renewable energies sources the national production system [5].

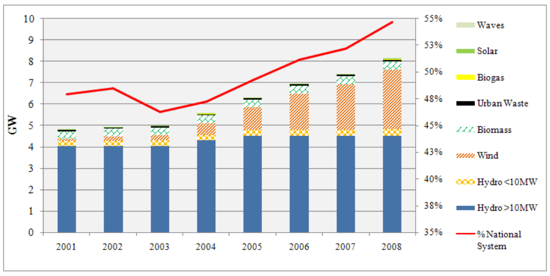

Figure 6: Evolution of installed power of renewable energy sources in Portugal

The capacity of power plants based on renewable sources has grown 69 per cent since 2001 in the national electric system (SEN for "Sistema Eléctrico Nacional"). The largest improvement occurred in the wind power production, but large hydro plants still represent the major part of power capacity with 55.4 per cent of total renewable energies.

2.2.2 Pollutant emissions

Electric vehicles in urban public transportation fleets do not affect directly air quality inside cities as they are free of emissions vehicles. However, the electricity consumption may present environmental impacts in the surrounding systems of thermal power plants where production is installed. Fig.7 to Fig.9 show the evolution of the specific emissions of the main pollutant gases and particles in the thermal power plants [6].

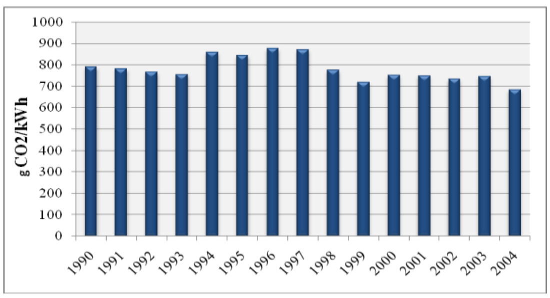

Figure 7: CO_2 specific emissions in the Portuguese large thermal power plants

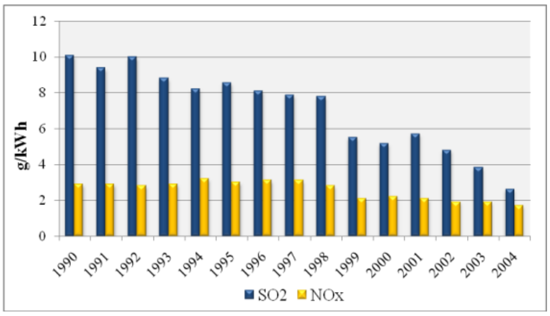

Figure 8: SO_2 and NO_x specific emissions in the Portuguese large thermal power plants

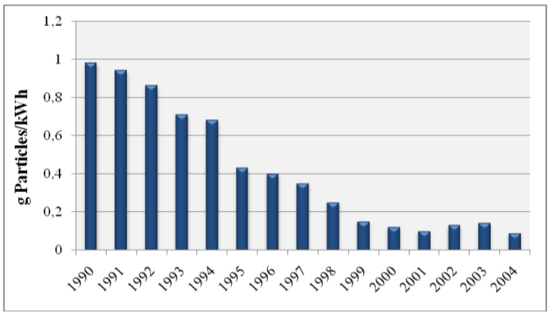

Figure 9: Particles specific emissions in the Portuguese large thermal power plants

From 1990 to 2004, the specific emissions of sulphur dioxide (SO_2), nitrogen oxides (NO and NO_2) and particles suffered a reduction, especially in 1999, with the start of the operation of the natural gas combined-cycle power plant of Tapada do Outeiro. CO_2 specific emissions were also reduced with the improvement of efficiency in the thermal electric generation, associated with the integration of combined-cycle natural gas power plants. The introduction of electrostatic precipitators in the coal power plants associated with the improvement of production efficiency with combined-cycle natural gas power plants reduced particles emissions by 91 per cent.

In order to evaluate environmental impact of electric vehicles in Portugal, and considering the production "mix" in 2007 (Fig.5), the specific emissions of the vehicles can be determined knowing the specific pollutant emissions of each power plant in the Portuguese electric production system [7] [8] [9].

