Transportation emissions in Lebanon: Extent and mitigation

M. El-Fadel[1], E. Bou-Zeid[2]
[1]*Department of Civil & Environmental Engineering, American University of Beirut, 850 Third Avenue, New York, NY 10022, USA*
EMail: mfadel@aub.edu.lb
[2]*Department of Civil & Environmental Engineering, American University of Beirut, P.O. Box: 110236 / 1500, Beirut, Lebanon*
EMail: eliebz@usa.net

Abstract

Transport related emissions have been long associated with adverse impacts on air quality particularly in densely populated urban areas. This paper evaluates the contribution of the road transport sector, in a typical small developing country, to air pollutants emissions. The Motor Vehicle Emission Inventory (MVEI) computer based model, with inputs adjusted to the fleet and conditions at hand, is used to predict the contributions of different classes of vehicles and to forecast the corresponding emissions for the year 2020. Emissions reduction and the sensitivity to changes in factors such as fleet age, fleet technology, average speed and travel volume are assessed.
Apart from the do-nothing scenario, two scenarios are developed to explore the feasibility and benefits of different mitigation approaches. The first scenario investigates the mitigation potential of measures related to the fleet age and new technology application. The second scenario addresses the effectiveness of transport planning and demand reduction in decreasing emissions. The results show various degrees of success in reducing emissions of different pollutants. Mitigation measures best applicable in Lebanon, economically and technologically, are presented. The need for an air quality management plan for the application of these mitigation measures is illustrated. Finally, a general framework for air quality management is developed.

Introduction

Inadequate air quality has long been considered as a serious health hazard. Its management, and the mitigation of pollutants emissions, have not been implemented similarly in all countries. Some countries have allocated adequate resources to mitigate adverse impacts associated with air pollution. However, many developing countries are still evaluating the damage caused by air pollution without taking any effective measures to counter the degradation of air quality, especially in urban areas. In these areas, transport related air emissions are of most significance since other major sources (i.e., industries, power plants, etc.) are not usually located in densely populated areas. Studies have been conducted to characterize emission sources and develop mitigation strategies for Lebanon (Staudte *et al.*[9]). However, recommendations from these studies have not been implemented to date.

Lebanon is a relatively small developing country in the Middle East region. Its area is about 10,400 km^2 with a population estimated at 3.5 million people. The country's economy was severely damaged by 17 years of civil unrest that ended in 1990. Infrastructure rehabilitation and development have been at the forefront of reconstruction activities particularly improvement of the transportation sector. A good transportation network is a necessity to the service-oriented economy in Lebanon and is expected to generate high travel demand compared to other countries with similar Gross Domestic Product (GDP).

Transportation Emissions

The transportation sector is commonly known to result in significant atmospheric emissions of numerous pollutants including: nitrogen oxides NO_x, carbon monoxide CO, sulfur dioxide SO_2, volatile organic compounds VOC, particulate matter PM, and lead (Faiz[6]; TRB[12]).

Concerns about tailpipe emissions impact on ambient air quality led many countries to impose strict regulations on gas emission rates and vehicle fuel economy. However, as traffic volume continues to increase, improvements are constantly needed to maintain total pollutants emissions and concentrations at acceptable levels. These concentrations are typically determined using field measurements and dispersion models. An important input to dispersion models is the inventory of pollutants released. This paper develops such an inventory for the on-road transport sector in Lebanon.

MVEI: Model Description and Parameters

The MVEI model, developed by the California Air Resources Board (CARB), is used to estimate the amount of pollutants emitted by the on-road transportation sector. The model's basic governing equation can be expressed as:

$$Q_T = \sum q_i a_i \quad (1)$$

Where: Q_T = total amount of gas emissions (grams)
q_i = emission factor for vehicle class (i) (grams/mile); and
a_i = activity level of class (i) (miles)

Emission factors and activities are calculated for classes of vehicles taking into account technology, age and other fleet parameters. The model itself consists of four modules, each with a distinct function as illustrated in Figure 1 (ARB[1]). The MVEI7G version released in 1996 was used in this study. The model parameters were modified to reflect the characteristics of the local fleet and conditions. The data was collected from several sources (TEAM[10], TEAM[11], Dar Al-Handassah[3], EDL[4], AUB[2], Faiz *et al.*[7]; IPCC[8]) or estimated when not available.

Simulation Scenarios

Several simulations were conducted to evaluate pollutant emissions under different mitigation scenarios ranging from a do-nothing scenario to the introduction of various technological improvements and policy setting. A description of each scenario and its purpose are summarized in Table 1.

