Transactions on Ecology and the Environment vol 66, © 2003 WIT Press, www.witpress.com, ISSN 1743-3541

Studying the impact of urban sustainable transportation on Lisbon air quality

C. Borrego[1], M.Lopes[1], A. I. Miranda[1], J. Valente[1], J.C. Couto[1], A. Haurie[2], A.Dubois[2] & L. Drouet[2]
[1]*Department of Environment and Planning, University of Aveiro, Portugal.*
[2]*University of Geneva, Switzerland*

Abstract

Transport is one of the major issues in urban environment due to its impact on the welfare of citizens. Traffic causes noise and emits several pollutants that decrease air quality in the urban air shed, being a source of stress and accidents affecting people in physical, psychological and social aspects.
The main objective of this study is to analyse the impact of different scenarios of transportation development on the urban air quality of Lisbon. The paper explores the possible penetration of new energy depending technologies in a context of sustainable urban transportation. The analysis is performed through four specific scenarios having a time horizon of 45 years and using an integrated energy model, the MARKAL-Lite model.
In this scope, the evolution of traffic in the city, its transportation system and its trends concerning the use of energy, as well as resulting impacts on the air quality are described. Additionally, atmospheric emissions and air quality monitoring data are analysed.
The application of MARKAL-Lite considering the different urban transportation scenarios allowed verifying the possibility to considerably reduce air pollutants emissions, and therefore increase the quality of the urban area namely in what concerns ozone levels, with acceptable costs in comparison with the costs without any emission reduction constraint.

1 Introduction

Transport is an important key issue in what concerns the most important climatic and air pollution related problems such as greenhouse gas emissions, acidification, eutrofication and tropospheric ozone. Thus, transportation and

Transactions on Ecology and the Environment vol 66, © 2003 WIT Press, www.witpress.com, ISSN 1743-3541

related emissions reductions were identified as a priority area under the Fifth and the Sixth Environmental Action Plan of EU, as well as in the strategy for the sustainable development. During the Gothenburg meeting, in 1999, the European Council identified the transport sector as one of the four priority areas where the establishment of a sustainable policy is needed. However, the main conclusion of recent European Environmental Agency (EEA) published studies [1,2,3,4] is that the emission reduction targets were not completely reached in EU by 2000.

Besides a reduction of 26% and 42% in nitrogen oxides (NO_x) and Volatile Organic Compounds (VOC) emissions, respectively, in EU since 1990, largely as a result of the introduction of catalytic converters for cars, from fuel switching and from plant improvement in the energy industries, the increasing road traffic has partly offset reductions achieved by emission abatement [2,4]. Emissions of acidifying gases and ozone precursors from transport decreased by 22% and 29% respectively between 1990 and 1999, while in the same period transport activity increased by 17% in passenger road transport and 30% in freight tonnes km [4].

To meet 2010 CLRTAP (Convention on Long-Range Tranboundary Air Pollution) Gothenburg Protocol and NEC (National Emission Ceilings) Directive targets, as well as the 2008-2012 Kyoto Protocol targets, will require substantial further emission reductions, particularly on transportation sector.

The reduction of atmospheric emissions is also important to fulfil the Air Quality Directives. According to 1999 monitoring data [2] the concentrations of various pollutants exceeded the limit values set to protect the health of the population. Urban areas are the most affected by pollution and the fraction of urban population potentially exposed to the main pollutants reaches 42% for NO_2, 28% for tropospheric ozone and 12% for PM_{10}.

These events motivated the present study, in which the main objective is to analyse long-term impacts for different transportation scenarios, in order to support decision making on the definition of emissions control strategies.

2 Transport and air pollution in Lisbon city

Lisbon, with 84 km^2 and approximately 600,000 inhabitants, is the major Portuguese city. However, if one includes the various satellite towns, the population of Greater Lisbon rises to approximately 2.1 million people within an area of about 1,000 km^2. During the last decade the number of inhabitants in Lisbon city decreased due to the migration of population to suburban residential zones. Nevertheless, Lisbon remains a very dynamic city providing work, business, services, education and amusement for people living in the surroundings. Thus, intense coming and going traffic fluxes are generated and release high amounts of atmospheric pollutants with consequences to the local and regional air quality. Figure 1 presents the great Lisbon area, the location of Lisbon city and its road network.

