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Transportation GHG emissions in developing countries. The case of Lebanon

M. El-Fadel [a,*], E. Bou-Zeid [b]

[a] *American University of Beirut, Faculty of Engineering and Architecture, 850 Third Avenue, New York 10022, USA*
[b] *American University of Beirut, P.O. Box 110236/1500, Beirut Lebanon*

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Abstract

This paper evaluates the contribution of the road transport sector, in a typical small developing country, to global greenhouse gas emissions. An inventory of transport emissions, using the Intergovernmental Panel on Climate Change methodology, is presented for the base year 1997. The Motor Vehicle Emission Inventory computer based model, with inputs adjusted to the fleet and conditions at hand, is used to predict 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. Scenarios are developed to explore the feasibility and benefits of two different mitigation approaches. The first approach stresses the reduction potential of measures related to the fleet age and new technology application. The second addresses the effectiveness of transport planning and demand reduction in mitigating emissions. The air quality impact of these scenarios is presented. The results bring to light the essence of the problem that technical improvements alone, in the existing fleet, will not be able to offset impacts due to the growth in future travel demand. Policy settings to counterbalance the increase in emissions are investigated in that context. © 1999 Elsevier Science Ltd. All rights reserved.

Keywords: Climate change; Greenhouse gases; Transport emissions; MVEI; Developing country

1. Introduction

Anthropogenic emissions of greenhouse gases (GHG) led, over the past 100 years, to a considerable increase in the concentration of these gases in the atmosphere. These GHG act as a blanket that retains solar heat in the atmosphere. Elevated concentrations of GHG cause increased atmospheric heat retention. This creates higher global temperatures or what is more

* Corresponding author.

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commonly known as global warming. This process is suspected to cause adverse environmental consequences including coastal zones flooding and desertification. Both flooding and desertification are likely to affect the country of Lebanon significantly since it is located at the border of desert regions and more than 60% of its economic activity lies in a narrow coastal plain along the Mediterranean sea (ERM, 1995).

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 has 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).

2. Transportation emissions

The transportation sector is commonly known to result in significant atmospheric emissions of numerous GHG including carbon dioxide CO_2, methane CH_4, nitrous oxide N_2O, nitrogen oxides NO_x, carbon monoxide CO, sulfur dioxide SO_2 and non-methane volatile organic compounds NMVOC (FCCC, 1997; Faiz, 1993; TRB, 1997). Carbon dioxide emissions are by far the most significant. In Lebanon, the transportation sector contributes 25% as CO_2 equivalent of the total GHG emissions (UNDP, 1998). This contribution is even more pronounced in some countries. For instance, the transportation sector in California emits 43% as CO_2 equivalent of the total GHG emissions (CEC, 1991). These numbers do not include emissions associated with fuel production activities which amount to 15% as CO_2 of the total GHG emissions in the case of California.

Energy use for transport resulted in 1.3 Gt of Carbon emissions in 1990 (IPCC, 1996a). This represents about 15% of the worldwide GHG emissions (FCCC, 1997; Faiz, 1993). This contribution is projected to increase significantly in the future as reported in the projections of Annex 1 countries to the Framework Convention on Climate Change (FCCC). Annex 1 countries perform continuously updated emission inventories, set mitigation targets and make their climate change programs data available to the FCCC. For 18 developed countries [1] included in the Annex 1, transportation emissions grew by 6.6% from 1990 to 1995 compared to a 1.2% increase in total GHG emissions for the same period. Consequently, for these countries, the contribution of the transport sector to global GHG emissions (excluding land use change and forestry) grew from 21.5 to 28% from 1990 to 1995 (FCCC, 1997). On-road vehicle emissions, particularly in developing countries, constitute the greater portion of emissions from transport related activities. In Lebanon, for instance, on-road vehicle emissions amount to 99% of total emissions from the transport sector (UNDP, 1998).

