Past and present trends of urban transport and related energy consumption, greenhouse gas and pollutants emissions in Greater Cairo

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ABSTRACT

The paper is based on a pioneer research project, DRTPC Study Experts. (2009), lead by the first author with active participation of the second. The project was performed through "Plan Blue" in cooperation with the Transportation Programme of DRTPC, Cairo University as acknowledged in the end of the paper. As it appears from its title, the paper focuses on analyzing past evolution of transport demand and supply in Greater Cairo over the last 30 years of the 20th centaury, utilizing the results of travel demand surveys carried in 1971, 1978, 1987, 1998 and 2001. Demand analysis includes the evolution of daily trips, trip purpose share, modal share and number of cars. Whereas, the evolution of transport supply covers an overview on transport projects implemented over the considered years. Further analysis of more recent trends of 2006/2007 vehicle registration in Greater Cairo by type and size is given. This allowed estimation of energy consumption and cost as well as emissions of green house gases (CO_2) and pollutants (CO, HC & NOx) in absence of actual measures and based on international norms and local experience supported by estimates of travel distance and speed. A comparative analysis of relevant evolution indexes and trends of growth between 1971 and 2001, taking the former as base year, is given. This includes the evolution indexes of urban development (population & urbanized area), those of travel demand (trips), vehicles and private cars and the indexes of the evolution of fuel consumption, CO_2 and pollutants emissions. The analysis aims at revealing the features of increased energy consumption and emissions as related to the drivers of urbanization and transport in this grand metropolis. A brief on main land use and transport policies and projects that helped, directly or indirectly, to relatively reduce traffic congestion , or at least prevented an increase, in Greater Cairo over the years and hence brought about reduced energy consumption, CO_2 emissions and air pollution is given. This serves as possible transferable lessons for other sister cities. It is hoped that the paper draws the attention of transport researchers to look at the trends of the past, whenever data permit, so as to learn and understand more on the dynamics of change of transport and its impacts on energy and environment and how this may reflect on the future.

Kew Words: Transport demand evolution, energy consumption evolution, GHG emissions evolution, Greater Cairo.

1. Introduction

Travel demand is always increasing in all cities of the world as a consequence of increased mobility, human activities and increased cars and other motorized modes of transport. In the same time, particularly in mega cities of the developing countries, traffic congestion, the difficulty to expand the transport system and infrastructure with the same rate of growth of travel demand and the difficulty to introduce effective supply management and to apply demand management, lead to negative consequences as increased energy consumption, greenhouse gas (GHG) and pollutant emissions.

Furthermore, over the past three decades, attention of cities, countries, international organizations and researchers have been focusing on issues of traffic congestion, energy consumption, CO_2 and pollutants emissions. However, the focus is quite often made in one point of time or directed to future forecasts. To contribute to research effort, it is believed that in addition we also need to look at the trends of the past so as to learn more and understand more on the dynamics of change of urban transport and its impact on energy consumption and the environment.

It is also clear that transport demand and supply are always affected and reflected by the extent of urbanization and urban activity development. In the same time transport (mainly the road-based modes) bears on energy consumption and increased GHG and air pollution. In other words, "transportation" lies in the middle, between "urbanization" from one hand and "energy/environment" from the other. It takes the burden of urban area expansion as a generator/driver of increased transport demand/supply (and their evolution by size and location) and causes important impact on the consumption of energy and environment degradation (and also their evolution by size and location). In the current paper we try to analyse the evolution of transport in Greater Cairo (GC) over the years as a consequence of urban development and population growth and the consequent energy and environment impacts over 30 years 1971/2001. Data from five successive transport studies, in which Origin/Destination (O/D) surveys were carried out in GC, in 1971, 1978, 1987, 1998 and 2001, are utilized applying needed mathematical adjustments to allow for compatible comparisons, Huzayyin, Ali S. (2004). Therefore, those particular five years were chosen for studying the evolution as no more recent O/D survey is yet carried out in GC. As availability permits, however, statistics for more recent years are referred to.

The paper starts with a brief on GC population, urbanized area and transportation at present. Next, the evolution of transport demand is discussed, focusing on past trips, trip purpose split and modal shares. In addition, transport supply expansion over the years is addressed, focusing on the main road infrastructure expansion and metro network history and successful growth. The paper, then gives a national outlook on energy, GHG emissions and air pollution comparing the situation with selected countries. The evolution of GC fuel consumption and cost, GHG emissions and pollution from transport is analyzed, starting with detailed analysis of the evolution of the road-based vehicular fleet. Next, comparative analysis between the evolution of urban development, transport demand, energy consumption, GHG (CO_2 equivalent) and CO and NOx emissions is given with relevant concluding comments. Finally, the paper briefly sheds light on successful policies and transferable lessons that may be possible for other cities of developing countries.

2. General Outlook on GC Evolution (1971/2001)

GC is the largest urban area in Africa and the Middle East and one of the most populous metropolises of the world. Cairo occupies the 11th rank within mega cities across the world in the period between 2000 and 2015. Over the 20th century the population increased from 0.6 million in 1900 to more than 10.5 millions in 2000. The rate of natural population growth in Egypt in 1966 was 0.260, became 0.304 in 1985, and started to decrease continuously until it reached 0.218 in 1996 and 0.195 in 2006; marking successful family planning policies.

GC population and urbanized area have similar steady rates of increase over the years; each has nearly doubled between 1971 and 2001, while they increased by nearly 50% in the mid period, 1987, compared to 1971. It is clear that urban expansion is not easy to take place over the surrounding desert because of the high cost of infrastructure and possible geotechnical problems of building on certain locations. In the same time, it is not easy to expand over the surrounding scarce fertile agriculture lands; for the obvious reasons. Accordingly, population density increased in 2001 by about 11.3% compared to 1971; reaching 39000 persons/km^2. However, informal expansion still occurred slowly over the past 40 years; and also parallel effort has been made since the 1980s to improve the situation. For detailed analysis on urban development in GC refer to DRTPC Study Experts. (2009).

