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Emissions Inventory Analysis of Mobile Source Air Pollution in Tel Aviv, Israel

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Air pollution from motor vehicles is an acute urban problem in many rapidly developing countries. Air quality monitoring in Israel has both demonstrated the severity of the problem in Israel and identified transportation emissions to be the major contributor to its etiology. Currently, a major concern is the high level of nitrogen oxide nonattainment in Tel Aviv. Thousands of nitrogen oxide violations are recorded there every year. This pollution both affects the local population and provides the driving factor behind the ozone formation downwind in Jerusalem and the West Bank. This paper presents the innovative effort to compile varying streams of data to create an urban vehicle emissions inventory for the city of Tel Aviv. The inventory provides an excellent understanding of the relative contributions of four air pollutants between and within each vehicle cluster. The major findings are that, of total urban vehicle emissions, cars purchased before 1993, when catalytic converters became mandatory, produce 60 percent of carbon monoxide and 55 percent of hydrocarbon emissions. City buses produce 67 percent of nitrogen oxide and 39 percent of particulate matter emissions. Trucks and taxis each contribute about an eighth of total nitrogen oxide and a quarter of total particulate matter emissions. The major policy direction suggested by these findings is diesel fleet vehicle mitigation. In short, an effective approach is presented for industrializing nations to quickly assess their mobile pollution sources, and the foundation data are compiled for further mobile-source analyses in Israel.

Air pollution has a significant effect on public health and the quality of urban life. Recognizing this fact, communities and nations establish standards for acceptable levels of pollutants in the air. Typically, these standards represent the level above which the air pollution constitutes a risk to the community. Once these standards have been set, a monitoring program is created to assess whether these standards are being met. Oftentimes, urban areas discover that they are exceeding the levels established by the standards and need to create policies to reduce the emission of pollutants. For these policies to be successful, it is essential to develop a detailed understanding of the emission sources.

The State of Israel is currently in such a position. The Ministry of the Environment established the current ambient air quality standards in 1992. Subsequently, a national monitoring system was designed and is being deployed in stages. The system has confirmed concerns about substantial nonattainment of the air quality standards. Of greatest concern are the high concentrations of nitrogen oxides in Israel's cities. Additional monitoring (both land-based and aerial) has shown the high rates of nitrogen oxide, as opposed to hydrocarbon, pollution in the Tel Aviv region to be the driving factor behind the high rates of vernal and autumnal photochemical smog further downwind in Jerusalem and the West Bank (*1*, p. 59). To develop a policy program to attain the air quality standards, particularly by reducing nitrogen oxide emissions, Israel's Ministry of Environment is currently assessing the country's pollution sources.

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One source, known to be particularly problematic in urban Israel, is exhaust from motor vehicles. This paper describes the innovative compilation of an urban emissions inventory and the related analysis of the contribution of mobile source polluters along the streets of Tel Aviv. The purpose of the study is to improve Israel's understanding of mobile source pollution to develop and assess effective air-quality improvement policies.

BACKGROUND

Israel

Israel is a small nation, roughly the size of New Jersey, on the eastern shore of the Mediterranean Sea. The majority of economic, industrial, and transportation activity occurs along the 65 km of coastal plain of which Tel Aviv is the center. The climatic conditions are similar to those in Los Angeles and include high air pressure with inversion heights of 1.0 to 1.5 km, westerly winds, and high rates of insolation. These characteristics, as in Los Angeles, are conducive to the development of air pollution problems. Pollutants have difficulty escaping through the high-pressure inversion layer, blow eastward into other population areas, particularly Jerusalem and the West Bank, and react with sunlight and each other to form photochemical smog (*1*). These existing environmental conditions provide a backdrop to the human activities of the region.

Israel is experiencing high rates of economic and population growth. As in many other rapidly industrializing nations, this growth is largely concentrated in urban areas. A symptom of the economic growth in Israel, also evidenced elsewhere, is an increase of motor vehicles both in absolute numbers and in relation to the population. Between 1980 and 1998, the number of vehicles on Israel's roads increased by 210 percent, whereas the population grew by 54 percent. Furthermore, vehicle use is increasing at a rate much faster than the road infrastructure. During the same period, the annual vehicle-kilometrage also increased by 210 percent whereas the nationwide road system expanded by 35 percent (*2, 3*).

The increase in both vehicles and vehicle-kilometrage necessarily brings an increase in vehicle emissions; however, the trend of urban growth concentrates these emissions within metropolitan areas. As a result, the pollution effect of the vehicle and vehicle-kilometrage increase is disproportionately experienced in and around cities.

