MODEL FOR PREDICATING CO_2 AND CO_2-EQUIVALENT EMISSIONS FROM TRANSPORTATION SECTOR AND MEASURES FOR REDUCING IT

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ABSTRACT

Protecting the environment against the impact of using the conventional energy systems is of the utmost importance, and both local and global impacts need attention. This paper introduces new models for predicating CO_2 and CO_2-equivalent emissions from transportation sector. CO_2-equivalent emissions estimation depends on significant factors such as, fuel used and fuel efficiency, emission rates, lifetime of transport mode and behavior of car driver, transport mode and transport volume. Application of the model and options for reducing greenhouse emissions from transportation sector are also presented.

Keywords: Transportation Planning, Transportation Management, Transportation Models, Transport and Environment, CO_2, CO_2-Equivalent Emissions, Fuel Efficiency, Emissions Rate.

INTRODUCTION

Energy is basic to the development of industry, public services, and transport. Its use has been growing rapidly, and the size of individual generation and conversion facilities has become enormous. The scale and cost of the requisite protection against pollution and its possible consequences have been growing, while the actual rate which these problems are being addressed, which is most crucial, has been rather slow.

The basic source for organic fuel brings with it large-scale pollution of the natural environment with combustion products. It is generally accepted that fossil-fuel consumption is responsible for much of the increase in atmospheric carbon dioxide (CO_2) concentration and that this increased CO_2 results in an increased longwave (infrared) radiative forcing of the troposphere that leads to a warming of the earth's surface. The CO_2 concentration in the atmosphere of the preindustrial period was 290 ppm (parts per million), and now it is 500 ppm [13,29].

The costs of facilities for eliminating emissions from fossil-fuel appear to be quit large. For example, installation of sulfur-dioxide-trapping facilities makes unit energy production costs 25-50% higher [28].

Reducing adverse ecological consequences and protecting the environment against the impact of conventional fossil-fuel-based energy systems is of the utmost importance. Recent international meetings have recommended reducing annual emissions of CO_2 and perhaps other greenhouse gases by 20 to 50 percent over the next 10 to 50 years to forestall or reduce atmospheric warming and other changes in global climate. The objectives of this paper is to develop a model for predicating CO_2 and CO_2-equivalent emissions from transportation sector, as well as to introduce application for the model and measures for reducing greenhouse gas emissions from this sector.

TRANSPORTATION AND THE GREENHOUSE EFFECT

Energy use is clearly the primary source of CO_2. Globally, fossil-fuel burning now accounts for 56 to 94 percent of the total net CO_2 release [27].

Egypt's energy requirements for transportation sector are mainly met by the use of conventional fossil-fuel energy sources. It is widely accepted now that the ever increasing use of petroleum is mainly responsible for the continuing build up of CO_2 in the atmosphere. Since CO_2 is a well known greenhouse gas, it could cause global warming which may lead to serious

consequences for the climate including rainfall, sea-level rise and associated effects.
In addition to vehicle operations, transportation contributes to CO_2 emissions through:

* The energy used to refine petroleum into fuels,
* The energy used to make and maintain transportation vehicles,
* The energy used to build transportation infrastructure,
* The energy used to make the materials from which vehicles and infrastructure are made, and
* The chemical processes of producing cement for infrastructure.

Several other gases - methane (CH_4), nitrous oxide (N_2O), ozone (O_3), and chlorofluoro carbons (CFC_s) - have a potentially important role in contributing to the greenhouse effect. Researches indicate that they could be responsible for about 50% of the total greenhouse temperature increase 50 years from now [17,21].

Transportation also contributes other gases that contribute to global warming: mobile air - conditioning equipment used in transportation is a significant emitter of CFC_s. Finally, motor vehicle operations release significant amounts of nitrogen oxides (NO_x), which may be precursors to N_2O, and carbon monoxide CO. CFC_s, CH_4, and N_2O contribute more per molecule to warming than does CO_2, and together at present atmospheric concentrations these other greenhouse gases may contribute roughly as much to warming as CO_2 does now [7].