In view of the continuous urban expansion and population growth of Cairo and later GC and as a consequence of the related development drivers, the evolution of "transport needs" of the residents, and visitors alike, and that of the "offered transport facilities" have always been increasing; with varying trends and rates of course. As there are obvious problems of congested corridors, traffic delay and crowded buses during peak periods, there are also successes and achievements of major infrastructure projects of new elevated roads, parking garages, improved buses and underground metro network introduction and continuous expansion. For detailed analysis on urban transport evolution in GC refer to Huzayyin Ali S. (2004) and DRTPC Study Experts. (2009).

Similarly, on the other hand for the outputs, as there have been continued increase in energy consumption from transport and deterioration in air quality and increased GHG emissions due to transport, there are also projects and policies aiming at saving energy and the introduction, and/or encouragement, of environmentally friendly transportation. Examples are many as mentioned later and detailed in DRTPC Study Experts. (2009).

3. General Outlook on GC Transportation in 2009

Figure 1 shows the main road network of the GC region in general; covering the new cities and the surrounding urban centers, whereas Figure 2 shows the main road network of GC inside the Ring Road boundaries. The road network is composed of a variety of road hierarchy ranging from elevated expressways forming strategic traffic corridors to collectors and local streets, in addition to numerous alleys in the old districts. Segregated Ring Road of some 100 km also exists and prevents through traffic from crossing the city. The River Nile passes through the city from the South to the North; constituting major geographical barrier between East and West side districts. Sixteen bridges cross the River and play important role in connecting those two sides and the islands. Numerous flyovers and underpasses exist, by-passing main squares and a number of main traffic tunnels are heavily used; two of which are 2.5 km length each, under-passing Old Cairo.

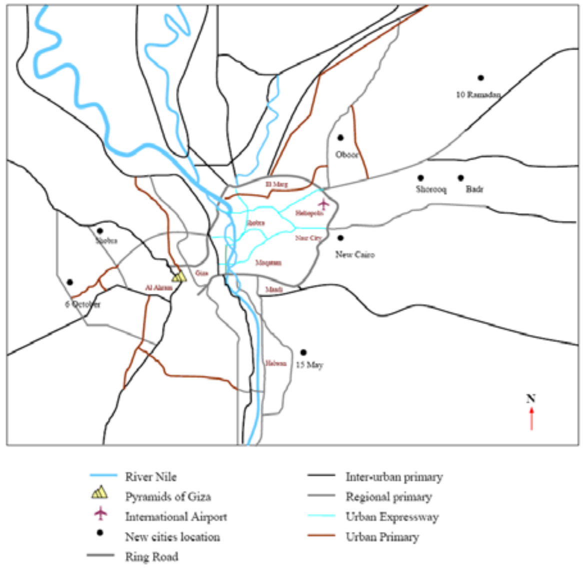


Figure 1: Greater Cairo Region main road network, (DRTPC Study Experts. (2009), based on JICA. (2002a)).

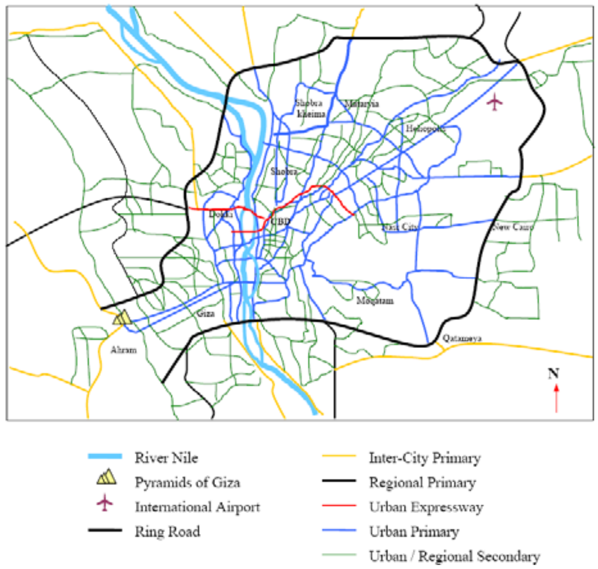


Figure 2: Greater Cairo main road network inside the Ring Road, (DRTPC Study Experts. (2009), based on JICA. (2002a)).

Among the existing private transport modes, the private car is the most important; while among formal and informal public transport, different modes play important roles. The formal modes include: bus and minibus with a network of more than 10000 km. The main operator is Cairo Transport Authority, CTA, which runs in addition, two tram systems and two Nile ferry lines. A number of private companies operate minibuses on concession lines. The most effective formal public transport mode is the metro, with a network of some 80 km; Lines 1 and 2 inaugurated in 1987 and 1996, respectively. Phases I and II of Line 3 due for opening 2011 and 2013, respectively. Implementation of Phases III and IV of Line 3 and Phase I of Line 4 are planned to start simultaneously after the beginning of operation of Line 3 Phases I and II. Informal public transport includes "shared taxi" microbuses and "cooperatives" minibuses. Benefiting from the small size and being operated by individual drivers/owners, those modes are demand responsive and market oriented.

4. Evolution of Transport Demand and Supply (1971/2001)

Based on Huzayyin, Ali S. (2004) and the O/D surveys of the successive transport studies of GC; references SOFRETU. (1973), JICA. (1989), SYSTRA/DRTPC, et al. (2001a), JICA. (2002a) and JICA. (2002b); the following evolution trends of transport demand are calculated.