Table 1: Specific pollutant emissions of an electric vehicle in Portugal, 2007

	Specific emissions (g/kWh)
SO_2	1.8
NO_x	0.99
CO_2	383
Particles	0.06

In order to accomplish the emission reductions targets, several investments are planned in a near future, especially in hydropower with an approximate increase of the hydropower capacity in 1.1 GW. In 2011, the new combined-cycle natural gas power plant in Pego will come into operation, with a capacity of 800 MW, which will reduce the burning of coal and pollutant emissions greatly.

3 Mobility in Coimbra

The city of Coimbra is placed in the Centre Region of Portugal and it is strategically between Lisbon and Oporto. In 2001, Coimbra had a fixed population of 101,069 and 148,443 inhabitants in the municipality. There is a total population of 431,379 in the Greater Metropolitan Area of Coimbra, made of 16 municipalities. The city has a total area of 58.82 km^2 and a population density of 1,718.28 per km^2 [10].

As a consequence of several large institutions in the city, like healthcare services, education, mainly university (about 35,000 high education students), administration and tourism, there is a large a daily influx of people from various locations in the region, or country. The city has about 139,000 daily movements, with only 25 per cent users of public transports from road and rail transportation companies. Fig.10 represents the percentage of the daily travel flux in the city of Coimbra [11].

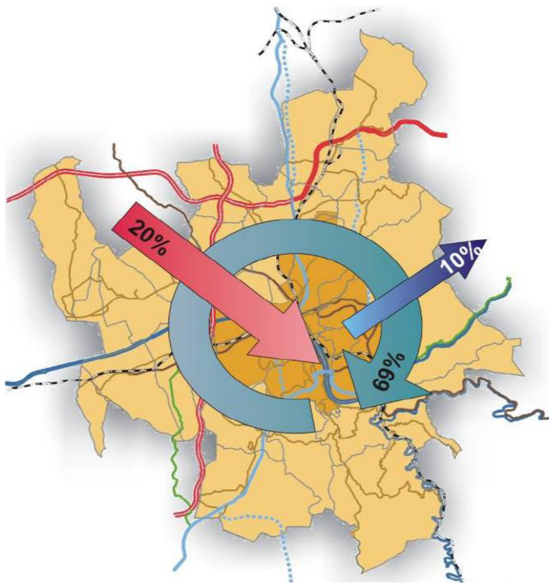

Figure 10: Mobility in Coimbra

It is estimated about 69 per cent of daily movements in Coimbra occur only inside the city. It is important to reduce the dependence on private vehicles in order to reduce traffic congestion and improve air quality. Efficient and clean urban transportation provide a solution to mobility and air quality problems inside the city.

4 Public transportation in Coimbra

4.1 Global indicators

An analysis of the key indicators in the public transportation in Coimbra provides useful information in order to evaluate the efficiency and evolution of the transportation system. The transportation fleet of the Coimbra Municipality Urban Transport Services (SMTUC for "Serviços Municipalizados de Transportes Urbanos de Coimbra") has 20 electric vehicles and 118 diesel buses and mini-buses [12]. Fig.11 and Fig.12 represent the evolution of the travelled distance of the fleet and passengers, respectively, in the urban circuits.

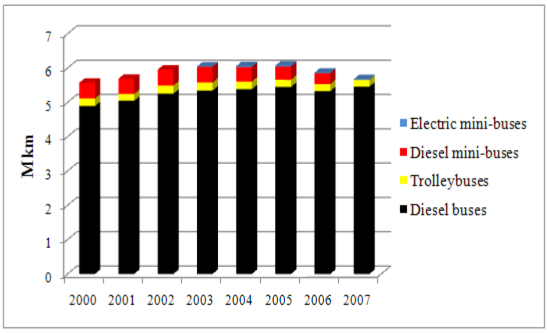

Figure 11: Evolution of km/year in the urban public transportation in Coimbra

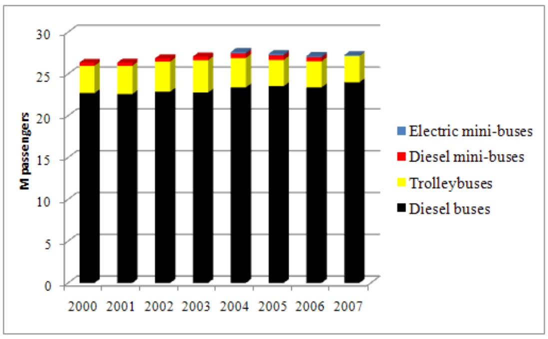

Figure 12: Evolution of passengers/year in the urban public transportation in Coimbra