Mobile Source Emissions Policies

The Ministry of the Environment (MOE) is aware of the problems of mobile source air pollution. Earlier studies of emissions based on fuel consumption in various sectors have highlighted vehicles as a major air polluter. Several important policies have been enacted. As noted above, in 1992 Israel revised its air quality standards and began to institute a nationwide system of air quality monitoring. As part of this program, monitoring stations specifically designed to study the emissions along transportation corridors have been deployed.

The Ministry of the Environment also has been involved in addressing tailpipe emissions at their source. An emission standard for carbon monoxide (CO) and an emissions monitoring program have been established. Catalytic converters have been mandatory on all private cars since model year 1993. Commercial and two-wheeled vehicles, however, remain exempt from this regulation (*1*).

In 1994, Israel adopted the directives of the European Community concerning transportation policies. These directives include a series of emission standards from motorcycles to buses. Although this adoption has had some benefits, most profoundly in the standards of newer vehicles, implementation and enforcement of these policies are not yet widespread.

Research and Planning

Currently the MOE is both undertaking internally and sponsoring externally a series of related research projects aimed at improving the implementation of air quality mitigation measures. One goal of the Ministry is to incorporate air quality into the nation's transportation plans. This research is aimed at that goal. Its purpose is to develop a methodology to gather existing information to develop urban emissions inventories. The focus of this study is Israel's economic and cultural capital, Tel Aviv.

Tel Aviv

Tel Aviv is the core of the Dan region, the metropolitan area made up of Tel Aviv and five surrounding municipalities. As the hub of the Dan region and, in many ways, of the country itself, Tel Aviv serves as a magnet for commuters and visitors. Although train commuting has become increasingly popular to sites along the city's periphery and there is much pedestrian and even some bicycle activity, motor vehicles provide the major form of transportation to and within the city.

The increases in car ownership have resulted in increased vehicular congestion in and around Tel Aviv. A 1996 study reported that, within the city, average driving speed was decreasing by between 0.5 and 1.0 km/h each year (*4*, p. 80). Severe peak-period traffic jams at the entrances to the city have become commonplace.

The MOE has recognized the high potential for mobile source air pollution inherent in this situation and has installed five "transportation" air-quality monitoring stations within the Dan region, three of which are within the borders of Tel Aviv. These transportation stations are located close to the road at heights of between 3 and 4 m. Each of these stations monitors concentrations of carbon monoxide as well as various nitrogen oxides (NO_x, NO, and NO_2). Two of the stations can also monitor particulate matter (PM) of varying diameter. Eventually, monitors measuring hydrocarbons (HC) may be added (*5*, p. 23).

Although currently neither PM nor HC monitoring can be compared across stations, there are substantial data on CO and NO_x. To date, there have been very few CO violations. There have been, however, significant NO_x violations. In 1999, the five regional transportation monitoring stations recorded a combined 1,470 violations of the 0.5-h standard for NO_x of 0.940 $\mu g/m^3$ and 41 violations of the 24-h standard for NO_x (as NO_2) of 0.560 $\mu g/m^3$ (*5*). As such, the MOE is particularly interested in identifying the sources of the NO_x pollution in the Israeli fleet. This criterion focused the design of the present study to emphasize identifying pollution shares rather than absolute amounts of pollutants.

EMISSIONS INVENTORY

This study compiles an emissions inventory for all vehicles on Israel's roads in 1998 and adjusts it for the characteristics of the traffic in Tel Aviv. The inventory identifies urban pollution shares between and within several clusters of related vehicle types. These shares provide a clearer understanding of the etiology of Israel's air pollution problems. That improved understanding offers the potential for successful mitigation.

The emissions inventory is based on a combination of three types of data: vehicle data, kilometrage data, and emission factor data. Figure 1 outlines the steps by which the inventory was generated. This methodology is innovative in two related ways: first, in its application of vehicle shares within the study area to adjust the nationwide fleet characteristics for the situation in Tel Aviv; and second, in its emphasis on relative pollution shares and not on absolute emission quantities. Focusing on shares of vehicles and pollution facilitates a very efficient and effective method to comparatively assess pollution from mobile sources.