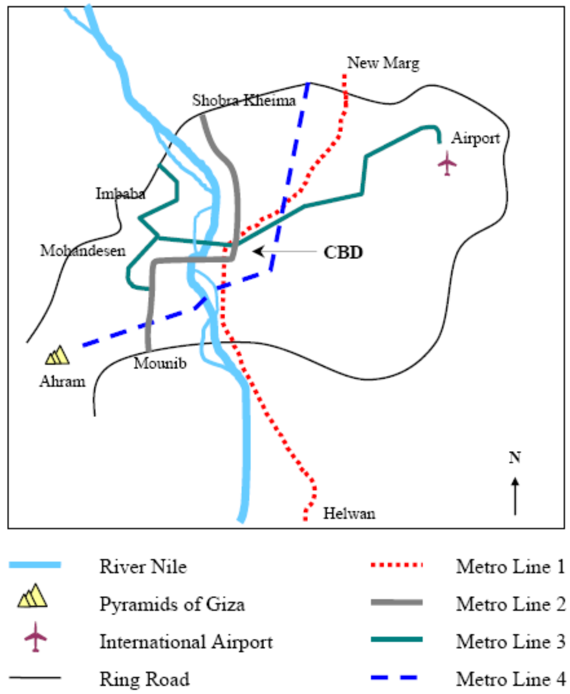
Total daily trips were 5.6 million in 1971, rising to 10.8 million in 1987, 14.1 million in 1998 and 21.6 million in 2001. Walk trips reached 26% of total daily trips in 1971, increasing to 36% for both 1987 and 1998 and then reduced to 32% for 2001. The latter drop is logical due to the much larger area of the 2001 survey compared to the earlier ones. It is estimated that the number of daily motorized trips in 2022 will increase to about 25 million, JICA. (2002a), which is nearly an increase of 174 % on the 14.4 million motorized trips observed in 2001 by the same reference. A recent estimate for 2009 motorized trips is given as about 17 million (reference not yet published). Person mobility trend nearly doubled between 1971 and 2001; rising from 0.8 trip/person/day, SOFRETU. (1973). to 1.64 trip/person/day, JICA. (2002a), with a rate of 1.42 trip/person/day in 1998, SYSTRA/DRTPC, et al. (2001b). So, it is clear that urban personal mobility is increasing by time. It should be noted, however, that the mobility of 1.64 trip/person/day reported from the 2001 survey is on the lower side. As mentioned above the GC study area in 2001 (including the new cities and the surrounding rural centers) was much larger than those of the other two studies.

To cope with the continuous increase in motorized trips, GC transport system has witnessed great expansion and changes in type, size and location, Huzayyin, Ali S. (2004). For instance, in 1971 public transport consisted only of three modes, bus, light rail tramway (tram and Heliopolis metro) and trolley bus. Currently, in 2010 public transport comprises 10 modes, namely CTA bus and minibus, GC Bus Company bus, Air-conditioned bus, River bus, light rail tramway (tram and Heliopolis metro), metro, private concession lines minibus and the informal shared taxi microbus and cooperatives' minibus. This is in addition to the yellow taxis owned and operated by two private companies which did not exit before 2006.

The informal shared taxi originally started gradually in 1979, and from 1985 they started to play a profound role, DRTPC Study Experts. (2009). In 1986 the CTA minibus was introduced and in 2001 the private minibus entered the market for the first time since 1960. The cooperative minibus informal modes were gradually introduced in the late 1990s and in 1997 CTA started the Air-Conditioned bus with the lines and fleet quadrupled in 2003.

Figure 3 shows GC present and future metro lines. On 27 September, 1987 Phase I of metro Line 1 was opened to service between Helwan Station in the south and the CBD. This is a historic day for urban transportation in Africa and the Middle East, marking the start of operation of the 1st Metro Line on their territories. Phase II followed in 1989. Later in Line 2 was opened in three successive phases in 1996, 1997 and 1999; with additional extensions in 2000 and 2005. As mentioned above the first two phases of Line 3 are scheduled 2011 and 2013, with further expansions to start soon afterwards. For details on the history of GC metro refer to Huzayyin, Ali S, et al. (1989); and for a precise up to date summary refer to DRTPC Study Experts. (2009). Figure 4 shows the trend of increase of metro trips 1987/2009.

The period 1971 to 2001 saw the opening of three additional Nile bridges, very large increase in over passes and underpasses and two car tunnels. Four major elevated expressways are completed; one of those was opened in 2009 to close the circle of the Ring Road. Terminal 2 of Cairo International Airport was opened in 1985 and Terminal 3 in early 2009; the only Airport project financed by the World Bank in the period 1995 to 2005, IEG. (2007).



NB:
L1 Operated 1987
L2 Operated 1996
L3 Phase I & II under construction (Phase I, opening 2011 and Phase II, opening 2013)
Phase III Feasibility & Tender Documents preparation (2009)
L4 Phase I Feasibility & Tender Documents preparation (2009)

Figure 3: Greater Cairo Metro Lines Network

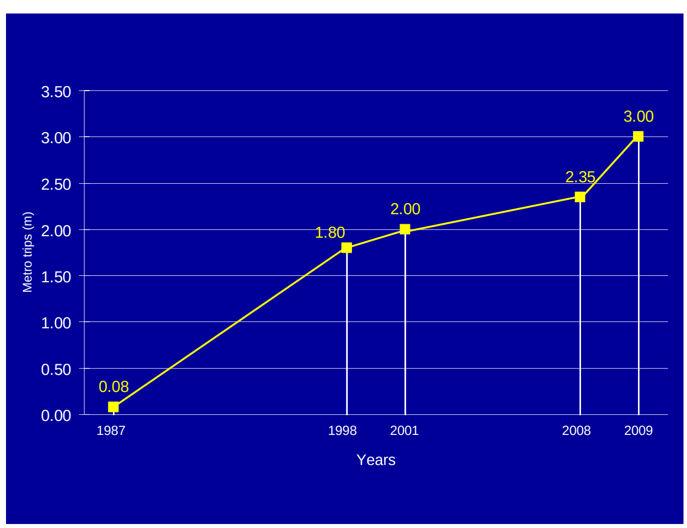


Figure 4: Evolution of daily metro trips in GC, 1987/2009.

The evolution of the number of cars is given for Cairo Governorate alone and not for GC, due to lake of precise statistics, Huzayyin, Ali S. (2004). Between 1976 and 2001 the number of cars in Cairo Governorate rose dramatically from about 86000 to about 625000 cars, a remarkable 727% increase. In 2007 the number reached about 960000 cars, which is an increase of 1116% compared to 1976, and of 154% compared to 2001. The evolution index between successive years (taking 1976 as a base year) is 4.2 for 1986, 5.9 for 1996, 7.3 for 2001 and 11.2 for 2007. However, SYSTRA/DRTPC, et al. (2001b), estimated car ownership in GC in 1998 as 1.2 cars/household and 0.03 cars/household for the highest and the lowest income groups, respectively, which is quite logical.