Simulation Results

Simulation results for the different scenarios are evaluated for each pollutant separately. Figure 2 shows the emissions trends for the four scenarios. The simulation results are given in Table 2.

Scenario 1

This scenario is the base scenario for 1997. It is useful for setting base year emission levels. The accuracy of the results can also be estimated by comparing fuel consumption from MVEI to actual fuel consumption obtained from governmental sources (ERM[5]). The actual consumption in 1997 was 1,270 thousand gallons/day. MVEI estimated consumption at 1,210 thousand gallons/day which is a satisfactory agreement. This agreement is a preliminary calibration procedure that does not exclude uncertainty in gas emissions. The uncertainty is mainly due to the estimation of emission factors for the Lebanese fleet from American and European test results (Faiz *et al.*[7]; IPCC[8]).

Emissions of lead and sulfur dioxide are proportional to the lead and sulfur content of the fuel respectively. These emissions were estimated in scenario 1 for 1997. For subsequent scenarios, these emissions are expected to be greatly reduced as unleaded fuel is introduced and the sulfur content of the fuel is reduced. However, the quality of the fuel in 2020 is very uncertain and no simulation for these emissions was undertaken.

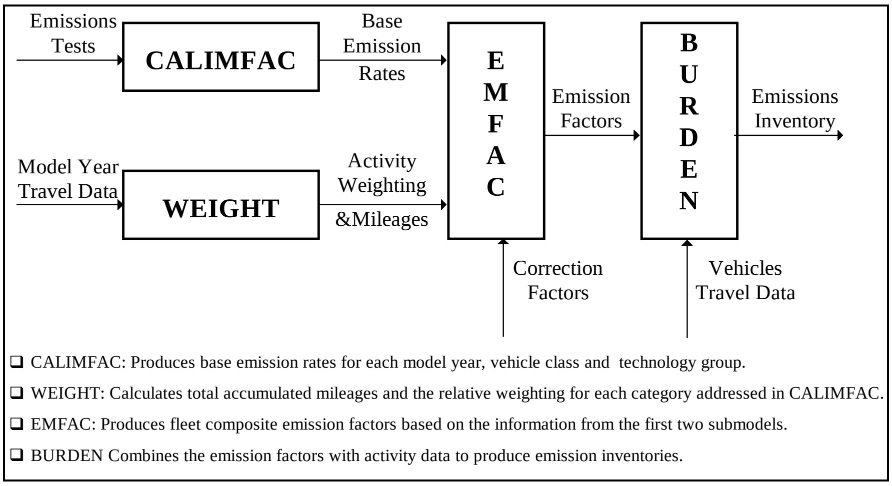

Figure 1: Sub-models and data flow in MVEI

Table 1. Scenarios description and relevance

	Scenario 1
Description	❑ Base conditions for the year 1997
Purpose	❑ Check MVEI model calibration versus fuel consumption ❑ Produce base-year emissions levels
	Scenario 2
Description	❑ Projection for 2020 ❑ Business-as-usual scenario ❑ Growth in fleet number is 2.5-3% per year ❑ Growth in activity per passenger car is 1.5 % per year ❑ I/M program equivalent to 1984 program in California
Purpose	❑ Predict the emissions in 2020 if no aggressive mitigation measures are adopted ❑ Serves as a benchmark against which emission reduction realized in scenarios 3 and 4 are assessed
	Scenario 3
Description	❑ I/M and clean fuel program equivalent to 1996 enhanced program in California ❑ Average fleet age reduced by 5 years from scenario 2 ❑ All gasoline vehicles are equipped with catalytic converters
Purpose	❑ Assess the maximum reduction in emissions from technological improvement.
	Scenario 4
Description	❑ “Best technology” conditions as in scenario 3 ❑ Average speed in time periods with congestion increased by 8 km/hour ❑ Reduction in passenger car activity to 1997 levels compensated by better urban planning and increase in public transport activity

Purpose	❑ Study the effect of travel improvement and management on pollutant emissions