Vehicle Data

Table 1 presents the nationwide vehicle data that were compiled to form the emissions inventory. The first column represents the types of vehicles for which data were collected. These include all portions

Existing Data

A = Number of Vehicles in the Nationwide Israeli Fleet
B = Average Yearly Kilometrage (in 1,000 km) per Vehicle
C = Vehicle Shares along the Roads of Tel Aviv by Cluster
D = Driving-condition based Emission Factors

Calculated Values

E = Percentage of National Fleet
F = Percentage of Cluster
G = Total Yearly Kilometrage per Vehicle
H = Percent of Total Yearly Kilometrage
I = Urban Adjustment Factors
J = Urban Adjusted "Emissions"
K = Vehicle Pollution Shares
L = Cluster Pollution Shares
M = Intra-Cluster Pollution Shares

Methodology

$E_x = A_x / (A_1 + A_2 + \ldots + A_{\text{All Vehicles}})$
$F_x = A_x / (A_1 + A_2 + \ldots + A_{\text{All Vehicles within Cluster}})$
$G_x = A_x * B_x$
$H_x = G_x / (G_1 + G_2 + \ldots + G_{\text{All Vehicles}})$
$I = C / E_{\text{Cluster}}$
$J_x = G_x * I * D_x$
$K_x = J_x / (J_1 + J_2 + \ldots + J_{\text{All Vehicles}})$
$L = J_1 + J_2 + \ldots + J_{\text{All Vehicles within Cluster}}$
$M_x = J_x / (J_1 + J_2 + \ldots + J_{\text{All Vehicles within Cluster}})$

Notes

The Urban Adjusted "Emissions" (J) has no meaningful absolute value. It is used to compare relative emissions and therefore its values are not reported in the paper.

FIGURE 1 Methodology.

TABLE 1 Israeli Fleet Vehicle and Kilometrage Data

	Vehicles			Kilometrage		
Type	Number	% of Fleet	% of Cluster	Average Annual (1,000km)	Total (1,000km)	% of Nationwide Total
Private Cars	***1,281,826***	***76.33***	***100.00***			***61.25***
Before 1977	11,517	0.69	0.90	13.1	150,872,700	0.42
1977-1984	143,799	8.56	11.22	15.2	2,185,744,800	6.03
1985-1988	184,700	11.00	14.41	15.2	2,807,440,000	7.75
1989-1992	252,783	15.05	19.72	17	4,297,311,000	11.86
1993-present	680,488	40.52	53.09	18.5	12,589,028,000	34.75
Diesel	8,539	0.51	0.67	18.5	157,971,500	0.44
Motorcycles / Scooters	***75,011***	***4.47***	***100.00***			***1.85***
Up to 50 cc	35,238	2.10	46.98	7.2	253,713,600	0.70
51 cc and over	39,773	2.37	53.02	10.5	417,616,500	1.15
Taxis	***12,644***	***0.75***	***100.00***			***3.30***
Gasoline	357	0.02	2.82	94.5	33,736,500	0.09
Diesel	12,287	0.73	97.18	94.5	1,161,121,500	3.21
Buses	***11,140***	***0.66***	***100.00***			***2.13***
Pre Euro 0	0	0.00	0.00	69.4	0	0.00
Euro 0	5,781	0.34	51.89	69.4	401,201,400	1.11
Articulated Euro 0	1,916	0.11	17.20	69.4	132,970,400	0.37
Euro 1	1,775	0.11	15.93	69.4	123,185,000	0.34
Articulated Euro 1	0	0.00	0.00	69.4	0	0.00
Euro 2	1,668	0.10	14.97	69.4	115,759,200	0.32
Trucks	***298,785***	***17.79***	***100.00***			***31.47***
Gasoline						
Up to 4 tons	152,454	9.08	51.02	31.6	4,817,546,400	13.30
Diesel						
Up to 9.9 tons	103,434	6.16	34.62	41.2	4,261,480,800	11.76
10.0 to 15.9 tons	8,685	0.52	2.91	47.9	416,011,500	1.15
16 tons or more	18,331	1.09	6.14	48.5	889,053,500	2.45
Minibuses	15,881	0.95	5.32	63.9	1,014,795,900	2.80
Total	**1,679,406**	**100.00**			**36,226,560,200**	**100.00**

Notes:

- Diesel cars are also included in the number of regular cars in this schema.
- The 321 gasoline trucks over 4 tons are not included in this study.
- The number of vehicles are from 1998.
- The average yearly kilometrage figures used are from 1996. These figures are very similar to those of 1998 and synchronize chronologically with the years for which car data are available.
- Dan does not have "Pre-Euro" or "Articulated Euro 1" buses in its fleet.