The evolution of daily trips by trip purpose share (%) is given in Table 1 for four survey years 1971, 1987, 1998 and 2001, Huzayyin, Ali S. (2004). Two main comments are drawn; the trend of work trips share dropped from 26% 1971 to 21% in 1987 and 20% in each of the years 1998 and 2001. This is mainly due to the reduction of the working days of the week to five days starting in the late 1980s. The trend of share of education trips out of daily trips shows clear increase from 15% in 1971 to 20% and 23% in 1987 and 1998, respectively, and 25% in 2001. This matches the continuous increase in the number of education institutions; the number of Universities in GC has increased from 4 in 1971 to 10 in 2001, Huzayyin, Ali S. (2004).

Table 1: Evolution of Greater Cairo trips by trip purpose share (%), Huzayyin, Ali S. (2004).

Trip Purpose	1971	1987	1998	2001
Work	26%	21%	20%	20%
School	14%	19%	22%	24%
Home	41%	48%	49%	49%
Other	19%	12%	9%	7%

Table 2 gives the evolution of GC daily trips by modal shares (%) for the main motorized modes; car (+ taxi), bus (+ minibus), light rail (tram + Heliopolis metro), metro and shared taxi. The following comments can be made, Huzayyin, Ali S. (2004). Car trips share increased from 14% to 31% and 38% of total daily trips by all modes in 1971, 1978 and 1987, respectively. This may be attributed to the application of the economic open door policy after 1973 allowing car imports increase. Then, sharp drop happened after 1987 and the percentage decreased to 20% in 1998 with a slight increase to 23 % in 2001 due to the rationalization of car imports in the early 1980s and also to the start of operation of metro Line 1 in 1987 which attracted many car users ever since. This is evident from the ever increasing number of parked cars around metro stations in the high income fringe districts. The metro offers freedom of mode choice to car users due to its high level of service compared to other public transport modes. Hence, the metro reduced car users' mode captivity; particularly to those living and working around its stations. Furthermore, the introduction of the Air Conditioned bus attracted many car users. For instance, between 1998 and 2001, the share of Air Conditioned bus trips out of total motorized trips rose from 0.3% to 1.0% and the daily trips increased 10 fold between 1997 and 2003. It would have been interesting if statistics on the past evolution of car use and not only cars and car ownership was available as it is more meaningful feature to study, Huzayyin, Ali S., et al. (1998).

It is also clear from Table 2 that the trend of the evolution of bus and minibus share of daily trips by all modes is steadily decreasing, Huzayyin, Ali S. (2004). In 1971 this share was 70% and in 2001 it became only 22%. This continuous decline is still undergoing as in 2008 daily trips on bus and minibus reached 2.2 million compared to 3 million in 2001. On the other hand, shared taxi share in daily trips increased steadily since it started to play an important role on from 1985; jumping from 6% in 1987 to 35% in 1998 and 37% in 2001. Clearly the shared taxi captured many of the bus users as it provides high accessibility, it is faster than buses and is demand responsive attaining almost instantaneously to any change in market needs.

Similarly, metro share of the market of daily trips has always been on the increase since its introduction in 1987 when the share was only 6% and reached 16% in 1998 and 17% in 2001, Huzayyin, Ali S. (2004). This increase is still growing jumping from 2 million trips/day in 2001 to average 2.35 million trips/day in 2008 (with a maximum record of 3 million trips/day) as reported by the operator. The metro is certainly capturing considerable number of trips from the bus as it did with those made by car. Finally, the sharp decrease in light rail daily trips is a result of the elimination of many of the tram tracks since the 1950s, TRL/DRTPC. (1992).

Table 2: Evolution of modal share of motorized trip (%), Huzayyin, Ali S. (2004)

Transport Mode	1971	1978	1987	1998	2001
Car and Taxi	14	31	38	20	23
Bus and Minibus	70	56	41	28	22
Light Rail tram	16	13	12	1	1
Metro*	0	0	3	16	17
Shared Taxi**	0	0	6	35	37

* Service started 1987

** Started to be competitive 1985

5. National Outlook on Greenhouse Gas Emissions and Air Pollution

Before looking at the seen of transport related energy and GHG and air pollution emissions from transport modes in GC, we start by a general outlook on the national seen as compared to other countries. GHG emitted from the energy sector is mainly CO_2 resulting from the consumption of fossil fuels for energy purposes in different sectors which increased from 83.070 Mt CO_2e in 1996, to 137.110 Mt CO_2e by 2005, with an annual average growth rate of 5.7%. During 2005, the contribution of the main sectors in GHG emissions was the electrical power production sector share of 35.35%, followed by the transport sector with the share of 26%, the industry with 20.45% and the residential and commercial sector with 10.42%. It was estimated, IEAAE. (2008), that in 2003 the annual growth rate of GHG emissions was 4.9% mainly from energy related activities. This would lead to an estimated contribution from energy in total GHG emissions in Egypt by 392.000 Mt CO_2e by the year 2022.

Table 3 gives energy supply and CO_2 emissions indicators of Egypt compared to selected countries in 2003, where it appears that the net energy supply of Egypt represents only 1% of total world energy supply; while GHG emissions amount to 0.5% of the world total. These are very small compared to the US and other main industrialized countries as Germany and France, for instance. Egypt CO_2 emissions per capita are also very low compared to other countries.

The anthropogenic sources of air pollution include industrial facilities, thermal power stations, illegal open burning of municipal solid waste and other hazardous waste, in addition to transport sources from vehicular traffic exhaust. Among the most common air pollutants are sulfur dioxide (SO_2) and suspended particulate matter (SPM). Leaded gasoline was abandoned in nationwide in 1998 and hence transportation does not cause any lead emissions. Other pollutants such as CO, NO_x and hydrocarbons are produced mainly from idling vehicles in the traffic stream. Since 2001 about 40 monitoring stations started to monitor air quality in different locations in Egypt. Reported data on air pollution in some of GC districts show that, in 2001, SO_2 measured concentration ranged between 12 $\mu g/m^3$ and 65 $\mu g/m^3$; thus exceeding Egypt Air Quality Limit of 60 $\mu g/m^3$, in some districts. Based on EEAA/EIMP. (2000/2006), high concentrations of CO of 8.23 mg/m^3 was observed in few residential areas due to traffic congestion and a maximum annual average concentration of NO_2 of 76 $\mu g/m^3$ in central residential areas and a minimum of 30 $\mu g/m^3$ in the industrial areas. The concentration of PM10 in GC is mainly in industrial areas and due to construction works and cement industries and not due to traffic, with annual average > 250 $\mu g/m^3$ in industrial areas and 177 $\mu g/m^3$ in residential areas, exceeding the limit value for Egypt of 70 $\mu g/m^3$.