According to Portuguese Terrestrial Transports studies, the number of dislocations in the suburbs of Lisbon has increased up to 42% from 1973 to 1998. In spite of the slightly change of the number of vehicles per 1000 inhabitants in the city centre, the suburbs present a growth nearly to 92%. The current number of vehicles trips between Lisbon and the suburbs represents 30 % from the total number of trips in greater Lisbon.

The public transportation system is mainly supported by buses and subway with 1200000 and 500000 passengers.km respectively.

The energy consumption, in Lisbon, associated to the transportation fuels has kept almost constant during the last six years (Figure 2).

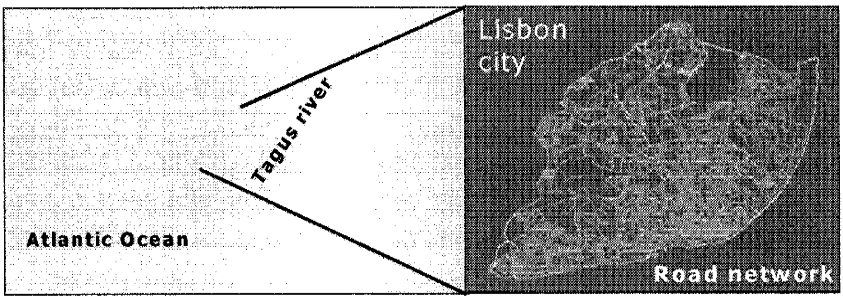

Figure 1: Maps of Great Lisbon area, Lisbon city and its road network.

The total energy consumption in Lisbon city, excluding the coal combustion reached the 1400 ktep (year 2000). The final demand of combustibles has increased, which is derived to the fuel oil contribution.

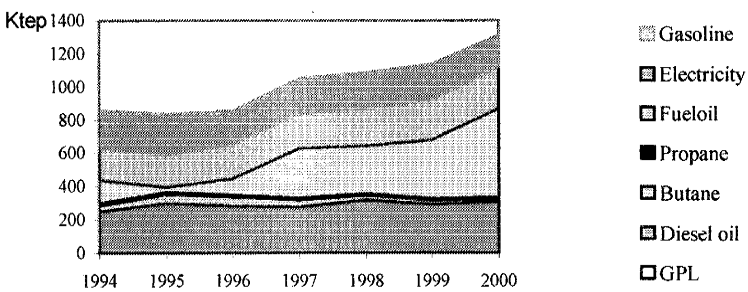

Figure 2: Distribution of energy carrier consumption in Lisbon.

According to emission estimates for Lisbon city [5] the road traffic is the main source of NO_x and carbon monoxide (CO) emissions, with both pollutants contributing around 70%. Figure 3 presents the contribution from different activities in Lisbon, in 2000, for CO and NO_x emissions.

Agreeing with the slight variation of gasoline and diesel consumption in Lisbon, the emissions of NO_x, CO and other pollutants stabilized since 1990.

Transactions on Ecology and the Environment vol 66, © 2003 WIT Press, www.witpress.com, ISSN 1743-3541

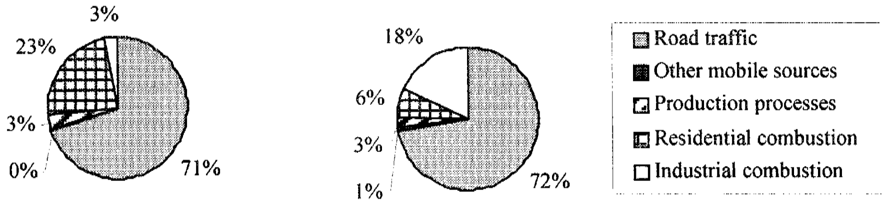

Figure 3: Contribution of CO and NO_x emissions from different activities in Lisbon, in 2000.