Diesel buses are the main transport type inside the public transport fleet, with 88 per cent of the total distance travelled and passengers transported. In 2007, the park & ride system called "Ecovia" was closed and the diesel mini-buses didn't travel any further distance. Electric mini-buses were integrated in the public Transport fleet in 2003 and travelled about 86,000 kilometers in 5 years. The average distance travelled by the trolleybuses was 215.5 thousands of kilometers and was about the same throughout the years. The occupation rate for type of vehicles can provide more precise information about the internal use of the fleet (see Fig.13).

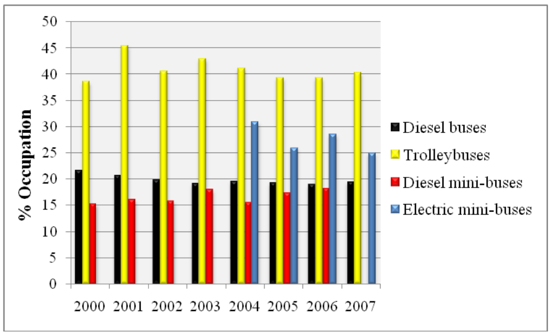

Figure 13: Occupation rate in the public urban transportation fleet in Coimbra

Occupation rate of trolleybuses are significantly above the other types of vehicles in the public transportation fleet with an average of 40.1 per cent. The electric vehicles, especially trolleybuses, serve some of the most important lines inside the centre of Coimbra and transport an average of 3.5 millions passengers per year.

4.2 History

The public transportation using electric traction started in Coimbra in 1911. The electric vehicles moved on rails and were supplied by contact with an aerial line using 550/600 Volts DC and reached the most popular areas in Coimbra.
With the development of power electronics and new necessities to transport more population, the first trolleybus line was inaugurated in 16 August of 1947 with 2 trolleybuses "Sécheron – Sauer" (see Fig.14). The old electric cars and rails were kept in some areas until the year 1980.

Figure 14: Trolleybus "Sécheron – Sauer" in Coimbra

The traction line was increased along the years and in 1956 was acquired a new rectifying substation in Montarroio area, with two groups of transformers-rectifiers of 600 kW, 1000 A and 600 Volts DC, each.
In 1964, trolleybuses replaced electric trams in the passengers' number, being the top collective transport system, but in 1976 diesel buses became the main collective transport type.
In 1990, the number of trolleybuses in the Coimbra urban Transport fleet reached a total of 43 electric vehicles. In 1993, the traction line extension reached the longest distance with 42 kilometers.
In 1998, the SMTUC considered closing the traction lines and trolleybuses, following the example of the Portuguese cities of Oporto and Braga. In the next years, the tendency was to reduce the traction power line extension and number of trolleybuses to cut maintenance expenses.
In 2003, SMTUC acquired 3 electric mini-buses to function in a new transportation system called "Blue Line" with no predefined stops, to provide transportation in the historical zone of Coimbra characterized by high slopes and narrow streets.
Nowadays, SMTUC have 16 trolleybuses in action for 3 different lines, served by a total extension of 22.5 kilometers of traction power line supplied by two substations (Montarroio and Calhabé) with a total rectifying capacity of 1,800 kW. Coimbra nowadays is the only city with trolleybuses in the Iberian Peninsula. In January 2009 a new rectifying substation was inaugurated in the SMTUC headquarters with 2 transformers of 670 kVA rated power, each [13].

4.3 Trolleybus fleet

The only working trolleybus model in the city of Coimbra is the "Salvador Caetano-Efacec" (see Fig.15), equipped with a 131 kW DC series motor and manufactured in Portugal. These trolleybuses reach a maximum speed of 60 km/h, weight 11.71 tones and do not have a backup system.