The 1973 oil crises coupled with concerns about tailpipe emissions impact on ambient air quality led developed countries (US, Europe and Japan) to impose strict regulations on vehicle

[1] Austria, Belgium, Canada, Czech Republic, Finland, France, Germany, Iceland, Ireland, Monaco, Netherlands, New Zealand, Norway, Slovakia, Sweden, Switzerland, United Kingdom and United States.

fuel economy and gas emission rates. In order to meet these regulations, manufacturers were forced to introduce design changes that improve engine efficiency and reduce emissions. These measures resulted in a decrease in vehicle GHG emission factors; however, the total GHG emissions continued to increase due primarily to the rapid growth of the vehicle fleet and travel demand. At present, improved technology has moderated the rate of increase of GHG emissions. Future predictions however, indicate that technology improvements may not keep pace with the increase in travel demand (FCCC, 1997; Faiz, 1993; Wade et al., 1994). Therefore, the total GHG emissions may increase significantly in the future. Estimates indicate that worldwide CO_2 emissions from motor vehicles could increase by 50% from their 1993 level by the year 2010 (Faiz, 1993).

3. Previous work and present needs

Global environmental concerns particularly potential climate change from GHG emissions have been at the forefront of current research work in the past decade (IPCC, 1995). Significant efforts and resources have been dedicated to understand the dynamics of the earth's climate and explore new policies or technologies to decrease GHG emissions. At present, large discrepancies exist between developed and developing countries. For example, the 18 countries (listed previously), representing around 10% of the world population emit around 45% of global GHG. The per capita emissions of GHG for these developed countries and other less developed or developing countries are shown in Table 1 for the year 1990 (FCCC, 1997; Wade et al., 1994).

Attention has been allocated to future emissions from large developing countries such as India, China or Brazil. The global contribution of smaller developing nations has generally not been characterized. The first step in that direction is the preparation of an inventory of GHG emissions by sources and removals by sinks for individual countries. Such an effort was recently undertaken in Lebanon in a fulfillment of the Framework Convention on Climate Change (FCCC), ratified by the country in 1994. The work was limited to the development of an inventory, with 1994 as a base year, using the Intergovernmental Panel on Climate Change (IPCC) reference approach (IPCC, 1996b) without addressing mitigation measures. Plans to develop such measures are under study. In this paper, several mitigation scenarios to reduce GHG emissions from the transportation sector are considered. These scenarios are intended as a guide for future policy settings or mitigation programs. At present, no mitigation efforts are applied and the prediction of possible policies in the future is highly uncertain. Therefore, the scenarios are not an assessment of the impacts of determinate policies.

The IPCC reference approach was used, with the year 1997 as base year, to validate national GHG emission estimates obtained through computer simulations. These simulations were performed using the Motor Vehicle Emission Inventory (MVEI) model as originally developed by the California Air Resources Board and modified to reflect the Lebanese situation. Emission projections were conducted for the year 2020 and mitigation scenarios, including technological improvements and policy settings, were compared with a no mitigation alternative. The impacts of these scenarios on ambient air quality were also considered. These impacts are particularly important in urban areas such as the capital Beirut where 50% of the transportation activity in the entire country is located.

Table 1
Populations and per capita CO_2 emissions in 1990

Country	Population (1000')	CO_2 emission (tonnes)
Annex 1 Countries		
Austria	7712	7.68
Belgium	9972	11.64
Canada	26,522	17.44
Czech Republic	10,362	16.00
Finland	4986	10.81
France	56,440	6.49
Germany	79,479	12.76
Iceland	255	8.52
Ireland	3503	8.77
Monaco	29	2.45
Netherlands	14,943	11.22
New Zealand	3346	7.61
Norway	4242	8.37
Slovakia	5300	11.00
Sweden	8559	7.16
Switzerland	6712	6.71
UK	57,237	10.08
USA	249,975	19.83
Non-Annex 1 Countries		
Kazakhstan	16,598	13.57
Ukraine	51,334	12.47
South Africa	35,173	8.80
South Korea	42,604	5.13
Lebanon	3500	4.20
Mexico	84,911	3.66
China	1,129,679	1.83
Brazil	147,278	1.47
India	848,632	0.73

4. The IPCC reference approach

The IPCC is an international organization founded by the World Meteorological Organization and the United Nations Environment Program to study climate change and devise response strategies (IPCC, 1995). It is responsible for building a worldwide inventory of GHG emissions. For this purpose, the IPCC developed three methodologies, of differing accuracy and refinement, to accomplish its task.