Notwithstanding this stabilisation of air pollutants emissions from traffic, Lisbon is an air quality problematic area in the European context. According to EEA [1], in 1999, and considering all European monitoring stations, the city has recorded the second highest hourly value of NO_x concentration at the urban background stations, the seventh highest NO_x hourly concentration in urban hotspot stations and the absolute maximum eight-hour average concentration of CO with the value of 22 $\mu g.m^{-3}$ (limit value=10$\mu g.m^{-3}$).

The national air quality network consists in 23 monitoring sites for NO_x, being 10 stations located in Lisbon. From the evaluation of total hourly infractions in 1999 (Figure 4) it is possible to verify that most of them occurred in Lisbon city. "Casal Ribeiro", a station located in the city centre is the most problematic one reaching almost 1000 exceedences of the limit value.

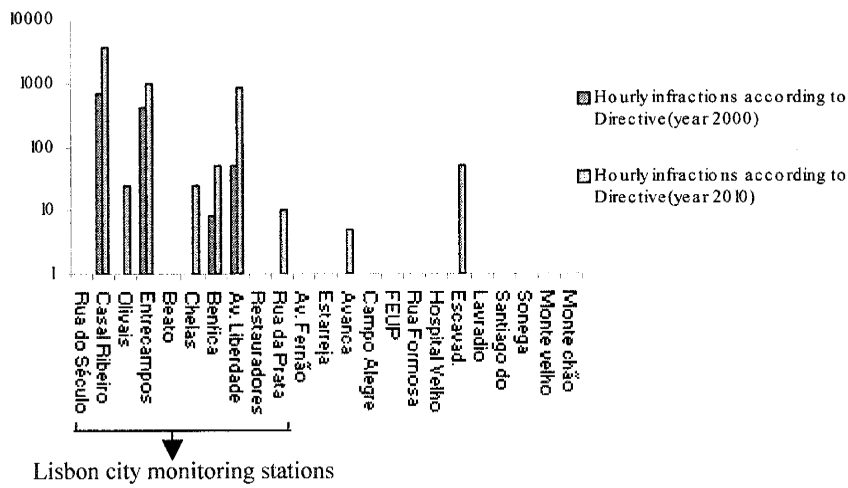

Figure 4: Total hourly infractions relative to NO_x for different air quality stations located in Lisbon and other regions of Portugal in 1999.

Transactions on Ecology and the Environment vol 66, © 2003 WIT Press, www.witpress.com, ISSN 1743-3541

Modelling studies carried out on this region using mesoscale dispersion models [5,6] show that road traffic emissions, particularly those from Lisbon city, are responsible for the most critical air quality episodes, specially photochemical pollution, producing harmful air quality effects in a wide coastal region (Figure 5).

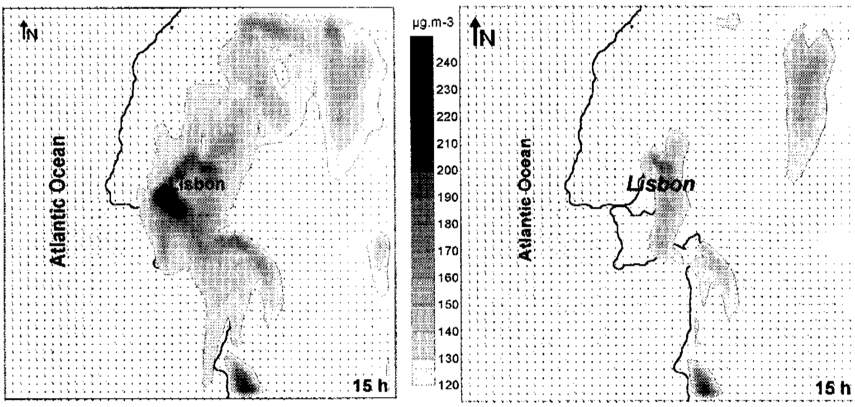

Figure 5:Wind surface field and ozone plume over the great Lisbon region at 15 UTC, in a typical summer day without and with the traffic emissions contribution [5].

3 Modelling the Lisbon city energy system

From Figure 3 it is possible to observe a significant contribution of the transportation activity to the total energy consumption in Lisbon. Modelling the Lisbon city energy system and considering different scenarios of transportation development will allow a better understanding of their potential impacts on the air quality.