The following assumptions are made:

- There is an even distribution of cars between 1983 and 1986.
- Half of the "Up to 1978" cars are from 1977 and 1978.
- The entire 11,140 bus Israeli bus fleet is broken down into the same type-of-vehicle proportions as the 1,349 bus Dan bus fleet was as of July 2000.
- The average yearly kilometrage for gasoline trucks between 2 and 4 tons is the same for all gasoline trucks under 4 tons
- The average yearly kilometrage for trucks larger than 25 tons is the same as that for trucks between 16 and 25 tons. In reality, larger trucks travel more in an average year.

of the Israeli motor fleet as categorized by the Central Bureau of Statistics (CBS) with the exception of vehicles designated for special services, such as ambulances and cranes (*2, 3, 6*). The taxonomy used here to define the types of vehicles in the fleet is constructed to best align CBS data with the available emission factor data. In addition, related types of vehicles are grouped into defined clusters. These clusters are Cars, Two-Wheeled Vehicles, Taxis, Buses, and Trucks.

The second column lists the number of vehicles of each type. These data also come from the CBS (*2, 3*); however, the data for buses are subdivided according to the ratios of the types of buses operated by the regional bus cooperative in the Dan region and not according to the actual nationwide fleet (*6*). This assumption therefore does not consider tour and regional buses, which also operate within the Dan region and Tel Aviv. This approach seems reasonable given the few routes of these types of long-distance buses within the city.

The third column presents the percentage of the nationwide vehicle fleet that is made up of each type of vehicle and vehicle cluster. Finally, the fourth column presents the percentage of the cluster that is made up of each type of vehicle. These two percentages are calculated based on the data presented in the second column.

Kilometrage Data

Table 1 also presents the vehicle-kilometrage data for the Israeli fleet. The fifth column lists the average yearly kilometrage per vehicle in thousands of kilometers for each type of vehicle. These data come from the Central Bureau of Statistics and are nationwide averages (*2*). These averages are multiplied by the numbers from the second column to calculate the total yearly kilometrage traveled by each type of vehicle as presented in the sixth column. These totals were then used to determine the percentage of the total yearly vehicle-kilometers traveled by each type of vehicle and presented in the seventh column.

Urban Adjustment

Urban travel patterns vary significantly from those experienced in suburban or rural settings. For example, heavy trucks used to transport goods over long distances may expend relatively few of their yearly kilometers traveled in urban areas; in contrast, taxis may spend only a small percentage of their yearly kilometrage outside of urban areas. As a result of this variation, the nationwide data need to be adjusted to represent the urban fleet mix on the roads of Tel Aviv.

Data were collected from traffic counts taken by the Tel Aviv Municipality and analyzed to establish vehicle breakdowns for 125 segments of major streets. These counts, made at different dates between 1996 and 1999, classify vehicles according to the following categories: private cars, motorcycles/scooters, taxis, buses, small commercial vehicles, trucks and special vehicles, and bicycles. The information from the counts was reported as percentages of total traffic (*7*). For the purposes of this study, the "small commercial vehicles" and "trucks and special vehicles" percentages were aggregated to correspond to the truck cluster information. Although the bicycle information is not relevant for this study on motorized vehicles, it is worth noting that bicycle traffic was never more than 1 percent of total traffic.

The percentages reported for each cluster were averaged to develop citywide percentages. These ratios were divided by the percentage of the national fleet comprised by each cluster to derive cluster-based urban conversion factors. Table 2 presents the vehicle clusters, the percentage of each cluster in the nationwide fleet, the average ratios for each cluster in the urban fleet, and the cluster-based conversion factors. This information demonstrates the disproportionately high shares of urban traffic made up of buses, taxis, motorcycles, and scooters compared with the national averages.

Emission Factors

To create an emissions inventory, it is necessary to understand the emission rates of the different types of vehicles in the Israeli fleet. Data from abroad can be useful to approximate these rates; however, given the vagaries of fuel mix, road conditions, driving styles, maintenance, climate, and so on, it is best to use locally measured emission factors. Toward those ends, the MOE has sponsored the efforts of the Internal Combustion Engine Laboratory of the Technion, the Israel Institute of Technology, to measure Israeli emission factors. Currently, Israeli emissions data are available for private cars and local buses (*8, 9*). In their report on buses, the Technion researchers include emission factors for diesel taxis and diesel trucks from a Swiss study. The researchers believe these factors are a close approximation for analogous Israeli factors. This study relies on this information. In addition, emission factors from the U.K. Emission Factors Database were used for certain PM emissions and adjusted to provide emission rates for gasoline-powered light trucks and motorcycles and scooters (*10*). It is assumed that these adjusted rates are similar to those in Israel.

In all cases, these emission factors are based on driving conditions. Because motor vehicles pollute at different rates based on the engine load, it is important to consider the loads being borne by the demands of the traffic. The generation of these factors attempts to account for that variation in driving conditions. The vehicles being studied travel a preestablished course. A sample of the vehicle's exhaust is collected throughout the course. The breakdown of pollutants in the sample is measured. By multiplying the amount of pollutant in the sample by the ratio of the total exhaust to the sample and dividing by the length of the course, the per-kilometer emission factor can be determined.