PROCEDURE FOR ESTIMATION OF CO_2 AND CO_2- EQUIVALENT EMISSIONS FROM TRANSPORTATION SECTOR

CO_2 and CO_2-equivalent emissions from transportation sector can be estimated from the following models:

$$Q = \sum_{m=1}^{5} (q_{m,CO2}+q_{m,CH4}+q_{m,N2O}) * TV_m$$

where:

Q: total CO_2 and CO_2-equivalent emissions in kg/year

$q_{m,CO2}$: CO_2 greenhouse gas emissions from transport mode m in kg CO_2/pass.km for passenger transport or kg CO_2/ton.km for freight transport

m: transport mode (car, bus, train, truck, tram)

$q_{m,CH4}$: CO_2-equivalent emissions from CH_4 (methane) in kg CO_2-equivalent/pass.km

$q_{m,N2O}$: CO_2-equivalent emissions from N_2O (nitrous) in kg CO_2-equivalent/pass.km

TV_m: transport volume, in pass.km or ton.km

$$q_{m,CO2} = \sum_{m=1}^{5} a_{m,CO2} * b_m * f_1 * f_2 / c_m$$

where:

a_{CO2}: factor for calculation of CO_2 emissions from primary energy consumed in kg CO_2 /MJ (MJ=Megajoules =10^6 Joule = 0.278 kwh). According to [1,11] a=0.369 for electricity (tram or train), a=0.0741 for diesel, and a=0.0693 for benzine (car, bus, and truck)

Table (1) shows the world-wide values of kg CO_2 /MJ and kwh for several energy sources.

b: specific primary energy consumption in MJ/veh.km [18,22]
= 2.6-4.65 for benzine vehicle (7.5 l-11.9 l/100 km)
= 2.26-3.65 for diesel vehicle (5.9 l- 9.6 l/100 km)
= 14.02 for bus (36.7 l/100 km)
= 7.08 for minibus (18.5 l/100 km)
= 78.9 for trains (749.1 kwh/100 km)
= 20 for trams

C_m: occupancy rate
= 2 for cars, 3 for taxi
= 200 for bus
= 300 for tram
= 1000 for train

f_1 and f_2: factors present behavior of car driver and status of transport mode (life time for car, bus and truck)

$$f_1 \text{ and } f_2 = 1.0 \text{ to } 1.7$$

These factors can be estimated from end energy consumption and specific primary energy consumption.

$$q_{m,CH4} = \sum_{m=1}^{5} a_{m,CH4} * b_m * f_1 * f_2 * e_{CH4} / c_m$$

$$q_{m,N2O} = \sum_{m=1}^{5} a_{m,N2O} * b_m * f_1 * f_2 * e_{N2O} / c_m$$

where:

a_{CH4}: factor for calculation of CH_4 emissions in kg CH_4 /MJ [11]
= $0.0974 * 10^{-3}$ kg CH_4 /MJ for benzine vehicle
= 0.005 to $0.0083 * 10^{-3}$ kg CH_4 /MJ for diesel vehicle

a_{N2O}: factor for calculation of N_2O emissions in kg N_2O /MJ
= $0.022 * 10^{-3}$ kg N_2O /MJ for benzine vehicle [11]
= $0.009 * 10^{-3}$ kg N_2O /MJ for diesel vehicle [11]

Table 1. The world-wide average values of kg CO_2/MJ and kwh for several energy sources [8,11]

Fuel	kg CO_2/MJ	kg CO_2/kwh*
Coal	0.0946	0.3403
Fuel Oil	0.0774	0.2784
Diesel / Gas Oil	0.0741	0.2665
Jet Fuel	0.0733	0.2637
Benzine	0.0693	0.2493
Natural Gas	0.0561	0.2018
Hot Dry Rock	0.0481	0.1730
Magma	0.00478	0.0172

* 1MJ = 10^6 J = 0.278 kwh

Table (2) illustrates the world-wide values of g CH_4 /MJ and g N_2O /MJ for several energy sources.

e_{CH4}: coefficient to convert CH_4 to CO_2-equivalent emissions

e_{N2O}: coefficient to convert N_2O to CO_2-equivalent emissions

According to Table (3), the effect of 100 year of 1 mass unit per year of CH_4 emissions has the same overall temperature effect "global climate warming" as 11 mass units of CO_2 emissions per year for 100 years. This means that, the plausible conversion factor of CH_4/CO_2 can be considered as 11. The corresponding mass conversion factor for N_2O to CO_2 emissions is 270.