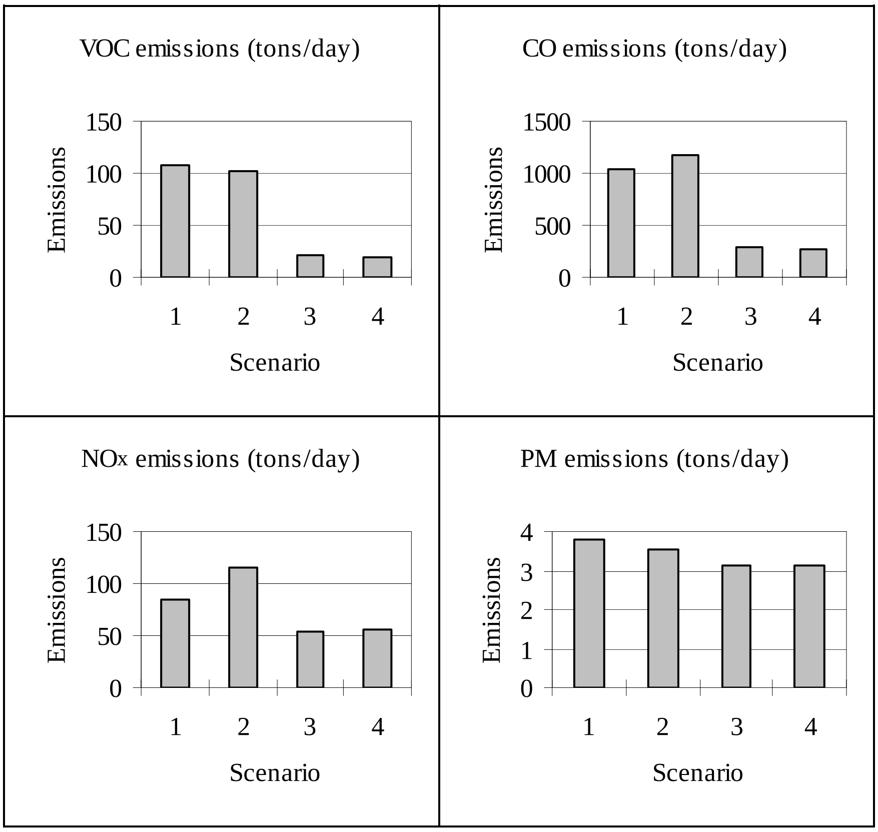

Figure 2. Emissions trends for the four scenarios

Table 2. Emission levels for the four scenarios (tons/day)

Year	Scenario	VOC	CO	NO_x	Total PM	Lead	SO_2
1997	1	107.21	1039.3	84.63	3.78	2.28	1.95
2020	2	101.31	1171.8	115.94	3.54	-	-
2020	3	21.43	294.05	54.45	3.13	-	-
2020	4	18.97	273.96	55.84	3.12	-	-

Scenario 2

This is the do nothing scenario for 2020. Minimal regulations are enforced. Emissions are slightly reduced for VOCs and total PM. The emissions of CO and NO_x increase slightly. This is mainly due to the increase in travel demand and limited emission reduction measures. However, emissions are kept near scenario 1 levels due to standard technological improvement in the fleet and application of minimal emission control regulations. This is the likely future scenario based on the current level of awareness regarding air pollution problems.

Scenario 3

This scenario assesses the potential of emission reduction through technological improvements in the fleet. Regulations are assumed to be enacted and enforced to reduce emission factors to the minimum. On the other hand, activity increases without any constraints. The results show important reductions in emissions for all pollutants. Reductions from scenario 2 levels range from 11.6 percent for particulates to 78.8 percent for CO

A sensitivity analysis indicated that the effects of average age reduction by five years, inspection/maintenance and fuel improvement programs yielded some reductions in emissions. However, the major factor that contributed to the reduction was the change in fleet technology through increasing the percentage of gasoline vehicles equipped with a catalytic converter from 50 to 100 percent. Note that MVEI assumes that vehicles equipped with catalytic converters are correlated with an improvement in average fuel efficiency and emission control. The presence of a catalytic converter is indicative of a better-than-average fleet technology.

Scenario 4

This scenario builds on the improvement achieved in scenario 3. While the increase in average speed by up to 8 km/hour during congestion periods has little effect on reducing emissions, activity reduction of private passenger cars by shifting to public transport and improved urban planning (which reduces trip length) may have a greater potential. In the MVEI model, emissions are assumed to be directly proportional to activity levels (equation 1). To compensate for the reduction in the activity of passenger cars, the total activity of buses was increased by 1 km for each reduction of 25 km in total car activity.