The courses are designed to simulate various driving experiences. For the purposes of this study, these experiences have been labeled stagnating, urban, surface road, and motorway. The courses include the stopping, starting, accelerating, and decelerating associated with each of these driving situations. Oftentimes the average speed of the course is reported. It is important that the emission factor not be considered specific to that speed, but rather specific to a type of engine demand for which that speed is an average. Road topography also plays a significant role in creating engine loads. The taxi, bus, and truck factors consider the emissions effect of inclines, and the numbers used in this study refer to a flat course as Tel Aviv has little elevation variation.

Table 3 presents the emission factors for CO, NO_x, and HC for each of the vehicle types. These are based on the four driving situations listed above. This study uses the driving conditions and the associated speeds published as part of the TNO-Inro CAR International model for determining mobile source air pollution along the roadside. The model's suggested speeds—to correspond with the designations of stagnating, urban, surface, and motorway—are 13, 22, 44, and 100 km/h, respectively. The actual average speeds associated with each emission factor are given in Table 4. In several cases, the same factors were used for both stagnating and urban speeds. This assumption seems reasonable in each case as the average speeds of the courses were between the two model speeds, or the speeds reflect the unique condition of certain vehicles. For example, buses exhibit a less-pronounced speed variation in relation to traffic. The dampened response to traffic conditions occurs because, regardless of congestion, buses must drive the same course and make the same number of stops.

TABLE 2 Urban Adjustment Factors for Tel Aviv (*2, 7, 9*)

Cluster	% of Nationwide Fleet	% of Urban Fleet	Urban/Fleet
Private Cars	76.33%	70.76%	0.927
Motorcycles/Scooters	4.47%	8.34%	1.867
Taxis	0.75%	12.25%	16.276
Buses	0.66%	3.38%	5.089
Trucks	17.79%	5.24%	0.295

Note: Based on modal averages of 125 street segments in Tel Aviv (*2,7,9*)

TABLE 3 Driving-Condition–Based Emission Factors for CO, NO_x, and HC

	CO Emission Factors (g/km)				NOx Emission Factors (g/km)				HC Emission Factors (g/km)			
Vehicle Type	Stagnating	Urban	Surface	Motorway	Stagnating	Urban	Surface	Motorway	Stagnating	Urban	Surface	Motorway
Private Cars												
Before 1977	105	105	51.64	47.02	0.92	0.92	1.985	2.92	7.74	7.74	3.82	4.19
1977-1984	59.2	59.2	29.69	27.01	0.89	0.89	2.21	3.33	5.88	5.88	3.15	3.56
1985-1988	51.3	51.3	21.25	19.49	0.59	0.59	2.43	3.53	5.27	5.27	2.85	2.91
1989-1992	37	37	16.443	14.89	1.08	1.08	2.722	3.81	5.2	5.2	2.66	2.99
1993-present	15.5	15.5	3.525	3.23	0.107	0.107	0.268	0.38	1.18	1.18	2.45	0.47
Diesel	0.75	0.75	0.46	0.28	0.81	0.81	0.63	0.51	0.154	0.154	0.085	0.045
Motorcycles/Scooters												
Up to 50 cc	10	10	10	10	0.05	0.05	0.05	0.05	6.08	6.08	6.08	6.08
51 cc and over	20	20	20	20	0.3	0.3	0.3	0.3	3.16	3.16	3.16	3.16
Taxis												
Gasoline	15.5	15.5	3.525	3.23	0.107	0.107	0.268	0.38	1.18	1.18	2.45	0.47
Diesel	0.75	0.75	0.46	0.28	0.81	0.81	0.63	0.51	0.154	0.154	0.085	0.045
Buses												
Pre Euro 0	5.7	5.7	NA	NA	31.7	31.7	NA	NA	1.92	1.92	NA	NA
Euro 0	4.68	4.68	NA	NA	21.6	21.6	NA	NA	1.57	1.57	NA	NA
Articulated Euro 0	6.4	6.4	NA	NA	29.4	29.4	NA	NA	2.13	2.13	NA	NA
Euro 1	1.49	1.49	NA	NA	14.2	14.2	NA	NA	1.43	1.43	NA	NA
Articulated Euro 1	2.62	2.62	NA	NA	20.4	20.4	NA	NA	2.02	2.02	NA	NA
Euro 2	1.19	1.19	NA	NA	12.4	12.4	NA	NA	0.86	0.86	NA	NA
Trucks												
Gasoline												
Up to 4 tons	33.97	24.77	10.21	20.74	1.483	1.489	1.627	2.546	4.66	3.90	2.47	1.76
Diesel												
Up to 9.9 tons	6	3	2	2	8	5	4	3	6	2.5	1.8	1
10.0 to 15.9 tons	8	4	4	2	17	9	10	5	6.3	3	2	1.2
16 tons or more	9	5	3	2	27	15	10	7.5	6	2.1	1.9	1
Minibuses	6	3	2	2	8	5	4	3	6	2.5	1.8	1