Table 3: Energy supply and CO_2 emissions indicators for Egypt and different countries in 2003 based on IEAAE. (2008).

Count.	Pop. (m)	Total Energy Supply					CO_2 Emission*		
		Prod. (Mtoe)	Import (Mtoe)	Net (Mtoe)	% World	Net toe/ Cap	Mt	% World	Ton / Cap.
USA	300	1654	730	2384	36.5	7.9	5697	20.3	19
GR	82	137	216	353	5.4	4.3	823	2.9	10
India	1110	436	135	571	8.7	0.5	1250	4.5	1.1
Brazil	189	261	20	281	4.3	1.5	332	1.2	1.8
Egypt	**74**	**78**	**- 14**	**64**	**1.0**	**0.9**	**153**	**0.5**	**2.1**
KSA	24	571	- 422	149	2.3	6.2	340	1.2	14.2
France	63	137	140	277	4.2	4.4	377	1.3	6
Turkey	73	26	69	95	1.5	1.3	240	0.9	3.3

*CO_2 emissions from fuel consumption only

Emissions are calculated using the IEA energy balances and the revised 1996 IPCC Guidelines.

6. Evolution of GC Fuel Consumption, GHG and Pollution Emissions from Transport

6.1 Evolution of road-based fleet

In order to calculate the evolution of GHG emissions and air pollution in GC it was necessary to start by analyzing the road-based fleet consisting of vehicles of various makes, models, sizes and ages. Table 4 gives the evolution of the number of vehicles by major types; 1971/2001. It is clear that vehicles are increasing at high rates during the more recent years 1998 to 2001, with 4.5% average annual increase rate. On the other hand, the available main street network in GC has not, and cannot be, increasing with the same rates either in length, width or capacity, resulting in continuous decrease in average travel speed. As cars (private cars, taxies and others) are always between 70% and 78% of all vehicles, they are examined in more detail in Table 5. Among all small cars, the private car is always dominating ranging between 79% and 84% of the total. It is interesting to observe that the number of taxis remained constant between 1987 and 1998, due to prohibition of registration of new taxis in that period, which in addition affected the age distribution of taxis. It is estimated that private cars of more than 25 years old are more than 17% of all private cars and 32% of the taxis are more than 25 years old, GTD. (various years).

Table 4: Evolution of vehicles in GC, based on GTD. (various years).

Year		Cars	B + MB	ST*	Truck	MC	Total
1971	No.	80755	2969	NA	9682	10687	104095
	%	78	3	--	9	10	100
1978	No.	167707	6062	NA	23179	32453	229401
	%	73	3	--	10	14	100
1987	No.	491923	12807	40000	82500	99653	726883
	%	68	2	6	11	13	100
1998	No.	902505	20276	50025	141857	166817	1281480
	%	70	2	4	11	13	100
2001	No.	1039617	27428	51005	162361	185158	1454699
	%	70	2	4	11	13	100
Ave. rate of increase/year (1998/2001)		4.7 %	11.8 %	0.7 %	4.8 %	3.7 %	4.5 %

Cars = (Private cars + taxi + other small cars), B = Bus, MB = Mini Bus, ST = Shared Taxi, MC = Motor Cycle, NE = Mode did not exit in the indicated year.
***** Estimated

Table 5: Evolution of the different types of small cars in GC, based on GTD. (various years).

Year		P Car	Taxi	Other	Total
1971	No.	68149	10400	2206	80755
	%	84	13	3	100
1978	No.	139945	22570	5192	167707
	%	84	13	3	100
1987	No.	385609	66314	40000	491923
	%	79	13	8	100
1998	No.	754036	66314	82155	902505
	%	84	7	9	100
2001	No.	876378	78483	84756	1039617
	%	84	8	8	100

Although CTA and other public busses and minibuses are heavily used, yet its evolution shows steady declining share, as it dropped from 53% in 1971 to merely 17% in 2001, confirming the decline in public transport bus use mentioned earlier. On the other hand, private, school and tourism busses are rapidly increasing due to increased schools, tourism and private businesses. Among all types of trucks, small trucks were about 17% in the 1970s and started to increase rapidly afterwards reaching about 60% in the 1980s and then remained unchanged. This is a result of the open door economic policy in the late 1970s. During the 1980s most of small trucks were fueled with gasoline, but after the increase of the price of oil they were converted into diesel; currently < 15% of small trucks are powered with gasoline engines, GTD. (various years).

6.2 Evolution of transport fuel consumption

To correctly calculate CO_2 and pollutants emissions, fuel consumption was calculated for different modes of transport. Data collected from fuel producers, fuel distribution companies and main consumers showed some inconsistencies and only give the fuel consumption for the whole country and not for individual cities. In addition, the required data and filed measurements and observations are numerous and extremely difficult and expensive to collect. Accordingly, specific fuel consumption and emission factors are used as given in different references, e.g., EDGER 3.2. (2000), EMEP/CORNIAIR. (2001), Ntziachristos, L. and Samaras, Z. (various years), according to vehicle type, engine technology, model and speed, in order to calculate fuel consumption and emissions. The following "generic" equation was used to estimate GHG and pollutants emissions. It should be noted that although the equation is given for calculating E_G, the annual emission for gas (G), it is used also to calculate fuel consumption through using the specific fuel consumption (SFC_{VT}) for specific vehicle type (VT) instead of emission factor (EF_{GVT}).