3.1 The Markal model

MARKAL-Lite is an energy model, describing the possible systemic choices in the organisation of the energy system available at the city level. It derives from MARKAL [7] and takes its name from the reduced scope of the energy system that is represented. MARKAL-Lite considers the transportation system as a part of the larger energy production and consumption system in an urban region. Below, only the main features of the model are summarised. A full description of the model can be found in [8,9].
Figure 6 shows the fundamental organisation of the so-called energy reference system (RES). The whole model is driven by the useful demands, or energy services (DM). In order to provide the services one has to install and use demand device technologies (DMD) that use final energy forms produced either by process technologies (PRC), when the energy form is storable, or by

Transactions on Ecology and the Environment vol 66, © 2003 WIT Press, www.witpress.com, ISSN 1743-3541

conversion technologies (CON), when the energy is non-storable (like electricity or low temperature heat); these energy transformation technologies use primary energy forms (SRC). The arrows in this diagram represent flows of energy carriers.

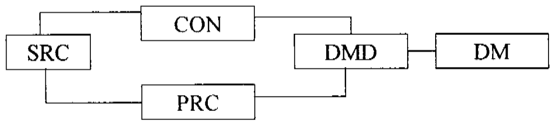

Figure 6: MARKAL model energy reference system

The model puts into competition a large array of potential technologies and energy forms with possible cascading effects. The representation of the investment and capacity transfer processes makes the model appropriate for policies analysis in a transition from one context, e.g. the low cost unlimited oil supply, to a very different one, like the sustainable development scenarios envisioned by modern cities. The model covers a time horizon of 45 years divided by 9 five-years periods.

MARKAL-Lite was adapted to the Lisbon characteristics in the scope of the SUTRA project (http://www.ess.co.at/SUTRA) with the purposes of modelling the city energy system, to reflect the specificities of the Lisbon system, to assess the environmental impact and the development of long-term scenarios.

The technologies are compared under the assumption that the price structure remains constant and not including taxes. The full description of the Lisbon MARKAL-Lite model will be the object of an extend paper. In this presentation the response of the model to more stringent environmental objectives concerning the transportation sector shall be illustrated

3.2 Environmental objectives

Two environmental objectives that were translated into emission constraints (E.C.) in the model were considered: (i) It was assumed that the policy in this urban region consists first in reducing the emissions of ozone precursors (NO_2 and VOCs mainly); (ii) The second possible environmental objective is to reduce the emissions of CO_2 in conformity with Kyoto/Marrakech agreements.

Ozone pollution is related to episodes and may be translated through the use of indicators that are built from the prevalence of critical weather conditions over a typical year. When only the precursors due to transportation are considered, it has been found possible to represent in a single linear expression the relationship between the precursor emissions and the O_3 pollution indicators [10]. The imposed constraints on the total NO_2 emissions due to the transportation sector are indicated in Table 1.

The second environmental constraint, imposed on the energy system, concerns the emissions of CO_2, the major greenhouse gas derived from combustion. The schedule of emissions bound shown in Table 1 corresponds to an objective of limiting to 6.4 $MT.year^{-1}$ the CO_2 emissions from 2010 onward. This objective is consistent with the Kyoto protocol commitment of Portugal.

Table 1. Upper bounds on NO_2 and CO_2 emissions considered in Lisbon MARKAL-Lite simulations.

Five-year period	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
NO_2 ($ton.year^{-1}$)	750	750	750	750	700	600	500	400	300
CO_2 ($Mton.year^{-1}$)	4.5	4.5	5.4	6.2	6.3	6.3	6.3	6.3	6.4

3.3 Scenarios for transportation trends predictability

The model simulates a market where different technologies compete for the production of energy forms and energy services that are demanded. In particular, the model considers different types of vehicles including existent and new upcoming technologies such as fuel cell vehicles.

Four main issues were identified to the development of scenarios: demographic, economic structure, technological and land use.

The analysis of these driving forces gave rise to four different scenarios, presented in Table 2, that reflect the general response of the Lisbon transport system to "extreme variations" due to general policy strategies.