Notes: To assist future researchers the reference locations of these factors are presented in full. Private Cars: Gasoline (*9*), Diesel (*8*) Table 18: Weighted Emission Factors for Taxis (Flat Course); Motorcycles / Scooters: (*10, adjustments by Rony Serry, MOE*); Taxis: Gasoline (*9*), Diesel (*8*) Table 18: Weighted Emission Factors for Taxis (Flat Course); Buses: All Buses (*8*) Table 14: Urban Bus Emission Factors (Flat Course). Note that information for higher speeds than urban traffic are not available; Trucks (including diesel Minibuses): Gasoline (*10, adjustments by the author*) Petrol LGVs - Fleet Weighted Emission Factors, Diesel (*8*) Table 19: Emission Factors for Trucks (Flat Course). The emissions factors given for diesel trucks and minibuses were measured for trucks weighing less than 7 tons, between 7 and 14 tons, and between 14 and 20 tons. These factors are applied respectively to the weight classes listed above for which Israeli vehicle data are available.

Emissions Inventory Analysis

Based on the above data, it was possible to do a citywide analysis to compare the pollution among and within each cluster of vehicles. Because this analysis was to examine mobile source air pollution in the city, the emission factors for urban driving were used.

Cluster Comparison

To compare the pollution contribution of each cluster, it was first necessary to calculate the relative emissions for each type of vehicle. This calculation simply multiplied each vehicle's total annual vehicle-kilometers both by the appropriate urban emission factor and by that vehicle cluster's urban adjustment factor. The resulting numbers do not have absolute significance; however, they provide a relative gauge of urban pollution. After these numbers are tallied, the percentage of that "pollution total" for each type of vehicle can be calculated. These percentages can be summed for each cluster to understand that cluster's relative pollution contribution.

Figure 2 graphically depicts the relative contribution of CO, NO_x, and HC by each cluster in Tel Aviv. The graph demonstrates that private cars are responsible for the vast majority of CO and HC emissions in the city whereas buses are the major contributors of NO_x emissions.

It should be noted that cold-start percentages are not taken into account in this analysis. This omission may cause a disproportionate consideration of CO and HC for two main reasons. First, those pollutants are most affected by catalytic converters. Second, the percentage of cold starts varies between private and fleet vehicles. The effect of this approach on NO_x emissions, the prime concern of this study, is assumed to be relatively insignificant.

Intracluster Comparison

Having determined the relative pollution contribution of each cluster, it is useful to understand the relative contribution of the vehicle types within each cluster.

Private Cars

Figure 3 presents this information for the private-car cluster and makes readily apparent that the older cars in the Israeli fleet are a major cause of the urban CO and HC pollution. Cars purchased before 1993 make up less than half of the private automobile fleet but account for 70 percent of CO, 77 percent of HC, and 85 percent of NO_x emissions from private cars.

It is important to note that, although the number of private cars in Israel has increased by about 50 percent between 1990 and 1998, more than 60 percent of the cars on the road in 1990 are still in use. This suggests that there is not a high rate of turnover in the Israeli private-car fleet. Older cars stay on the roads and are joined by newer ones.

TABLE 4 Reported Average Speeds of Emission Factor Course

Vehicle Type	Average Speed in Kilometers per Hour			
	Stagnating	Urban	Surface	Motorway
Private Cars				
Before 1977	15.4	15.4	50	90
1977-1984	15.4	15.4	50	90
1985-1988	15.4	15.4	50	90
1989-1992	15.4	15.4	50	90
1993-present	15.4	15.4	50	90
Diesel	15.4	15.4	50	90
Motorcycles/Scooters				
Up to 50 cc	No Variation Given for Speed			
51 cc and over	No Variation Given for Speed			
Taxis				
Gasoline	15.4	15.4	50	90
Diesel	20	20	40	80
Buses				
Pre Euro 0	Urban Driving / Flat Course			
Euro 0	Urban Driving / Flat Course			
Articulated Euro 0	Urban Driving / Flat Course			
Euro 1	Urban Driving / Flat Course			
Articulated Euro 1	Urban Driving / Flat Course			
Euro 2	Urban Driving / Flat Course			
Trucks				
Gasoline				
Up to 4 tons	10	20	45	100
Diesel				
Up to 9.9 tons	10	20	40	60
10.0 to 15.9 tons	10	20	40	60
16 tons or more	10	20	40	60
Minibuses	10	20	40	60

Note: See Table 3.