$$E_G = \Sigma_{VT} \Sigma_V EF_{GVT} \times AD_V$$

$$EF_{GVT} = f(VT, FT, AVS)$$

where,

E_G	=	Annual emission for gas G
EF_{GVT}	=	Emission factor of gas G for specific vehicle type (VT)
VT	=	Vehicle Type category {small vehicles (cars), bus, truck, etc.}; taking age and engine technology (including emissions controls) into consideration
FT	=	Fuel Type
AVS	=	Average Vehicle Speed
AD_V	=	Average Travel Distance (km/year) of vehicle V
VT	=	1, 2, 3, ………, m
m	=	Number of Vehicle Type categories
i	=	1, 2, 3, ………, n
n	=	Number of vehicles of each Vehicle Type category

After applying reasonable assumptions and adjustments on average speed and annual travel distance for each vehicle type based on local experience and available statistics coupled with appropriate verification, the equation led to the results outlined below, DRTPC Study Experts. (2009). The evolution of fuel consumption by fuel type is given in Table 6 where it can be seen that fuel consumption was steadily increasing at a high rate of 6.8% during the period 1987 to 2001, due to the increase of vehicles and vehicular traffic and the corresponding decrease in average travel speed. The table also gives energy consumption of the metro expressed as Ktoe (Kilo ton of oil equivalent) for comparison purposes, calculated considering local electricity mix and the generation and transmission efficiencies of electricity. It can be seen that energy consumption of metro is less than 5% of the total energy consumption in 2001, which is very low compared to its modal share in transport of 17% of total motorized daily trips in that year. Whereas, the average annual rate of increase of the total energy consumption in road-based transport is about 7% during the period 1998 to 2001. This is higher than the rate of increase of the total number of vehicles of 4.5% as given in Table 4 for the same period. This could be due to the decrease of the average speed that strongly affects specific fuel consumption (liters/km). The high rate of gasoline consumption is also reflected in Table 6 and could be a problem taken into account that Egypt production from oil and oil products are decreasing. Expansion of metro network could be part of the solution.

Table 7 gives the evolution of GC transport energy consumption by fuel type and road-based modes and metro, DRTPC Study Experts. (2009). It indicates that most of transportation fuel is consumed by small cars, mainly private cars and taxis reaching 51% of the total transport energy in 2001, while trucks consume 27% of the total transport energy in the same year.

Table 6: Evolution of GC transport energy consumption by fuel type and road-based modes and metro, DRTPC Study Experts. (2009).

Year	Gasoline (kt)	Diesel fuel (kt)	RB (Ktoe)	M (Ktoe)	RB + M (Ktoe)
1971	100	107	224	---*	224
1978	196	168	395	---*	395
1987	647	467	1209	4	1213
1998	939	863	1951	88	2039
2001	1204	982	2368	99	2468
Ave. rate of increase/year (1998/2001)**	9.4%	4.6%	7.1%	4.2%	7.0%

RB = Road-Based Modes, M = Metro
* Metro operation started in 1987
** Only given for 1998 and 2001 to base on the calculations after the both of the Metro lines 1 and 2 are operated.

Table 7: Evolution of fuel consumption (Ktoe) by transport modes in GC, DRTPC Study Experts. (2009).

Year	Mode*	S Car	B+MB	ST	Truck	M	Total
1978	No.	188	82	NE	97	NE	367
	%	51	23	0	26	0	100
1987	No.	556	166	117	355	4	1198
	%	46	13.7	10	30	0.3	100
1998	No.	913	269	175	577	88	2022
	%	45	13	9	29	4	100
2001	No.	1203	305	182	656	99	2445
	%	49	12	8	27	4	100

***** S Car = Small Car, B+MB = Bus and Minibus, ST= Shared Taxi, M = Metro

It is interesting to note that both of the above mentioned modes have the highest fuel consumption per unit movement of pax.km or ton.km, respectively, EEAA. (1999). The share of buses and minibuses in the total energy consumption is decreasing confirming the results mentioned earlier concerning the decline of their modal shares.

Table 8 gives the evolution of the cost of fuel of transport modes in GC based on Metschies G. P. (2007), as given in DRTPC Study Experts. (2009), where it is clear that the cost is continuously increasing irrespective of the fluctuation of international oil prices. The difference between local and international prices is accordingly fluctuating and sometimes the international fuel prices are less than local prices. In 1998 prices of crude oil dropped to very low values and in turn the international prices of petroleum products dropped. During the period of high crude oil prices the international price of fuels, especially diesel could be several times more than the local price which was kept low through subsidies. In 2004 Egypt ranked second after Venezuela when considering fuel subsidy as 14 % of total state revenues were spent on subsidizing fuel. In the same year other countries such as the US and France earned about 12% of its total state revenues from fuel taxation and this reached a high of 33% in South Korea, Metschies G. P. (2007). Rationalization of fuel consumption and using transport modes of low specific fuel consumption such as the metro can effectively reduce the fuel subsidy and expected imported fuel bill in the near future. For detailed analyses on the impact of metro on reducing fuel consumption and GHG emissions in GC see DRTPC Study Experts. (2009).

Table 8: Evolution of Greater Cairo estimated cost of fuel consumption in transport based on Metschies G. P. (2007).

Year	Local Price ($ M)	International Price ($ M)	Int. Oil Price ($/Barrel)
1971*	21.7	24.5	6
1978*	56.2	73.8	14.35
1987	279.7	287.5	17.66
1998	485.0	388.6	11.84
2001	560.8	737.3	21.82

* Metro not existing

6.3 Evolution of GC greenhouse gas emissions and air pollutants from transport

GHG emitted from road transport in GC are CO_2, CH_4 and N_2O. While CO_2 emissions are directly related to fuel consumption and type of fuel with minor effect of vehicle characteristics, CH_4 and N_2O are strongly affected by vehicle characteristics. Generally, most CH_4 is emitted from gasoline and CNG powered vehicles as well as the two stroke motorcycles. However, the metro contribution to gas emissions comes from the fuel burned in power stations. The equivalent GHG emissions for the metro are calculated from the equivalent fuel consumption as discussed above taking into account that the electrical power stations fuel in Egypt mostly run on natural gas.

Table 9 gives the evolution of GHG emitted from GC vehicular transport fleet. The increase of CO_2 is similar to that of fuel consumption given in Table 9. CO_2 equivalent of GHG emitted from GC transport in 2001 is about 7.2 million tons which represents more than 26% of that emitted from the transport sector in Egypt. The increase in the percentage of gasoline vehicles are converted to run with CNG can reduce CO_2 emissions as the emission factor of CNG is about 2.6 kg CO_2 per kg fuel compared to about 3.1 kg CO_2 per kg fuel for gasoline and diesel. Here again GHG emissions due to use of the metro is less than 3% of the total emission from GC transportation.