The first is the reference approach, or tier 1, applied for situations where data is lacking. In this approach, transportation emissions are determined on the basis of total fuel consumption of all categories (expressed in energy units) and emission factors for GHG emitted from each fuel. The fuel consumption data is readily available with a relatively good accuracy. However, emission factors are a major source of uncertainty because of their dependence on many parameters such as combustion technology, fuel characteristics and emission control technology. The effect of these parameters is not easily quantifiable and requires country specific information which is typically lacking in developing countries. The last two approaches are for countries that have collected, or have adequate resources to collect, the data needed to perform in-depth inventories.

Note that the IPCC methodology adopts the concept of double counting of carbon emissions (IPCC, 1996b). The method assumes that all the carbon in the fuel is converted to CO_2, then counts the CO and VOC emissions independently as an additional source of carbon emissions. This may introduce differences between the IPCC approach and models that do not double count (like MVEI), especially when the combustion process emits large amounts of non-CO_2 carbon. The double counting in the IPCC approach can be avoided by modifying the tier 1 method. The usage of double counting is justified to account for the ultimate conversion of all carbon into CO_2 while reflecting the higher radiative forcing potential of other gases.

The reference approach was used to estimate the GHG emissions for the year 1997. The total emissions were estimated at approximately 6940 Gg of CO_2 equivalent (the amount of CO_2 that, if released into the atmosphere, will have the same global warming effect as the mixture of gases actually released). CO_2 equivalent emission for a gas is obtained by multiplying the emissions of that gas by its Global Warming Potential (GWP). The GWP of a gas is defined as the time integrated radiative forcing resulting from the instantaneous release of a unit mass of the gas in today's atmosphere expressed relative to a reference gas. This factor is gas specific and depends on the time scale (limits of the integral). GWP values of different gases have been constantly modified by the IPCC to reflect the improved understanding of the dynamics of radiative forcing in the atmosphere. The values remain uncertain and research is needed to incorporate all the processes affecting radiative forcing in the estimation of GWP.

The GWP values will continuously vary in the future as the concentration of the GHG in the atmosphere change and induce changes in the dynamics of the radiative forcing process. In this paper, a 100-year period is adopted and the GWP values are based on the IPCC guidelines of 1990 to 1996. GWP values for indirect greenhouse gases (CO and NO_x) were used. Although they may not be highly accurate, these GWPs still are a valuable tool for the incorporation of all emissions into one single number. This is mostly important when assessing mitigation measures that reduce the emissions of some gases and increase the emissions of other gases. The effect of indirect greenhouse gases is not easy to model since these gases do not contribute to radiative forcing but their presence affect the concentrations of important components such as ozone. GWPs used in this paper are expressed below.

GHG	**100-year GWP**
CO_2	1
CO	2
NMVOC	4
CH_4	24.5
NO_x	40
N_2O	320

The IPCC reference approach indicates that CO_2 emissions account for about 60% of the potential radiative forcing (atmospheric heat retention capacity) resulting from the transport sector in Lebanon (Fig. 1). At present, the contribution of N_2O to the warming potential is relatively minimal but it is expected to increase significantly in the future. This can be attributed to the increase in the use of 3-way catalytic converters which are likely to increase N_2O emission factors by as much as 17-fold (De Soete and Sharp, 1991).

5. 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 is the total amount of gas emissions (grams), q_i the emission factor for vehicle class (i) (grams/mile) and a_i the 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. These functions and the flow of data in MVEI are illustrated in Fig. 2. The MVEI7G version released in 1996 was used in this study. This was the first version of the model that estimates CO_2 emissions (ARB, 1996).