Table 2. The world-wide average values ofg CH_4/MJ and g N_2O/MJ for several energy sources [11].

Fuel	g CH_4/MJ	g N_2O/MJ
Coal	$0.1 * 10^{-3}$	0.002-0.070
Natural Gas	$0.3 * 10^{-3}$	0.002
Jet Fuel	0.0114	----
Diesel Cars	0.005-0.0083	0.009
Diesel Trucks	0.005-0.0083	0.051
Benzine Cars	0.0974	0.022

Table 3. The Global Warming Potential [12].

Element	Life Time	Direct Effect for Time Horizin of		
		20	100	500 Years
CO_2	12.0	1	1	1
CH_4	10.5	35	11	4
N_2O	132.0	260	270	170

APPLICATION

The road network of Alexandria city has been chosen for a case study to examine the environmental effect of the transportation operation. The main roads of Alexandria's network has been selected to examine the effect of using the conventional energy system in transportation operations on the quality of the air in Alexandria city. Applicating the previous models for a traffic load estimated in the year 1995 on the primary corridors of Alexandria city Figure (1), the amount of CO_2 and CO_2-equivalent emissions produced in this year on some parts of these arterial roads achieves 180,000 tons Figure (2). Under the existing traffic and transportation conditions and with an average growth rate of 3% per year, this value will achieve 288,000 tons in the year 2015. Using another cleaner source of energy such as natural gas or electricity from magma can reduce the last value to 189,000 or 11,500 tons respectively.