The retention of older cars is due in part to the high tax rate on new automobile purchases, which causes older vehicles to artificially retain their value.

Motorcycles and Scooters

These vehicles are a ubiquitous part of the Tel Aviv roadways (and sidewalks). The warm climate and total lack of rain from April through October enable such vehicles to provide a useful means of urban transport. The difficulty of finding automobile parking, the high cost of fuel, and the relatively inexpensive price of two-wheeled vehicles when compared with cars affirm the choice of many young Israelis to purchase motorcycles and scooters.

Such vehicles are responsible for a relatively low percentage of total urban vehicle emissions. Nonetheless, the small-engined two-wheelers do not efficiently combust fuel, and they emit HC at a rate similar to private cars more than 20 years old. Given the low fuel consumption of such mopeds and scooters, these vehicles are relatively high HC polluters per liter of fuel.

Taxis

Taxis provide a significant mode of urban transportation. More than 97 percent of Israel's taxis run on diesel fuel, and as such this cluster accounts for 13 percent of urban NO_x emissions. As commercial vehicles, taxis are not required to have catalytic converters. Nonetheless, taxis are required by the state to be less than a decade old and to meet certain maintenance requirements. As a result, these vehicles are in relatively good shape, particularly in comparison to comparable vehicles in many cities in North America.

Buses

Traditionally, city buses have garnered high shares of the urban mobility market in Israel. However these shares have been dropping nationwide as vehicle ownership increases. Between 1990 and 1998 the number of people using public transportation decreased by 30 percent (*1*). In the Dan region, according to a 1996 survey, only 21 percent of trips are made by bus (*2*).

Israel has begun to apply European standards to bus purchases. Figure 4 presents the emission breakdowns for each type of bus. Currently only about one-third of local buses in Tel Aviv meet the Euro 1 or Euro 2 standards. As can be seen in Figure 4, the switch to Euro 2 engines entails significant emissions reductions. The regional bus cooperative currently plans to purchase only Euro 2 buses or better (Yitzhak Cagan, Dan Bus Cooperative Spokesperson, unpublished data). However, it is unclear at what rate new purchases will replace older buses. To date there has been no experimentation with alternative fuels to diesel. As a result, buses are responsible for the major

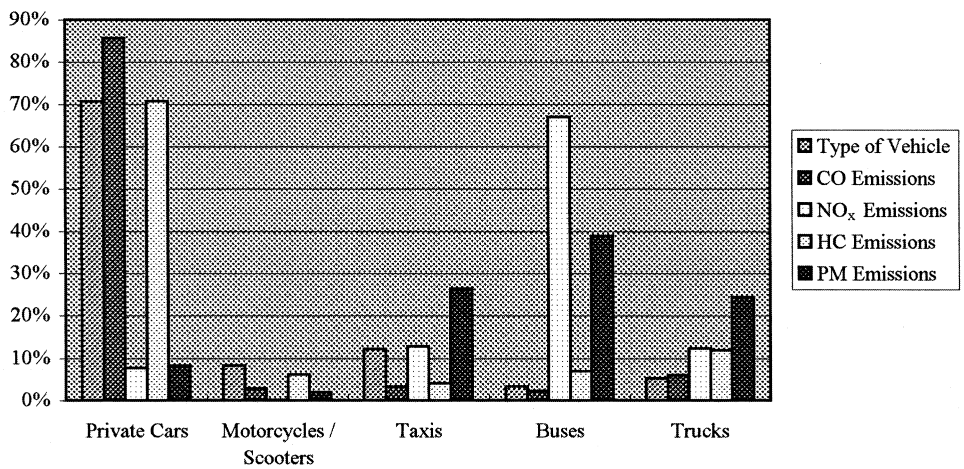

FIGURE 2 Cluster comparison.

FIGURE 3 Car cluster.

portion of urban NO_x emissions. Recent discoveries of natural gas just off the Israeli coast have sparked interest within the Ministry in considering future deployments of natural gas buses. Currently, the Ministry is particularly interested in the use of liquid petroleum gas (LPG) and is exploring a pilot LPG bus acquisition.

Trucks

The truck category includes a broad array of gasoline and diesel vehicles. Figure 5 demonstrates the pollution shares of each type. The high numbers of small trucks (both gasoline and diesel) and minibuses, which together account for more than 90 percent of the cluster, are responsible for the lion's share of truck CO and HC pollution. However, trucks over 10 tons, which account for 9 percent of all trucks, are responsible for 34 percent of truck NO_x emissions and 37 percent of truck PM emissions.