6. Model features and IPCC dependence

The MVEI model estimates emissions of conventional pollutants CO, NO_x, Lead, Organic Compounds (reactive, total, volatile, or total hydrocarbons), particulates (PM_{10} or total) and

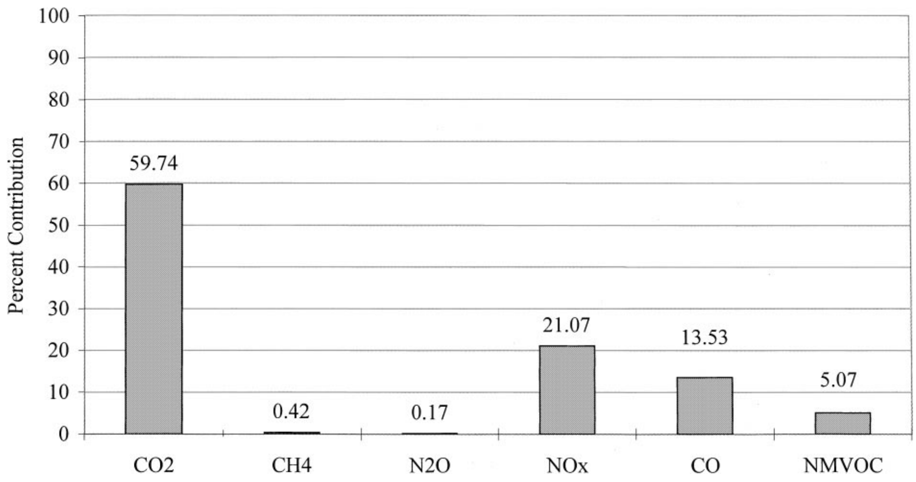

Fig. 1. Contribution of GHG to global warming for 1997 using the IPCC methodology.

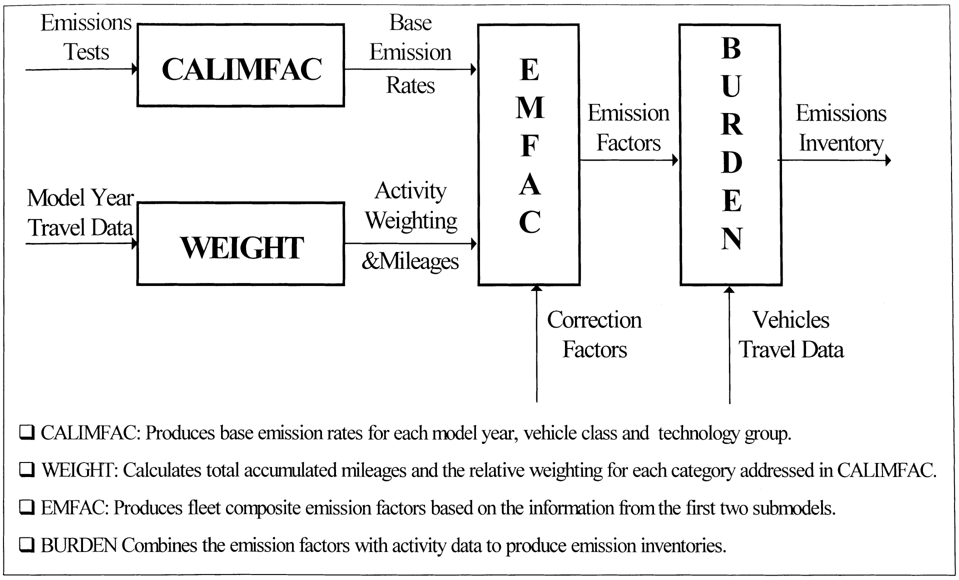

Fig. 2. Sub-models and data flow in MVEI.