Table 2. Scenarios and main driving forces.

Scenario	Description	Demographic/ Economic Structural	Technological/ Land Use	Transport Service Demand	Share Public Transport
SC1	Young and virtuous	Increasing	Increasing	+ 30%	+ 15%
SC2	Young and vicious	Increasing	Decreasing	+ 30%	+ 1%
SC3	Old and virtuous	Decreasing	Increasing	+ 10%	+ 15%
SC4	Old and vicious	Decreasing	Decreasing	+ 10%	+ 1%

Scenarios 1 and 2 reflect a young society (population growth and stable youth share), with high tele-work level and high mobility rates. Scenario 1, as well as scenario 3, is a virtuous scenario. It reflects increases in public transport share, in car occupancy rate and decrease of average car trip length due to a mixing land use. It also has high penetration rates of clean transport technologies (fuel cell, electric and hybrid vehicles). In contrast, the vicious scenarios reflect stability in the public transport share, decrease of the car occupancy rate and increase of average car trip length. The rates of penetration in these scenarios of clean transport technologies are low. Scenarios 3 and 4 outline an old society with negative demographic rates decrease in youth share, low telework level and small increase in mobility rate.

The variations on indicators that characterize the four main driving forces are reflected in MARKAL by change on transport service demand and share of public transports (Table 2). Some minimum rates of new technologies penetration were also considered depending on scenarios. The rest of the energy system was left unchanged [11].

3.4 Lisbon MARKAL-Lite model results

Lisbon MARKAL-Lite was applied to each scenario the market composition for transport sector was studied. The analysis of results shows on scenario 1, the most critical one in terms of transport and emissions increase, a progressive installation of clean technologies in public transport (methanol then fuel cell buses) after the end of life of existing buses (figure 7). For the cars sector, new technologies appeared from 2025 with, eventually a penetration of hydrogen car as can be seen on Figure 8. In the last three scenarios, new technologies for cars are not installed, but a comparable behaviour to scenario 1 is observed for the Public Transport sector due to the high contribution of buses actual technologies on total emissions.

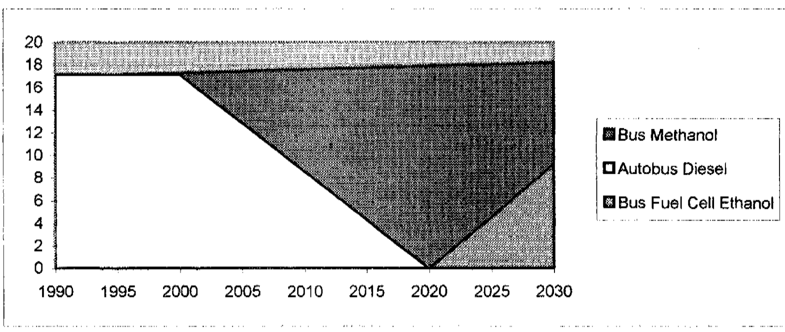

Figure 7: Installed capacities of buses for scenario 2 in 1000 km.day^{-1}.

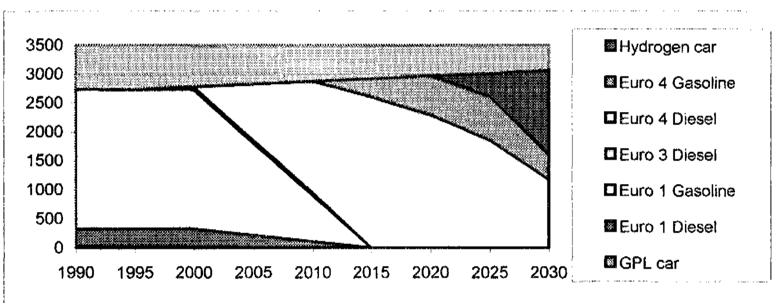

Figure 8: Installed capacities of cars for scenario 1 in 1000 km.day^{-1}.