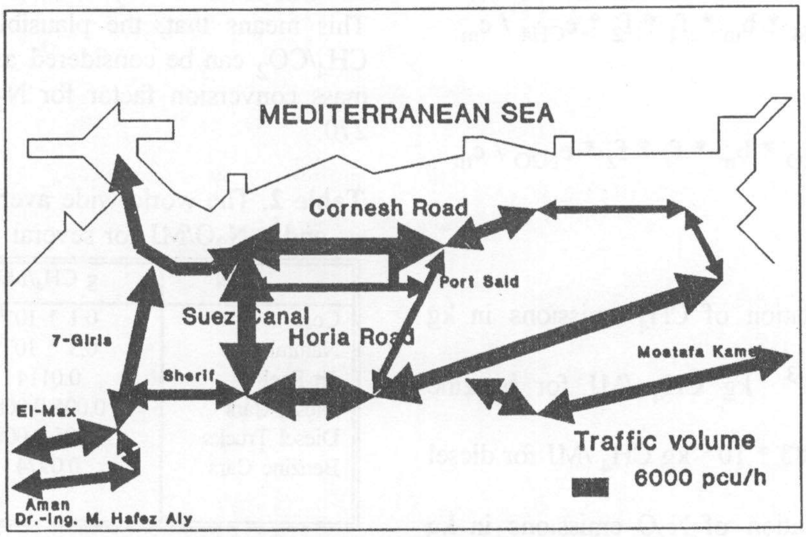

Figure 1: Traffic Load on the Primary Corridors in Alexandria City 1995

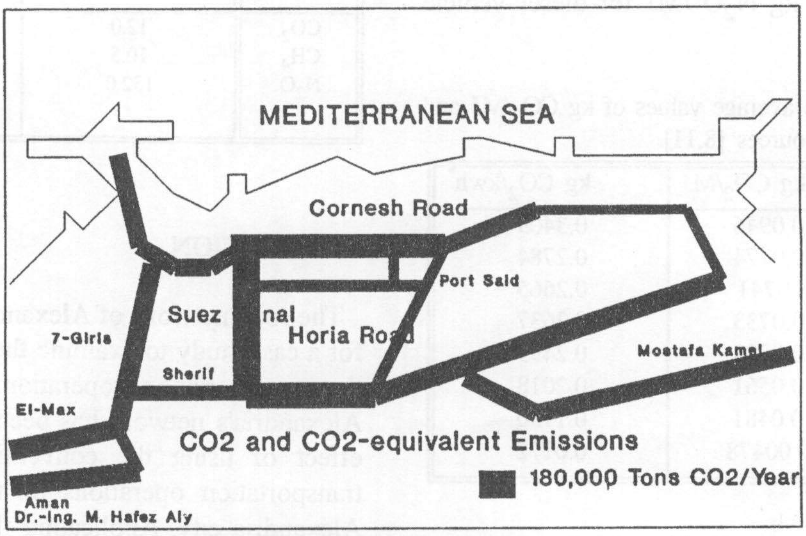

Figure 2: CO2 and CO2-equivalent Emissions Produced in the Year 1995 on The Main Streets of Alexandria City

Figure (3) shows the amount of the CO_2 and CO_2-equivalent emissions produced in the year 2015 on the main streets of Alexandria city by using natural gas or electricity from magma.

The total amount of the CO_2 and CO_2-equivalent emissions produced in the year 2015 on the transportation network of Alexandria city has been predicated for an estimated traffic volume of 838.2 Mio. Passenger.kilometer on private cars and taxis, 4,363 Mio. Passenger.kilometer on bus (public transport), and 5,760 Mio. Passenger.kilometer on Tram and Train, and for a modal split of 76.1% public transport, 6.3% private car, the result illustrates that 602,500 tons CO_2 and CO_2-equivalent emissions will be produced in this year. This value has been estimated to be 377,000 tons in the year 1995.

The total amount of CO_2 and CO_2-equivalent emissions predicated for the year 2015 can be reduced to 36% or 3% respectively, if the natural gas or electricity from magma will be used for the transportation sector.

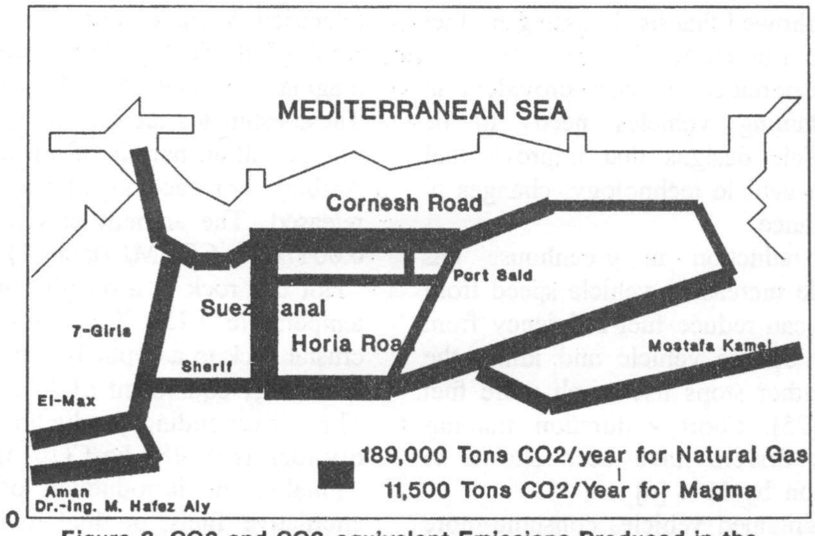

Figure 3: CO2 and CO2-equivalent Emissions Produced in the Year 2015 on the Primary Streets of Alexandria City Using Natural Gas or Electricity from Magma