SO_x. It also estimates CO_2 emissions and fuel consumption. For gasoline fueled cars, light duty trucks and medium duty trucks (which account for 80% of CO_2 emissions typically); the model has built-in CO_2 emission factors and calculates fuel consumption by carbon balance expressed as:

$$C_{\mathrm{F}} = C_{\mathrm{CO_2}} + C_{\mathrm{CO}} + C_{\mathrm{VOCs}} \tag{2}$$

where C_{F} is the carbon content of the fuel (g of carbon), $C_{\mathrm{CO_2}}$ the carbon emitted as CO_2 (g of carbon), C_{CO} the carbon emitted as CO (g of carbon) and C_{VOCs} the carbon emitted as VOCs (g of carbon).

For other classes of vehicles, the model follows the Corporate Average Fuel Economy (CAFE) approach without calculating CO_2 emissions. The CO_2 emissions for these classes are accounted for by using the IPCC method with the fuel consumption values obtained from MVEI. Other model features include:

- The model estimates total VOC emissions, which are divided into CH_4 and NMVOC using estimates of CH_4 emissions by the IPCC method.
- N_2O emissions are also accounted for using the IPCC method.
- A two-step deterioration modeling is adopted (deterioration rate decreases after a certain mileage).
- The model uses several built-in correction factors for temperature, speed, fuel, cycle, and high emitters.

The model parameters were modified to reflect the characteristics of the local fleet and conditions. The data was collected from several sources or estimated and hence the accuracy of this data is not consistent. The parameters of interest and the degree of accuracy of the data are shown below. The accuracy was characterized as low, medium or high since numerical quantification of this accuracy is not feasible. Note that projections of policy related parameters, like inspection and maintenance programs, is at best uncertain and the accuracy depicted is for the current situation.

Data category	Accuracy
Activity volumes [a] i.e. vehicle miles traveled and starts.	medium
Activity distribution by time period [a]	medium
Temperature data [b]	high
Fleet populations [a]	medium
Basic emission rates [c]	medium
Clean fuels phase-in dates [d]	high
Inspection and maintenance program in place [d]	high
Lead and sulfur content in fuel	high
Age distributions [a]	medium
Mileage accrual rates [a]	medium
Distribution ratios of vehicles with or without catalytic converter and diesel versus gasoline [d]	low
Fuel delivery system technology split: carburetor, point or throttle body fuel injection [d]	low
Average speed distribution [a]	medium

[a] (TEAM, 1994a; TEAM, 1994b; Dar Al-Handasah, 1994 and EDL, 1994).
[b] (AUB, 1996).
[c] (Faiz et al., 1996 and IPCC, 1996b).
[d] These parameters were assumed according to the scenario.

7. Simulation scenarios

Several simulations were conducted to evaluate GHG 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 2. All scenarios are compared to the base conditions in the years 1997 and 2020.

8. Simulation results

Simulation results for the different scenarios are evaluated in terms of the total mass of emissions expressed as CO_2 equivalent. Table 3 summarizes the percent contribution of each gas to total CO_2 equivalent emissions and the total quantities of the various GHG emitted. Figs. 3 and 4 illustrate the percent contribution of each gas to total CO_2 equivalent emissions for the different scenarios and the total GHG emissions, respectively.

Table 2
Scenario's description and relevance

Scenario	Description	Purpose
1	Base conditions for the year 1997	Check MVEI model calibration versus IPCC results and produce base-year emissions levels.
2	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 N_2O emission factor of scenario 1 was multiplied by 5 due to increased use of catalytic converters (de Soete et al., 1991; Wade et al., 1994)	Project the GHG emissions in 2020 if no aggressive mitigation measures are adopted. This scenario mainly serves as a benchmark against which emission reduction realized in scenarios 3 and 4 are assessed.
3	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 N_2O emission factor of scenario 1 was multiplied by 10	Assess the maximum possible reduction in emission from technological improvement
4	"Best technology" conditions as in scenario 3 Average speed in time periods with congestion increased by 8 km/h Reduction in passenger car activity compensated by better urban planning and increase in public transport activity	Study the effect of travel improvement and management plans on GHG emissions. Assess the feasibility of a reduction to 1997 levels in 2020