Figure 15: Trolleybus "Salvador Caetano-Efacec"

Table 2 describes the distance of each complete circuit and the working hours of trolleybuses in these lines.

Table 2: Lines served by trolleybuses

	Distance (km)	Working Hours
Line 4	8,5	6h45m – 21h30m
Line 60	7,8	7h35m – 19h30m
Line 103	9,6	7h15m – 20h00m

The trolleybuses only function in the working days from 6h45m to 21h30m, with 7 units maximum. The traction line is disconnected in the night period, weekends and holidays and in the month of August for maintenance purpose. Lines 4 and 103 are served in the night period, weekends and holidays by diesel buses.

4.4 Trolleybus traction lines

The trolleybus traction lines have a no-load rectified voltage of 640 Volts and the rectifying stations are supplied in 15 kVolts from the distribution electricity grid. The energy consumption of the traction grid will be the sum of the two active rectifying substations, placed in Montarroio and Calhabé.

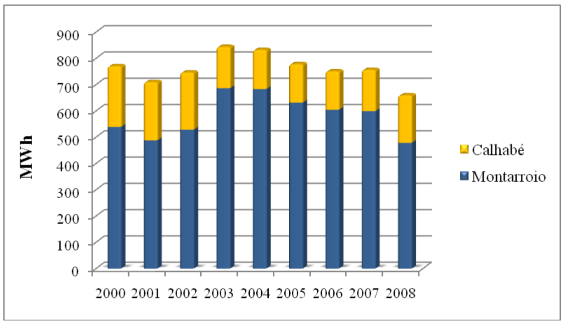

Figure 16: Annual consumption of trolleybus traction lines

The average consumption of electric energy was 760 MWh. Montarroio substation represented 76.5 per cent of the total electric consumption, especially because it supplies lines 4 and 103, the main consumers. From 2000 to 2008, electric consumption was reduced in 14.4 per cent. The number of trolleybuses during the peak consumption hours, with a higher tariff, was reduced in order to reduce electric bill. In 2008 the electric bill with the electric traction line was €75,500.

4.5 Trolleybus vs. diesel buses

A comparison of trolleybuses and diesel buses must be carried in order to compare them with diesel buses in the same category inside Coimbra urban transports (see Fig.17).

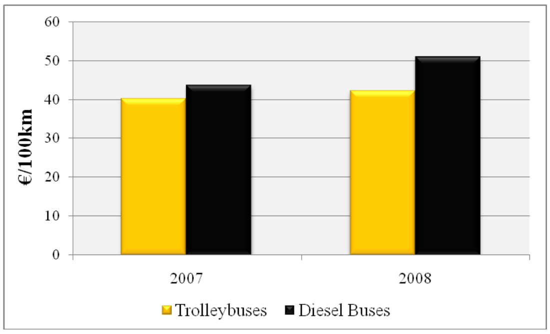

Figure 17: Operation costs of trolleybuses and diesel buses in Coimbra urban public transportation fleet

The operation cost of trolleybuses in 2007 was €1.91 lower than diesel buses; however in 2008, with the raise of the price of oil in the global market, the difference was €7.31, with an increase of 16.8 per cent compared to 4.7 per cent in the electric bill. The operation costs with diesel buses even reached €65 per 100 kilometers during the oil prices crisis in July of 2008.

The price of electric energy isn't affected by the oil barrel price change as much as diesel. An electric production system independent of fossil fuels can provide cheaper and cleaner electric energy, reducing costs with trolleybuses as the main mean of transport inside cities like Coimbra.

Besides reduced operating costs, trolleybuses have other advantages like high performance and overload capacity, they are quiet, require low maintenance, they have a longer life than diesel buses (trolleybuses have an average life of 40 years and diesel buses 15 years) and are about 25 to 40 per cent more energy efficient than diesel buses. The adoption of regenerative braking systems could reduce electric energy consumption by over 20 per cent. Table3 compares CO_2 emissions from trolleybuses and equivalent diesel buses in 2007.