To examine the effect of using the conventional energy system in transportation operations on the quality of the air in Alexandria city, the CO_2 concentration (ppm = weight of CO_2 produced in tons/weight of the air of a height 3 km in the catchment area in Mio. tons) on the air produced from this sector has been estimated to be 34 ppm in the year 1995 and 57 in the year 2015. This means that 13 % of the conventional energy user produces 34 ppm CO_2 concentration in the atmosphere in the year 1995, and 57 in the year 2015, and the CO_2 concentration increases by 1 ppm per year in the air of Alexandria city as a result of using the conventional energy in the transportation sector. Considering the other conventional energy users such as industry and household, the CO_2 concentration may achieve 285 ppm in the year 1995, and 438 in the year 2015. Table 4 illustrate the world-wide average values of CO_2 concentration in the air in ppm.

To reduce emissions of greenhouse gases from the operation of transportation vehicles various measures will be needed.

MEASURES FOR REDUCING CO_2 and CO_2-EQUIVALENT EMISSIONS FROM TRANSPORTATION SECTOR

Efforts to reduce the transportation sector's emissions will require such potentially changes as:

* Improving fuel efficiency
* Switching to cleaner fuels
* Modifying the travel demand

IMPROVING FUEL EFFICIENCY

Improving vehicle fuel efficiency reduces the quantity of fuel needed to supply a vehicle fleet, as does reducing growth in demand for travel. In addition, improvements in vehicle weight, and aero-dynamics are largely independent of fuel and engine technology and would allow a given volume of fuel to provide a greater operating range.

According to the well known vehicle fuel economy model, improvements of fuel efficiency can be compounded by:

* reduction in tire rolling resistance,
* reduction in aerodynamic drag resistance, and
* reduction in mass

Enormous improvements in vehicle fuel economy are technologically possible [25]. High taxes on fuel inefficient vehicles must be required if the

Table 4. The world-wide CO_2 concentration in ppm [29].

Year	1880	1900	1980	1984	2000	2025
CO_2 ppm	260	280	338	384	568	760

technologically and economically achievable vehicle fuel efficiency potential is to be realized. Bleviss and Walzer [2] have been showed that by focussing on fuel economy alone, cars can be made very efficient.

The behavior of transportation service providers in operating and maintaining vehicles needs to be coordinated with vehicle designs that improve fuel efficiency. Changes in vehicle technology, changes in operating and maintenance practices can bring reduction in greenhouse gas emissions. For example increasing vehicle speed from 90 km/h to 105 km/h can reduce fuel efficiency from 5 to 30%, depending on the vehicle and idling the engine [10]. Cold weather stops use much more fuel than a fuel heater [25]. Short - duration training programs for vehicle drivers have been shown to reduce fuel consumption by 10% [6].

Similarly, poorly maintained vehicles consume more fuel than good maintained. Local vehicle inspection programs which test fuel efficiency as well as other emission control and safety equipment could reduce fuel consumption. If inspection and maintenance programs for vehicle fuel efficiency become widespread, these programs might cause vehicle makers to design vehicles that require less cost and effort to maintain and perhaps also reduce the long-term cost of the inspection program.

SWITCHING TO CLEANER FUELS

A shift to natural gas has been advocated for transport. This is because, natural gas reserves, in energy terms, are several times as large as liquid fuel reserves. Not only it is more plentiful, but also because of its lower carbon content, natural gas release less CO_2 per unit of energy when burnt than oil fuels [18]. Furthermore, natural gas-based fuels are thought to be less polluting than benzine or diesel.

Natural gas reduce carbon dioxide emissions, since combustion of it releases only about 0.0561 kg of CO_2 per MJ (Megajoule) of energy produced, whereas for liquid fuels, the corresponding value is about 0.0693 to 0.0741 kg/MJ [11].

Fuel from solar or renewable biomass feedstock would eliminate emissions.