Table 3
Total GHG emissions and percent contribution to global warming

GHG	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	%	Gg/year	%	Gg/year	%	Gg/year	%	Gg/year
CO_2	66.47	3940.00	77.59	9126.00	85.38	6897.00	83.29	5390.00
CH_4	0.48	1.16	0.54	2.60	0.55	1.82	0.52	1.37
N_2O	0.21	0.04	1.17	0.43	2.47	0.62	2.44	0.49
NO_x	18.91	28.03	13.06	38.39	8.93	18.03	11.06	17.89
CO	11.61	344.03	6.60	388.00	2.41	97.37	2.41	78.09
NMVOC	2.32	34.34	1.05	30.94	0.26	5.27	0.28	4.58

8.1. Scenario 1

For the base year 1997, a relatively good agreement was obtained between the IPCC estimation method and MVEI (4145 Gg of CO_2/year for the IPCC method versus 3940 Gg of CO_2/year using

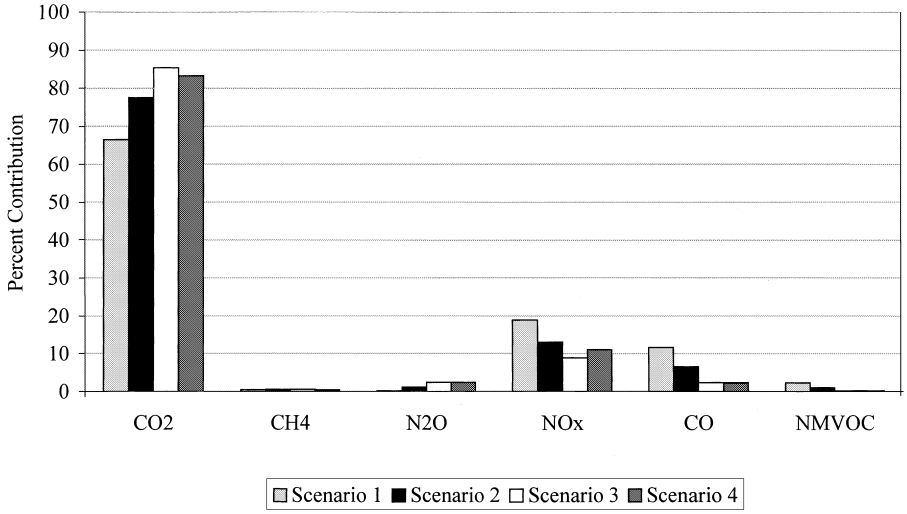

Fig. 3. Percent contribution of GHG emissions for the different scenarios (CO_2 equivalent).

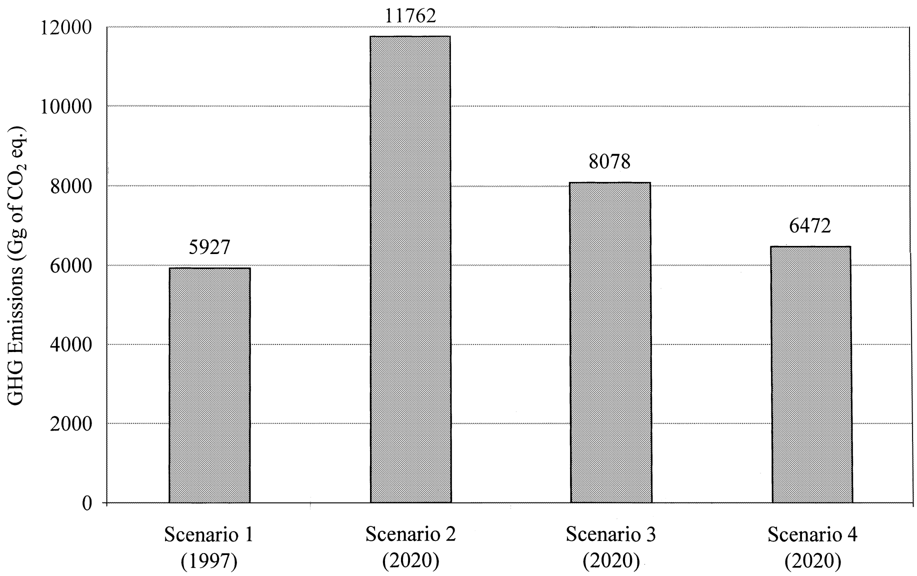

Fig. 4. Total GHG emissions for the different scenarios.