Table 3: CO_2 emissions from trolleybuses and diesel equivalent, 2007

Trolleybus without regeneration	Average consumption (kWh/100 km)	363.9
	CO_2 emissions (kg/100 km)	139.4
	Total fleet CO_2 emissions (tones)	278.8 (non-locally)
Diesel equivalent Bus	Average consumption (liters/100 km)	51.9
	CO_2 emissions (kg/100 km)	176.4
	Total fleet CO_2 emissions (tones)	352.7 (locally)

Comparing trolleybuses with equivalent diesel buses, the main advantage for electric traction is the zero impact in the local environmental and less emissions even at non-local level.

However, trolleybuses have disadvantages such as the traction line require frequent maintenance, they are tied to fixed routes and they cost about from 5 times the similar diesel capacity model.

4.6 Electric mini-buses fleet

Coimbra electric mini-buses fleet has started operating in September 2003 in the "Blue Line" service. This type of vehicle, from the brand "Gulliver" (see Fig.18) is able to provide transport in the historical zone of Coimbra with high slopes and narrow streets. Each vehicle has autonomy for about 4 hours. The batteries are mostly recharged in the night periods with cheaper electric energy prices, but also in day periods, when it is necessary.

Figure 18: "Gulliver" electric mini-bus

The "Blue Line" has an extension of 3 kilometers and each bus have an average daily travel of about

45 kilometers [14]. The average energy consumption per 100 kilometers of the electric mini-buses fleet from 2005 to 2007 is represented in Fig.19.

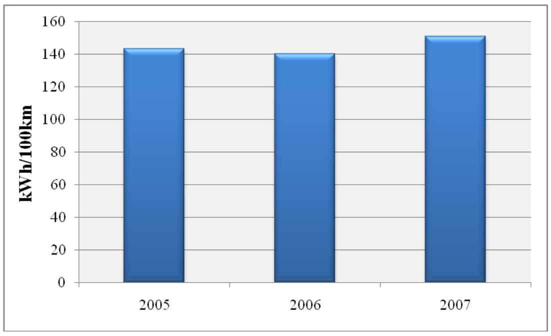

Figure 19: Electric mini-buses annual average consumption

The average consumption of electric mini-buses was 145 kWh per 100 kilometers. Considering the electric energy price of €0.08 per kWh for recharging the batteries of the electric mini-buses, the price per 100 kilometers is about €11.5. The operation cost with fuel for the diesel mini-buses in the same circuit is about €25 per 100 kilometers. Besides the smaller operation cost, electric mini-buses have the same advantages of trolleybuses when comparing with diesel equivalent buses, see Table 4.

Table 4: CO_2 emissions from electric mini-buses and diesel equivalent, 2007

Electric mini-buses	Average consumption (kWh/100km)	151.1
	CO_2 emissions (kg/100 km)	57.9
	Total fleet CO_2 emissions (tones)	9.8 (non-locally)
Diesel equivalent mini-buses	Average consumption (liters/100 km)	25
	CO_2 emissions (kg/100 km)	67.5
	Total fleet CO_2 emissions (tones)	11.5 (locally)

Comparing electric mini-buses fleet with diesel equivalent buses in the same travel conditions, the use of electric vehicles will be favorable in several aspects, such as emissions reduction in a global scenario, zero emissions locally, and they emit little noise in operation, when compared to diesel buses, an important factor inside Coimbra historical zone.

4.7 Future perspectives

The main policy of the Coimbra Municipality Urban Transport Services regarding public transportation and the welfare of the population is the use of alternatives to fossil fuels, with trolleybuses with a key role inside the city. This policy was improved in a recent past with the creation of the first electric mini-bus line and the installation of a public elevator in the historical centre.

In the near future, SMTUC will start the renewal of the trolleybus fleet. At the end of 2009, SMTUC will have in operation a modern trolleybus. The new trolleybus, a “SOLARIS Trollino 12” (see Fig.20), is equipped with a 210 kW induction motor and has a 100 kW EURO V diesel motor as backup system.