Most geothermal resources produce significantly less CO_2 than the fossil- fuels for equivalent energy outputs [8]. Efforts to reduce CO_2 emissions from fossil-fuels will probably raise the cost of fossil-fuel power and will make geothermal energy more price competitive. Increased geothermal production (hydrothermal resources, hot dry rocks, and magma) of energy (electricity) may reduce the greenhouse effect. U.S. Geological Survey has estimated that the heat of magma is between $5.28 * 10^{22}$ and $5.28 * 10^{23}$ J [19]. These estimates are the energy equivalent of 8610 and 86,100 billion barrels of oil (half the reserves of Saudi Arabia). For each kg of magma, 0.0003 kg CO_2 are released. The amount of CO_2 released by magma is 0.00478 kg CO_2/MJ (table 1).

Hot dry rock is a deeply buried crustal rock with a temperature > 150 °C. $1.3 * 10^{25}$ J are contained in the crustal rock to a depth 10 km in the U.S.A. [3]. This is the energy equivalent of $2.12 * 10^5$ barrels of oil [14]. The corresponding production of CO_2 released by hot dry rock is 0.0481 kg CO_2/MJ.

Finally, the introduction of new vehicle that uses alternative fuels, or dual fuel, may provide a partial solution to the problem of increasing greenhouse gas emissions and the global warming result.

MODIFYING THE TRAVEL DEMAND

Demand for transportation services affects greenhouse gas emissions both in its size and in choice of transportation modes used to provide the service.

Options for influencing mode choice include:
* increasing occupancy ratio (car - pooling),
* increased use of public transport,
* land use changes, and
* teleworking or telecommuting

Car - pooling has obvious attraction as a solution to greenhouse emissions. Present occupancy rates for cars, especially for work - related trips are low, and car pooling could be implemented, using existing car fleet. It also helps reduce the cost of car travel. The main focus has been on increasing occupancy of commuter vehicles, in order to reduce congestion and associated air pollution.

Public transport is already useful in reducing greenhouse emissions. The main way of increasing public transport's share under existing transport conditions would appear to be by offering better level of service and additional peak and off-peak service on existing routes, and by starting new bus services in areas not presently served by public transport. It is therefore clear that modal shift under these conditions would reduce greenhouse emissions.

Altering land use patterns in urban areas has been suggested as means of reducing travel, fuel and emissions [20].

Teleworking or telecommuting reduces the amount of car travel related to work trips, especially during congested periods.

Finally, increasing vehicle charges or fuel costs, like a proposed "carbon tax", and reduction in city centers parking places would reduce travel demand or make a modal shift.

CONCLUSIONS

This paper has focussed on the environmental effect of the transportation operation, and the way of predicating CO_2 and CO_2-equivalent emission from transportation sector. New models were developed to estimate CO_2 and CO_2-equivalent emissions from a certain transport network. Significant factors were considered, such as transport volume and mode, fuel used and efficiency, lifetime of transport mode, behavior of car driver, and emissions rates for fuel used.

Applicating the model on Alexandria as a case study showed that the amount of the CO_2 and CO_2-equivalent emissions produced in the year 1995 on the transportation network of Alexandria city achieves 377,000 tons, and this value will achieve 602,500 tons in the year 2015.

The CO_2 concentration (ppm) from transportation sector has been predicated to be 34 ppm in the year 1995 and 57 in the year 2015. The CO_2 concentration increases by 1 ppm per year in the air of Alexandria city as a result of using the conventional energy in the transportation sector. The total CO_2 concentration from transportation sector and other conventional energy users has been estimated to be 285 ppm in the year 1995 and 483 in the year 2015.

Aggressive intervention will be needed to reduce emissions of greenhouse gases from the operation of transportation vehicles. Such intervention, in the form of improving fuel efficiency, requirements for the use or production of alternative fuels, standards for vehicle operation and maintenance, introducing of dual fueled vehicles, car pooling, reduction in parking places, modal shift, and teleworking could reduce substantially the expected growth rates in transportation energy consumption and the associated emissions. Using cleaner fuel such as natural gas or electricity from magma for operating the transportation sector in Alexandria city will reduce the total amount of CO_2 and CO_2 -equivalent emissions produced in the year 2015 by 36% or 3% respectively.

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