MVEI). For the same year, 97% of the radiative forcing results from the combined CO_2, NO_x and CO emissions.

8.2. Scenario 2

Projections for the year 2020 under scenario 2 indicate that total emissions, expressed as CO_2 equivalent, will nearly double in comparison to 1997. This is mainly due to the increase in travel demand and limited emission reduction measures. This is the likely future scenario based on the current level of awareness regarding air pollution problems. Under this scenario, the CO_2 contribution will increase from 66.5% to 77.6% of the total GHG emissions.

To assess the benefits of standard fleet technology improvement from 1997 to 2020, a simulation was conducted with activity levels and fleet populations as projected for the year 2020 but using 1997 fleet technology (i.e. 1997 emission rates). The total GHG emissions in 2020 would have increased by an additional 8% approximately, if the fleet technology during the 1997–2200 period remained unchanged.

8.3. Scenario 3

In scenario 3, a reduction of 31% below business-as-usual (scenario 2) was proven to be feasible. In this scenario, CO_2 contributes 85% of the total GHG emissions and N_2O emerges as the third largest contributor to the global warming. A sensitivity analysis indicated that the combined effect of average age reduction by five years, inspection/maintenance and fuels improvement programs yielded minor reductions in emissions. The major factor that contributed to the reduction was the change in fleet technology increasing the percentage of gasoline vehicles equipped with catalytic converter from 50% to 100%.

Note that MVEI assumes that vehicles equipped with catalytic converters are correlated with an improvement in average fuel efficiency. While catalytic converters do not directly improve fuel efficiency, their presence indicates a better-than-average fleet technology. Emission factors in the model are fairly sensitive to changes in average speed. However, the normal range of average speed variation in the country is relatively narrow to introduce appreciable emission variation. Inspection and maintenance programs and improved fuels reduce the non-CO_2 emissions significantly. However, their impact on total GHG emissions remain minor.

8.4. Scenario 4

This scenario builds on the improvement achieved in scenario 3 to maintain 1997 emission levels relatively constant. While the increase in average speed by up to 8 km/h 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 directly proportional to activity levels (Eq. (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. It was found that the activity per car should be reduced to 7800 km/car/year. This traveled distance is relatively low in comparison with current driving mode which amount to no less than 10,000 km/car/year in 1997 and projected at 14,000 km/car/year for 2020 (EDL, 1994). Hence the feasibility of such a reduction is questionable.

Alternatively, if the activity is kept constant, at 10,000 km/car/year, from 1997 to 2020 (which means that the growth occurs only in the number of vehicles without an increase in the activity of vehicles) a 10% increase in GHG emissions to 6471 Gg of CO_2 equivalent/year is expected to occur in the year 2020 in comparison to 1997. This is consistent with lower limits of the global emissions projections of the IPCC for the year 2020. These projections indicate an increase in transport emissions in 2020 ranging from 8 to 107% from the 1990 levels depending on the mitigation measures implemented (IPCC, 1996a).

9. Comparative assessment and air quality impacts

At the current rate of environmental legislation and enforcement in Lebanon, which is relatively similar to many developing countries, scenario 2 is likely to prevail in the future. This will result in a 100% increase in GHG emissions in 2020 from their 1997 levels. This is consistent with World Bank projections of 50% average increase by 2010 (Faiz, 1993). Scenario 3 indicated that substantial improvements can be accomplished through measures that aim at improving the fleet technology.