Figure 20: Trolleybus “SOLARIS Trollino 12”

The implementation of hydro electric generation in the Coimbra dam-bridge and the setting up of a larger AC-DC substation in the SMTUC headquarters, will allow the expansion of the traction lines and of the services served by trolleybuses. This expansion will contribute to a more sustainable transportation in Coimbra.

5 Electricity from hydropower in Coimbra

5.1 The Coimbra dam-bridge

Foreseeing the hydropower potential of Mondego River, the longest Portuguese river with a total extension of 234 km, a study was carried out in order to evaluate the installation of a very low head run-of-river small hydro in an already existing dam-bridge in Coimbra to generate electric energy for trolleybus traction lines and electric mini-buses. The dam-bridge is located in the northwest of the city, near the SMTUC headquarters, about 1,340 meters downstream of

Santa Clara Bridge and 340 meters upstream the rail bridge (see Fig.21).

Figure 21: Upstream view of Coimbra dam-bridge

The structure has 9 slots with mobile floodgates designed for a maximum discharge of 2,000 m^3/sec and it was concluded in 1981. The river basin area is 4,950 km^2 and the dam has a total capacity of 1.6 hm^3. The capacity of the dam is very low compared to a typical large hydro reservoir. The main purposes of the dam is the regulation of flows and ensure water levels to provide water to irrigation, municipalities and industries (cellulose) from the main channel placed in the right margin of the dam. Besides the main channel, there are a small fish passage and a small channel for irrigation purpose in the left margin of the river.
The hydroelectric production will depend on the discharges of the main upstream reservoir dams of the system Aguieira–Raiva–Fronhas, which generate energy mainly during peak consumption hours. The available flow and control of discharges in the Coimbra dam-bridge will be maximized to about 2 hours and a half after the discharges in Aguieira and Raiva dams.

5.2 Hydrological analysis

In order to evaluate the available flow from river Mondego in the Coimbra dam-bridge a hydrological analysis was carried out. This analysis will take in consideration the available flow for the production of electric energy. For the forecast of the minimum and maximum hydropower production we can analyze the chart of the water volume discharged through the main gates of the dam and secondary channels by hydrologic years, which are considered to be from October to September, see Fig.22 [15].

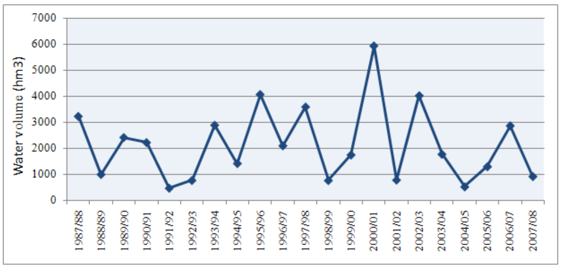

Figure 22: Water volume discharged per hydrological year in Coimbra dam-bridge

With this information we can predict the impact of extreme hydrological situations in the last 21 years in the production of energy. The minimum and the maximum water volumes discharges occurred in the hydrological year of 1991/92 and 2000/01, respectively. Fig.23 represents the monthly average of the average daily flows available for the electric energy production per month in the last 21 years.

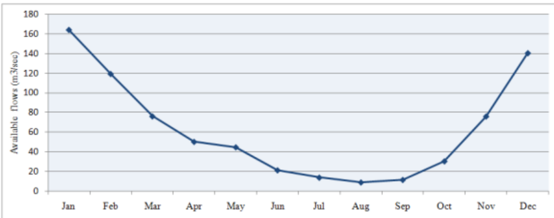

Figure 23: Monthly average of the average daily flows available for the production of energy

The main influence in the available flow is the rain precipitation. In winter, there is much more available flow for hydropower, but in dry months the available flow for electric production will be very low. The water needs for irrigation, cellulose industries and municipalities are larger in the summer months. The traction line is disconnected for maintenance in August, where the available flow for the production of energy is lower.

5.3 Technology

As the main civil works in the structure have already been done, the hydropower installation costs will be reduced to about 50 per cent of total engineering. The expenses will resume to hydro-mechanical, hydro-electrical and electrical equipment. The dam is meant to be equipped with a recent technology developed specifically for very low head small hydro power plants (see Fig.24).