Table 9: Evolution of greenhouse gas emission from transport in GC, DRTPC Study Experts. (2009).

Year	RB			M	Total CO_2	% of total
	CO_2 (k t)	N_2O (k t)	CH_4 (k t)	CO_2 (k t)	(equivalent k t)	Egypt transport GHG
1971	582	0.02	0.12	NE	617	NA
1978	1018	0.04	0.25	NE	1093	NA
1987	3304	0.15	0.88	8 (0.2%)	3576	NA
1998	5396	0.19	1.33	179 (3%)	5972	22
2001	6537	0.21	1.47	212 (3%)	7189	26
Ave. rate of increase/year (1998/2001)*	7%	3.5%	3.5%	6%	7%	NA

RB = Road Based Modes, M = Metro
NE= Not Existing, NA= Not Available
* Only given for 1998 and 2001 to base on the calculations after the both of the Metro lines 1 and 2 are operated.

Table 10 demonstrates the vast increase in emission rates of the main air pollutants caused by the increase of vehicles and the longer idling time and the associated decrease of travel speed. During the period 1998 to 2001, CO emissions increased at an average annual rate of 5.2%, NO_x at 4.1 % and VOC at 4.4%. CO and VOC are expected to increase at higher rates in the coming years due to decreased speeds, JICA. (2002a), and longer idling times. The larger contribution will be due to small gasoline cars that operate with rich fuel air mixture at idling and very low speeds.

Operating on rich fuel air mixture means incomplete combustion and emission of larger amount of CO and VOC. Converting gasoline engines to run with natural gas will reduce CO emissions and increase VOC emissions. However, VOC emitted from natural gas vehicles is mostly methane which is a less effective pollutant when compared to VOC emitted from gasoline engines.

Table 10: Evolution of pollutants from transport in GC, DRTPC Study Experts. (2009).

Year	NO_x (k t)	CO (k t)	VOC (k t)
1971	7	39	5
1978	11	57	9
1987	31	182	27
1998	49	217	38
2001	55	251	43
Ave. rate of increase/year (1998/2001)	4.1%	5.2%	4.4%

7. Comparative Analysis between the Evolution of Transport, Energy Consumption, GHG and Pollution Emissions and Concluding Comments

Figure 5 shows the indexes of the evolution of GC main urban development indicators, transport, energy consumption, GHG emissions and air pollution emissions between 1971 and 2001 taking 1971 as the base year for the comparison (1971 value = 1). Those indicators are listed below and commented hereinafter.

- Urban development: Population and urbanized area.
- Transport: Total trips, total number of vehicles and total number of cars.
- Energy: Fuel consumption in transport.
- Green house gases: CO_2 equivalent.
- Air pollution: CO and NOx.

- Population and urbanized area have the smallest increase of evolution with nearly the same trend of growth, both scoring a 2001 index of nearly twice the values in 1971, indicating that in 30 years GC nearly doubled in population and urbanized area.
- On the other end of the scale, numbers of vehicles and cars have the biggest indexes between 1971 and 2001 compared to all other indicators. In 2001, the number of vehicles is 14 times more than in 1971 and nearly the same for cars. Furthermore, the slopes of the evolution lines of both vehicles and cars are the highest among those of all other indicators, indicating the fast growth, particularly after 1978 in which liberal economy was followed and between 1998 and 2001 when more car assembly plants were licensed and banks started to facilitate car purchase loans.
- The above results show that big increase in motorization over the considered 30 years of evolution, a trend that is still happening and certainly affecting energy consumption, increased CO_2 equivalent and pollution due to increased traffic congestion and the difficulty to expand the street capacity and metro network with the same pace of vehicle increase.

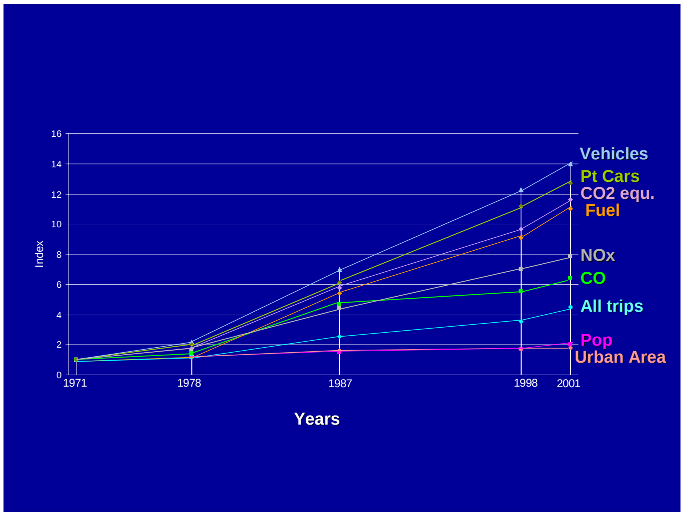


Figure 5: Evolution indexes of main indicators of urban development, transport and energy/environment in Greater Cairo 1971/2001 taking 1971 as base year, (1971 =1).

- The slope of the line of the evolution index of trips is more than that of population increase. This shows that people mobility is always increasing over the years regardless of the size of the population; indicating the effect of economic and urban activities growth on daily travel and hence on energy and the environment in view of the difficulties of streets and metro expansion mentioned above.
- The evolution index of the total number of trips for 2001 is nearly 4.5 compared to 1971, which is nearly 0.35 of the 2001 index for the total number of cars of nearly 13. This confirms two important conclusions; (a) the majority of trips are made on public transport (and on foot; 32% in 2001 as mentioned in Section 4) and (b) the minority using the private car are congesting the streets and causing energy/environment adverse effects.
- The evolution indexes of fuel consumption and CO_2 equivalent emissions are nearly equal; both between 11 and 12, and so is the trend of increase as the slopes of the evolution lines of both are almost equal as they are highly correlated. Also as of 1998 and for the reasons mentioned above about the increase of private cars, the slopes of the lines of evolution of fuel consumption and CO_2 emissions increased more than those observed in the period before 1998.
- For air pollution, the evolution index of NOx is 8 and that of CO is 6.5; both are less than that of CO_2 equivalent. This shows that the effect of increased vehicular traffic on GHG is more than that on local pollution due to the less polluting vehicles in the past 20 years and the increased use of the metro. In the same time the indexes of evolution of NOx and CO are still higher than that of the total number of trips, confirming that although the majority of travelers do not use the car, yet car users cause air pollution as mentioned above.