Concerns about ambient air quality may indeed bring about strict regulations on fleet conditions and vehicle activity. Such regulations will assist in reducing GHG emissions, but greater benefits can be introduced if reducing GHG is set as a primary target. The current trend is towards more transport demand as traffic conditions improvement (through investment in the infrastructure) and economic revival are likely to unleash suppressed trips (TEAM, 1994b). Furthermore, urban planning is heading towards the "business city center and residential suburbs" model that results in longer trips.

The effects of different scenarios on pollutant emissions were considered. The trends of CO and NO_x emissions are similar. They increase from 1997 to 2020 if scenario 2 is applied. The implementation of scenarios 3 and 4 will reduce the emission of these pollutants due to the enforcement of inspection and maintenance programs, improved fuels, and utilization of catalytic converters. This reduction results in emission levels well below the 1997 levels, especially for CO emissions, which were reduced to 22% of their current level. NMVOCs are reduced even in scenario 2 due to the application of regulations equivalent to those applied in 1984 in California. These regulations reduce VOC emissions by evaporation. N_2O emissions rises in all scenarios due to the wider use of catalytic converters which increase the emission rates of this pollutant. SO_2 emissions are dependent on the fuel sulfur content. Prediction of regulation enforcement on sulfur content is uncertain.

10. Regulatory aspects 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., 1997) demonstrated that institutional and regulatory reforms are greatly needed. Based on simulation results, it is evident that passenger cars will contribute 85% approximately of the total gasoline consumption (equivalent to 75% of total fuel consumption in the road transport sector) in 2020. Among the various transportation activities, the road transport sector will still be the most significant GHG emitter. Road travel activity will increase more rapidly than aircraft and freight activity.

The current taxation system is based primarily on vehicle model year. It imposes higher taxes on newer models which are generally more efficient and contribute less emissions. This tends to be the case in many developing countries thus giving an incentive to buy or keep older, cheaper cars. Moreover, pollution control devices such as catalytic converters are taxed similarly to other spare parts. Such tax structure should be modified to encourage the purchase of fuel efficient, less polluting cars. On the other hand, pollution control devices should benefit of special low taxes.

In addition, controlled inspection and maintenance (I/M) programs are non-existent. The organization of a new I/M program is critical. This program should insure the good tuning of engines, the repair of pollution control systems, and the optimization of the vehicle's fuel economy; factors that significantly affect the emissions of the fleet.

The maximum attainable improvement in the fleet technology (scenario 3) will still be insufficient to compensate for the travel volume increase expected if no travel management is introduced. Therefore, the public transport sector should be modernized, improved and marketed. Dedicated bus lanes would render public transport more reliable and attractive. Moreover, the urban areas should be made friendly to non-motorized transport. Bicycle lanes and improved sidewalks have the potential to make considerable contributions to mitigation efforts.

Tax incentives and public policies should move urban planning in a direction of mixed, commercial and residential, zones. This will reduce trip length, which has been in net increase in Lebanon in the last few years. However, the impact of these policies on energy consumption should first be assessed. More aggressive mitigation measures, such as alternative fuels or electric cars, would need new infrastructures and large capital investments. These measures are not likely to be adopted or attempted at a large scale, at least not in the near future.

11. Summary and conclusions

Mitigation measures to reduce GHG emissions from the road transportation sector in Lebanon were investigated. Improvement of the fleet by inspection and maintenance programs, fuel quality regulations and other policies can reduce the projected radiative forcing of GHG emissions by 31% in 2020 compared to a slower and less aggressive legislation. Nevertheless, travel volume increase was found to be more important than technology improvements in the fleet. Hence the need to reduce activity volume, mainly through better urban planning and improved public transport, if the emissions are to be held at a relatively constant level.

The IPCC methodology (reference approach) was used to estimate emission levels and check computer based simulations using MVEI. Although it was not devised to estimate GHG emissions, the MVEI model proved to be a useful tool in conducting sensitivity analysis and what-if scenarios. Emission factors of other GHGs (CH_4, N_2O) are however not incorporated in the current version of MVEI and future developments are needed in this regard.

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