Initial Policy Considerations

This urban emissions inventory identifies older cars as the overwhelming CO and HC polluters. Improving the maintenance and efficiency of these vehicles (as well as that of scooters and gasoline-powered trucks) and encouraging a turnover to newer vehicles are the major vehicle-related policy options to be considered. An analysis of the benefits, costs, and feasibility of such mitigation approaches will be necessary. In addition, improving the quality of the gasoline will likely have significant HC reduction benefits.

Buses are seen to be the major producer of NO_x emissions; however trucks and taxis combined are also responsible for about a quarter of total NO_x emissions. There is a clear need to migrate the bus fleet to buses meeting Euro 2 standards or better. This may be effectively accomplished without waiting for vehicle turnover by retrofitting bus engines. There is also some consideration of developing an LPG infrastructure for fleet vehicles. The buses, taxis, and some of the trucks, which are the large NO_x polluters, may all be appropriate candidates for such alternative fueling.

Currently, there is a limited level of specificity for PM emission factors for gasoline-powered vehicles. Table 5 presents the PM emission factors used in this study along with their sources. Despite these limitations, there is a clear need to address the high PM shares of diesel fleet vehicles. Taxis and trucks each account for roughly a quarter of total PM pollution, and buses account for almost 40 percent of PM pollution. Because particulate emissions drop precipitously in

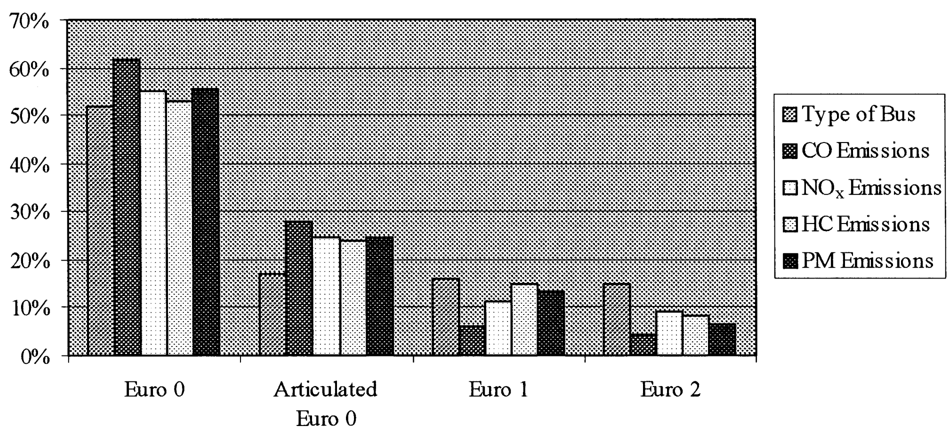

FIGURE 4 Bus cluster.

REFERENCES

1. Gabbay, S. *The Environment in Israel.* Ministry of the Environment, State of Israel, Jerusalem, 1998.
2. *1999 Statistical Abstract of Israel: Number 50.* Central Bureau of Statistics, State of Israel. Hemed Press, Jerusalem, 1999.
3. *Motor Vehicles 31 XII 1998.* Central Bureau of Statistics, State of Israel, Jerusalem, July 1999.
4. *Energy in the Urban Environment: An Action Plan for the City of Tel Aviv: Final Report.* Vol. 1. Interdisciplinary Center for Technological Analysis and Forecasting, Tel Aviv University, Tel Aviv, State of Israel, June 1996.
5. *Air Quality Monitoring in Israel—Annual Report 1999.* Ministry of the Environment, State of Israel, 1999.
6. Spokesperson's Office. Dan Bus Cooperative, State of Israel, July 1999.
7. "Traffic Counts." Traffic Division, Municipality of Tel Aviv-Yafo, State of Israel, 1998.
8. Tartakovsky, L., M. Gutman, Y. Aleinikov, M. Weinblatt, and Y. Zvirin. *An Evaluation of Vehicle Emissions in the Haifa Area.* Technion, Haifa, State of Israel, Jan. 2000.
9. Gutman, M., L. Tartakovsky, Y. Dayan, Y. Aleinikov, Y. Zvirin, and A. Serry. *An Estimation of Israeli Vehicle Emission Factors.* Interim Report. Technion, Haifa, State of Israel, 1996.
10. *U.K. Emission Factor Database.* London Research Centre, in collaboration with RSK Environment. July 2000. http://www.london-research.gov.uk/emission.

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