8. Evolution of Main Mitigation Policies and Projects for Reducing Energy Consumption and Environmental Degradation from Transportation

This section briefly addresses main policies/projects that helped, directly or indirectly, to reduce CO_2 emissions and air pollution in GC and which may be transferred to other cities in developing countries. Those are summarized as they relate to land use, transport and energy/environment policies and projects. It is interesting to note the chain of successive positive environmental improvements of each category. As when land use improvements take place they can indirectly reduce traffic congestion, which in turn reduces energy consumption leading to reduced CO_2 emissions and air pollution. Also, when effective transport policies/projects are introduced they will directly reduce traffic congestion which in turn benefits saving energy and reducing CO_2 and air pollution. Finally, when effective energy and environment policies/projects are in effect they will directly reduce energy consumption, CO_2 emissions and air pollution. In other words, this demonstrates clearly the apparent links mentioned earlier in Section 1, and that "transport" lies between "land use" (as input) from one hand and "energy/environment" (as output) from the other.

We start by two of the useful land use policies/projects between 1980s and 2000s, namely the relocation of many of the concentrated activity units and centres that were in and around the CBD to modern sites scattered in carefully planned sites along the fringes of the agglomeration, e.g., wholesales fruits & vegetables markets and industrial workshops. Implementation was not easy, however, and needed patience and big effort from the local authority. Another example is the policies of decentralization of many smaller activity centres (shopping centers, recreation units and businesses) from inner areas to outer districts. Other micro impact example is the control of adaptive reuse of land use units which was subject to improved control.

Example of transport policies/projects between 1970s and 2000s are mentioned earlier and we only address few of those as examples. Some of the early projects started well before the energy, environment and global worming were issues of concern and still had positive impact reducing those concerns. For instance, the new bridges over the Nile and many overpasses and underpasses constructed at locations of congested street intersections and squares in the 1970s and 1980s. More recent example is the completion of the Ring Road in 1995 which contributed enormously to eliminating through traffic from crossing GC inner areas. Exerting similar effect is relocating major intercity bus and shred taxi terminals from central districts to GC peripheries. Further examples are the construction of underground and multi-storey car parks in, and around, the CBD and major central districts since the late 1980s and building new elevated expressways since the 1990s (progressing till now) and the metro expansion mentioned earlier, all contributed much.

Before describing main policies/projects related directly to energy saving and mitigation of GHG and pollution emissions, it is important to note that in 1982 the Egypt Environmental Affairs Agency (EEAA) was established as the 1st governmental agency for the environment. In 1994, the 1st Environment Law was approved and in 1997, the 1st Ministry for the Environment was established. Those institutional steps have been vital for exerting sound environmental impacts; not only for GC but also at the national level. Early example is the 1997/2004 EEAA/USAID Cairo Air Improvement Program, which included vehicles testing in workshops, on the road and in fueling stations with > 50000 vehicles tested, supporting the creation of the national program for vehicle inspection at traffic police licensing centres starting 2003 and supporting emission testing and engine tuning of public transit diesel buses in Cairo. Other successful policy that started in 1994 and still progressing is encouraging taxi drivers to convert into CNG operation. The start was with one company established to do the conversion and 10 filling stations, now they are 6 and 93, respectively. Currently some 63000 vehicles converted into CNG, 75% of which are taxis, mainly operating in GC. This represents about 3% of the world CNG vehicles, which is quite considerable for GC. More recent very successful policy (started as an EEAA pilot in 2007 and continued at full scale by the Ministry of Finance in 2009) for a Program of Renewal of GC Taxi Fleet and abolishing old cabs (about 34000 older than 30 years). In the last 6 months of 2009, the number of abolished old cabs reached 14000 replaced by 2009 models and in three years all cabs will be renewed. Currently EEAA is undertaking a project sponsored by GEF and UNDP and implemented by the Transportation Programme, DRTPC, Cairo University, namely "Sustainable Transport Project for Egypt", which includes pilot projects for GC and other cities. The pilots in GC cover, for example, gradual introduction of demand management measures, bus priorities and pedestrian areas and new high level of service bus to integrate with the metro, encouraging car users to shift.

9. Closer

The paper attempts to look at past trends and indexes of the evolution of GC transport demand and supply and related energy consumption and energy cost, CO_2 and pollution emissions. The analyses included comparative analysis of the trends of evolution in the last 30 years of the past century and investigated reasons behind the findings. It revealed also that as there are many land use and transport elements that contributed to traffic congestion, reduced speeds and, hence, energy/environment consequences over the past 40 years; there are also many policies and projects that brought about and still bringing positive and sustainable impacts on reducing energy consumption and money spent on energy and reducing GHG emissions and air pollution from transportation. It is believed that some transferable lessons can be useful for sister cities in other developing countries with varying application warrants and scales.

Furthermore, it would be extremely useful if the same work done in this paper can be repeated for other mega cities in the developing countries if data is available. This would permit comparative assessment of the evolution indexes and trends of the different indicators of urban development, transport and energy/environment (as shown in Figure 5) towards understanding the evolution and the interrelationships of the indicators in a generic way. Finally, future research is also needed to address mathematical modelling to link land use, transport and energy/environment, bearing in mind what is mentioned earlier about the intermediate position of "transport", demand and supply, receiving input from "land use" development from one hand (*as input*), and exerting consequences on "energy" needs and bearings on "environmental" impacts, GHG and pollution emissions, from the other hand (*as output*). This is though well catered for, in the industrialized countries literature, it is still lagging in the developing countries context where the local conditions and the prevailing constraints of cities do not only complicate the analysis but also prevent prototype one to one transfer of results. Nevertheless, researchers should never loose hope!

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