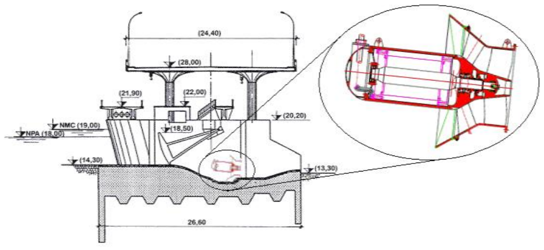

Figure 24: Profile view of Coimbra dam-bridge with a turbine-generator unit

This recent technology consists in the installation of groups of turbine-generators units into the gates slots of the dam, with a low hydraulic structure impact as well as minimum environmental and visual impacts. The energy output will be assessed as a function of the number of turbine-generators units in work, which will produce energy as a function of the available flow.

5.4 Power plant capacity

The power plant capacity can be calculated, using the following equation:

$$P_C = 9.81 \cdot Q_M \cdot H_M \cdot \eta_C \qquad (1)$$

Where P_C = Power plant capacity, in kW
Q_M = Maximum flow discharge, in m^3/sec
H_M = Power plant gross head, in meters
η_C = Global efficiency of the power plant

The maximum flow for the power plant can be obtained from the flow duration curve in the dam-bridge, obtained from hydrological data from January 1987 to April 2009.

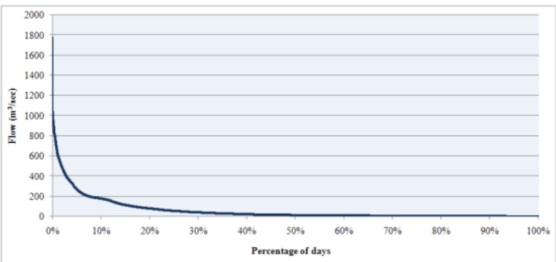

Figure 25: Coimbra dam-bridge flow duration curve

The flow duration curve is the main element of any hydroelectric project. The selection of the maximum flow for the production of energy depends essentially on an economical, technical and environmental analysis. In a preliminary layout the considered maximum discharge for the Coimbra dam-bridge power plant was approximately 150 m^3/sec, equaling day 45 (12.5 per cent of the year). With respectively, a maximum and minimum gross head of 4.3 and 1.8 meters, the power plant capacity was considered to be 4,850 kW, divided by 14 units of turbine-generators. Each turbine would have a maximum output of 346.9 kW for a flow discharge of 12.6 m^3/sec and a minimum output of 80.4 kW for a flow discharge of 10.2 m^3/sec.

5.5 Energy production

The average annual energy produced from hydropower can be determined using Eq.2:

$$E = 9.81 \cdot 24 \cdot \int_{t_1}^{t_2} N \cdot H \cdot Q \cdot \eta \cdot dt \qquad (2)$$

Where E = Electric energy production, in kWh
N = number of units in operation
H = Gross head, in meters
Q = Flow, in m^3/sec
η = Efficiency of the power plant
t = number of days

From the flow duration curve, the annual average energy production can be obtained from the operation area in the flow duration curve of the mini-hydro (see Fig.26).

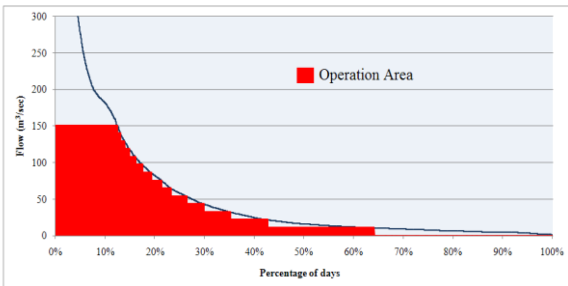

Figure 26: Small hydro operation area

According to Eq.2 and the operation area in Fig.26, it is possible to obtain an average generated electric energy of approximately 7.5 GWh per year. The amount of produced energy for the hydrological year of 1991/92, which was taken in account as an extreme dry period, will be about 1.2 GWh. On the other hand, the produced energy in extreme rainy periods, such as the period of 2000/01, will be about 10.2 GWh. The difference of the production for rainy and regular years is not as significant as the production in dry years. For very large flows, the head in the dam will get reduced and the produced energy in the turbine-generator units will get negatively affected.
The produced energy can be sold to the national grid according to the special price regime for small hydropower plants for an average price of €80 per