A slight increase on the total cost is also observed when one introduces environmental constraints (Table 3), showing that the air quality on Lisbon city could improve with cost-effective options on transport system. The total costs for the other scenarios are lower than the observed ones for scenario 1, once the total demand for transportation on these scenarios is lower.

Table 3. Total cost increase in scenario 1 (M€) with different E.C.

Without E.C.	With CO_2 E.C.	With CO_2+NO_2 E.C.
52 004	52 494	52 499

4 Discussion and conclusions

The preliminary results obtained from the Lisbon MARKAL-Lite model implementation show the possible technological response of the transportation sector to the introduction of severe restrictions on emissions of O_3 precursors and, more importantly, of CO_2 emissions. It has been noticed that, as observed already for other case studies, the objective of Greenhouse Gas (GHG) emissions abatement tends to also solve the local pollution problem. At the Lisbon city level the Kyoto objectives seems to be at the limit of what is possible, given the technological choice. These results are an example of the kind of analysis permitted by this modelling approach and its potential. A more comprehensive study, implying other sectors than just the transportation one, in particular the industry and power generation, is necessary when one deals with the assessment of GHG abatement policies.
The main conclusion of this study is that it is possible to ensure an increase on Lisbon transportation system in terms of passengers.km controlling at the same time the increase on traffic emission with an acceptable cost. This means that it is possible to promote a sustainable development of the Lisbon transportation system, particularly if the city trends to be young and virtuous.

Acknowledgments

This work was sponsored by European Commission, through the SUTRA Project (EVK4-CT-1999-00013). The authors wish to thank to the financial support of the 3rd EU Framework Program and the Portuguese Ministério da Ciência e do Ensino Superior, for the PhD grant of M. Lopes (PRAXIS XXI/BD/13756/97) and for the research grant of J. Valente in the scope of STRATOZON Project (POCTI/CTA/42702/2001).

5 References

[1] European Environmental Agency. Air Quality in Europe – State and trends 1990-99, Topic report 4/2002, , Copenhagen, 2003.
[2] Barkman, A., Jol, A., Goodwin, J. & Mareckova, K., Emissions of atmospheric pollutants in Europe, 1990-99, Topic report 5/2002, European Environmental Agency, Copenhagen , 2002.
[3] Jol, A., Gugele, B., Ritter, M. & Mareckova, K., Greenhouse gas emission trends in Europe, 1990-2000, Topic report 7/2002, European Environmental Agency, Copenhagen , 2002.
[4] European Environmental Agency, TERM 2001, Indicators tracking transport and environment integration in the European Union, Copenhagen, 2001.
[5] Monteiro, A. Lopes, M., Borrego, C. & Miranda, A.I. Contribution of air pollution to the management of carbon cycle on a Portuguese coastal region. Coastal Environment – Environmental problems in coastal regions IV, ed. C.A. Brebbia, WIT Press, pp. 395-404, 2002.
[6] Borrego, C.; Tchepel, O.; Barros, N. & Miranda, A.I. Impact of road traffic emissions on air quality of the Lisbon region. *Atmospheric Environment*, **34**, Pergamon, pp. 4683-4690, 2000.
[7] Fragniere E., Haurie A. & Kanala R, A GIS-based regional energy-environment policy model, *Int. J. of Global Energy Issues*, Vol. 12, Nos 1-6, pp. 159-167, 1999.
[8] Fragniere E., "Choix énergétiques et environnementaux pour le canton de Genève", Ph.D. Thesis, Faculté des Sciences Economiques et Sociales, Université de Genève, Genève, No. 412, 1995.
[9] Fragniere E. & Haurie A., A stochastic programming model for energy/environment choices under uncertainty, *Int. J. Environment and Pollution*, Vol. 6, Nos. 4-6, pp. 587-603, 1996.
[10] Haurie A., J. Kubler, , A. Clappier & H. van den Bergh, A Metamodeling approach for integrated assessment of air quality policies, Technical report Logilab, University of Geneva, 2002, to appear in Environmental Modeling and Assessment.
[11] Caratti, P., Pinelli, D. & Tarzia, V. Scenarios of Sustainable Urban Transportation, Deliverable 11 of SUTRA project (EVK4-1999-00006P), 2002.