The activity is assumed to be stabilized at 1997 levels (10,000 km/car/year) (which means that the growth occurs only in the number of vehicles without an increase in the activity of vehicles). This assumption is largely optimistic. However, the scenario was introduced to study the potential of emissions reduction through traffic demand management. The MVEI results show slight improvement over the reductions attained in scenario 3.

Air Quality Management and Future Needs

The simulated scenarios are highly dependent on regulation enactment and enforcement that would improve the state of the Lebanese vehicle fleet and moderate the increase in travel demand. In this regard, previous investigations (Staudte *et al.*[9]) demonstrated that institutional and regulatory reforms are greatly needed. Among the various transportation activities, the road transport sector will still be the most significant pollutant emitter. Road travel activity will increase more rapidly than aircraft and freight activity.

Institutional framework and capacity for environmental management in Lebanon are relatively weak and remain fragmented because of the overlap in responsibility between a number of ministries or governmental agencies. In addition, the resources and staffing levels provided for environmental management are very limited. There is considerable need to strengthen the existing institutions with responsibilities for environmental management. This effort should be focused on the Ministry of Environment with encouragement to private sector participation in providing environmental services and Non-Governmental Organizations for monitoring and enforcement.

Short term environmental management measures that should be adopted in the context of Lebanon to reduce traffic-induced emissions can be classified under two categories namely, technical and legislative. The technical measures include improvement of fuel quality or introduction of fuel alternatives (i.e., phasing out leaded gasoline, imposing limitations on diesel passenger cars) and compulsory vehicle testing and maintenance at state controlled and certified garages. The legislative measures relate to taxes on emissions from fuel and private vehicle ownership.

These measures are inter-related and a well-coordinated implementation effort is necessary to accomplish a perceptible improvement in urban air quality. Table 3 summarizes these measures with suggested means of enforcement, incentives, and effects.

These measures could be introduced with relative ease from a technical and institutional perspective. However, the cultural attachment to the private car, combined with the present absence of alternatives, means that restrictions on their use will not be welcomed, and measures will need to be accompanied by public awareness campaigns to increase understanding of the linkages between pollution from vehicles, individual responsibility for vehicle management, and human health.

Urban air quality is the major environmental problem associated with transport related activities (Jitendra *et al.*[13]). In this respect, monitoring data provides a useful tool for raising public awareness and can even be used as the basis for a public alert system in traffic management schemes. Such a system relies on a monitoring network to alert the responsible authority when high background levels of pollution and unfavorable meteorological conditions are likely to give rise to serious health effects in asthma sufferers or other vulnerable groups. When this occurs, parts of the urban area can be closed to cars until the emergency has passed. Therefore, in order to identify the magnitude of the problem of poor air quality, and evaluate the effectiveness of policy measures, a network of air quality monitoring stations should be established in the medium to long term.

Table 3. Short term measures to reduce traffic induced emissions in Lebanese urban areas

Measure	Activity	Enforcement	Incentive	Effects
1. Fuel improvement strategy	➲ Phase out leaded gasoline ➲ Reducing sulfur content in diesel ➲ Check use of alternative fuel	➲ Determination of limit values of health impacting for content in gasoline and diesel ➲ Gather information on gasoline and diesel qualities ➲ Gather information on prices for Compact Natural Gas (CNG) and CNG-running vehicles ➲ Cost-benefit analysis of phasing in CNG vehicles	➲ Cut down of subsidies on diesel ➲ Provide subsidies on the use of vehicles running with alternative fuel ➲ (see also measure 3)	➲ Direct decreasing of emissions (lead, SO_2, and fine particulate) ➲ Running buses on alternative fuel as example for the private sector to run similar buses
2. Compulsory annual test of the vehicles emission levels	➲ Certification and control of garages to force regular technical inspections (annual emission test) and to control them	➲ Orientation towards an enforcement of controls and severe penalties to improve the efficiency of the compulsory annual test of vehicle emission ➲ Feasibility study on the implementation of compulsory annual emission tests	➲ Tax privileges on owner of tested cars and additional regular inspections at certified garages ➲ (see also measure 4)	➲ Minimizing the vehicle emission to 50% ➲ Improvement of the technical standard of the garages through financial support
3. Emission-related taxes on mineral oil	➲ Taxes or raising of taxes on mineral oil for leaded fuel and diesel ➲ No taxes or freezing of taxes on unleaded fuel ➲ Substitution of value added taxes by emission related taxes on fuel	➲ Announcement and publication of vehicle types, that are able to drive on unleaded fuel without any technical changes or devices	➲ Self-induced incentive by the lower price of unleaded fuel	➲ Reduction of lead and particulate ➲ Decrease in vehicle-movement ➲ Higher revenues from taxation ➲ Sensitization of population for buying cars driven on unleaded fuel ➲ Preparation for selling cars fitted with catalytic converters or setting catalytic converters for refitting
4. Emission-related registration fees and annual taxes on vehicles	➲ Classification of vehicles by type and age into emission brackets ➲ Determination of emission related rates of taxation on vehicles	➲ Definition and establishment of emission brackets and assignment of types of vehicles to the brackets	➲ Rates of taxation for low-level-emission cars will not be raised for the next 5 years ➲ Taxes for high-level-emission cars will be raised by up to 100 % related to their classification	➲ Improvement of the vehicle fleet step by step within 5 years ➲ Decreasing of the emission ➲ Higher taxes revenues to use for environmental and health issues