MWh, which can increase the internal rate of return and reduce the payback time of the investment.
An economical impact of the CO_2 emissions reduction provided by the clean production of energy can be estimated if we take in account the specific emissions of the thermal power plants in the Portuguese system and the price of CO_2 in the market. For an average price of €25 per ton of CO_2 and 620 g/kWh emitted by the thermal production system, the annual average production of the mini-hydro can be evaluated to reach €116,250. The economical evaluation of CO_2 emissions reduction is already taken in account in the special feed-in tariff, according to the Portuguese decree-law 225/2007 of 31 May.

6 Conclusions

The use of electric traction instead of typical combustion engines in the public transportation fleet is part of the sustainable solution to decrease the use of oil and to improve the air quality inside cities. In order to provide mobility for the public it is required an efficient transportation system. Electric vehicles have been well received by the population and trolleybuses are nowadays seen as a symbol of the city. The SMTUC see trolleybuses and electric mini-buses as the future type of transports, with less operation costs, less noise in operation and locally free of emissions. These advantages must be complemented, and will only have a real effect if electric traction accomplishes the reduction of pollutant gases emissions. Portugal has improved in the last years the amount of electric energy produced from renewable energies, to reach the targets established by the European Union.
The city of Coimbra, with electric vehicles already in the urban public transportation fleet, has decided to improve the concept of sustainable mobility with the production of electric energy from a clean hydropower source, with the main structure already implemented. The production and integration in the electric fleet is shown in Fig.27.

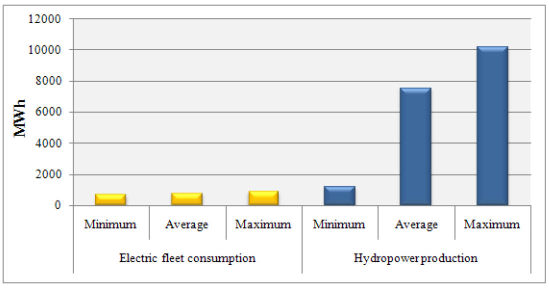

Figure 27: Electric fleet consumption and hydropower production

The minimum expected hydropower production will be about twice the maximum consumption of the electric mini-buses and trolleybuses. The connection of the small hydro with the national grid will allow the supply of electric energy to the traction line if the hydropower production is not enough, and the surplus energy will be sold to the national grid, especially in the night periods.
The Portuguese electricity generation "mix" has suffered positive changes regarding the use of pollutant carbon emissions due to increased use of natural gas instead of coal and the increase in renewable generation. The production of energy from hydropower will be enough to provide clean energy to the electric vehicles fleet and will substitute the burning of fossil fuels necessary to produce electric energy. The amount of CO_2 avoided in Portuguese power plants for the three scenarios of hydropower production is resumed in Fig.28.

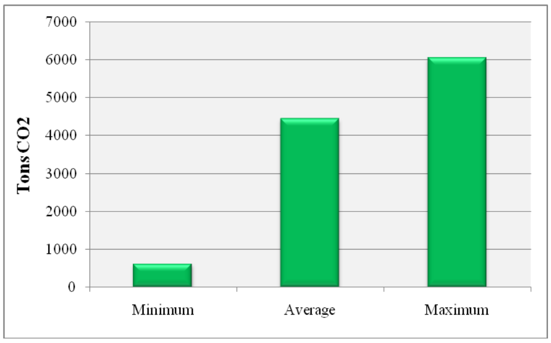

Figure 28: CO_2 emissions avoided with hydropower production

In an average year of hydropower production, the integration of clean energy with the electric vehicles fleet of the Coimbra urban public transports will be able to reduce pollutant emissions by 4,450 tonnes of CO_2. The local production of electric energy will be also reduce electric grid losses by transportation and in an average hydrological year will be able to further supply about 2,500 houses in the city of Coimbra.

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