Conclusion

The effects of different scenarios on traffic related pollutant emissions were examined using the Motor Vehicle Emission Inventory. The trends of CO and NO_X emissions are similar. They increase from 1997 to 2020 if the business-as-usual scenario is assumed. The implementation of emission standards and traffic management will reduce the emission of these pollutants. This reduction is to levels well below the 1997 levels, especially for CO emissions, which were reduced to 22 percent of their current level. VOC and particulates emissions are reduced even in the business-as-usual scenario due to fleet technology improvement and to the implementation of minimal emission control regulations. This improves combustion efficiency and reduces VOC emissions by evaporation. These large reductions are due to the relatively high emission rates of the current Lebanese fleet. Subsequent reductions after the fleet has been modernized will be harder to attain. SO_2 and lead emissions are directly proportional to the fuel sulfur and lead content respectively. Prediction of regulation enforcement for fuel quality is uncertain. Regulatory reforms are also needed to implement those mitigation measures. A network for air quality monitoring will aid in determining the air pollution level and the impacts of the transport sector on air quality.

References

1. ARB, *Methodology for estimating emissions from on-road motor vehicles (6 volumes),* Technical Support Division, Mobile Source Emission Inventory Branch, Air Resources Board, California EPA, 1996.

2. AUB, *Weather data summary for the year 1996*, Department of Mechanical Engineering, American University of Beirut, Beirut, Lebanon, 1996.

3. Dar Al-Handasah (Shair & Partners), *Maintenance and rehabilitation of Lebanon road network. phase report*, Council for Development and Reconstruction, Beirut, Lebanon, 1994.

4. EDL, *Study for planning of refineries in Lebanon,* Electricité du Liban (in French), Ministry of Hydraulic and Electric Resources, Beirut, Lebanon, 1994

5. ERM, *Lebanon: assessment of the state of the environment,* Technical Report, Environmental Resources Management, METAP-World Bank, Ministry of the Environment, Beirut, Lebanon, 1995.

6. Faiz, A., Automotive emissions in developing countries: relative implications for global warming, acidification and urban air quality, *Transportation Research Part A*, **27A (3)**, pp. 167-186, 1993.

7. Faiz, A., Weaver, C.S. & Walsh, M. P., *Air pollution from motor vehicles: standards and technologies for controlling emissions,* The International Bank for Reconstruction and Development/The World Bank, Washington D.C., 1996.

8. IPCC, *The Revised 1996 IPCC guideline for national greenhouse gas inventory. Reference Manual (3 volumes),* Intergovernmental Panel on Climate Change, London, UK, 1996.

9. Staudte, M., Rau, M. & El-Fadel, M., *Urban air quality monitoring program for the Greater Beirut Area, Lebanon*, Transtec-Fitchner Consortium, the Ministry of Environment, Beirut, Lebanon, 1997.

10. TEAM International, *Greater Beirut transportation plan, data collection. report No.4,* Council for Development and Reconstruction, Beirut, Lebanon, 1994.

11. TEAM International, *Greater Beirut transportation plan, household survey results. report No.9,* Council for Development and Reconstruction, Beirut, Lebanon, 1994.

12. TRB, *Towards a sustainable future: addressing the long-term effects of motor vehicle transportation on climate and ecology,* Special Report 251. Transportation Research Board, National Research Council, Washington D.C., 1997.

13. Jitendra, J.S., Tanvi, N. & Carter, J.B. (eds.), *Urban Air Quality Management Strategies in Asia, Guidebook,* The International Bank for Reconstruction and Development/The World Bank, Washington D.C., USA, 1997.