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ESTIMATION OF EMISSIONS AND FUEL CONSUMPTION OF SUSTAINABLE TRANSPORT MEASURES IN METRO MANILA

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ABSTRACT

Environmentally sustainable transport (EST) strategy measures for Metropolitan Manila are assessed in terms of reduction in emissions and fuel. Measures include vehicle inspection, engine replacement, use of alternative fuels and biofuels, non-motorized transport, travel demand management and improvement of public transportation. Travel activity in terms of traffic volume and travel speeds of the travel demand forecast model estimates and the database of the 1996 Metro Manila Urban Transportation Integration Study (MMUTIS), emission factors from the Vehicular Emission Control Planning (VECP) project and fuel consumption factors from MMUTIS and recent studies on jeepneys and buses are utilized to generate the baseline emissions of criteria pollutants (HC, CO, NO_2, PM and SO_2) and fuel consumption (diesel, gasoline, alternative fuel/biofuel) in 2010 and 2015. Local emissions and fuel consumption are estimated for each strategy measure and compared with respect to the baseline values. Measures such as implementation of vehicle inspection, mass transit network expansion and travel demand management contributed to higher overall local emission reductions while the switch to CNG buses, mass transit network expansion and travel demand management measures resulted to significant reduction in fossil fuel consumption.

Key Words: *emissions inventory, fuel consumption, travel demand forecast model, environmentally sustainable transport*

1. INTRODUCTION

With the deterioration of air quality of Metro Manila that was attributed mostly to particulate matter emissions from transportation in the 1990s, several studies funded by international organizations were conducted to assess the state of the environment and formulate policies to reduce emissions from motor vehicles. These studies have concluded particulate matter, followed to some degree, by carbon monoxide and nitrogen dioxide, are the key air pollutants attributed to motor vehicle traffic. The annual average concentration of total suspended particulates has been

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observed to exceed the annual average standard starting in the late 1980s. According to the Philippine Environmental Management Bureau (2003), in recent years, the concentration of fine particulate matter ($PM_{2.5}$) had exceeded the annual guideline value. Sulfur oxides and total organic gases were still within air quality standards. Ambient lead concentration has generally decreased from 1987 up to 2000. Also, more than 70% of the people in Metro Manila are concerned with the effects of motorized vehicle emissions on their health or air pollution in general based on surveys conducted in 2000 (Yai and Vergel, 2002) and 2001 according to the Philippines Environment Monitor 2002 (The World Bank Group, 2002)

The implementation of the Philippine Clean Air Act of 1999 started in 2000 and emission standards were enforced on motor vehicles starting 2003. National government agencies and some local governments have started activities in line with the Clean Air Act. In 2001, partnerships with non-government organizations (NGOs) and the private sector and the academe have been forged to coordinate activities on clean air in the metropolis. With numerous foreign-funded studies and programs of national government organizations related to clean air (environment and natural resources, energy, transportation and communications, and, trade and industry departments and line agencies) and initiatives of local governments and civil society, there had been no study that integrated and coordinated previous studies and government plans and programs. In this study, several project studies and researches and national government programs and plans are reviewed to develop the policy scenarios for environmental assessment.

The objective of this study is to evaluate the effectiveness of the selected environmentally sustainable transport (EST) strategies in terms of reduction in emissions of criteria pollutants such as PM, CO, HC, NOx and SOx and fuel consumption.

Baseline emissions and fuel consumptions of present and future years are also estimated by the study, thus establishing a more accurate emissions inventory from mobile or transportation sources.

2. POLICY SCENARIOS AND ASSUMPTIONS

Policy scenarios were developed based on the review of past project studies and researches conducted by different local and international organizations. The scenarios aside from the business-as-usual scenarios can be generally classified into 3 categories based on a framework for selecting instruments (World Bank, 2001): a) reducing vehicle-kilometers, b) reducing fuel used per vehicle kilometer, and c) reducing emissions per unit of fuel used.

2.1 Baseline Scenarios

Travel demand forecasts were modeled for 2010 and 2015 using the main transportation network in place in 2010. The 2015 Baseline scenario assumes that the primary and secondary road network development is based on the Metro Manila Urban Transportation Integration Study (MMUTIS) (JICA, 1999) Master Plan for roads in 2015.

The Baseline scenarios in 2010 and 2015 assume that the motor vehicle emission standards have already been initially implemented as reflected by the I/M (inspection and maintenance) Scenario of 2005 in the Vehicular Emission Control Planning (VECP) Project Report (Asian Development Bank, 1992). The scenario assumes that PM, NOx and SOx emission factors are reduced by 30% while the CO and HC emission factors are reduced by 40%. The implementation of the motor vehicle exhaust emission standards in the Clean Air Act started in January 2003. The scenarios with the corresponding assumptions on transport network, demand and enforced policies are summarized in Table 1.

Table 1 Baseline Scenarios

Scenario	Transport Network, Demand and Policy Assumptions
Baseline 2010	2010 transportation demand + 2005 transport network + I/M Scenario
Baseline 2015	2015 transportation demand + 2005 transport network + primary and secondary road network in 2015 + I/M Scenario

2.2 Reducing Vehicle Kilometers

Scenarios under this category include increasing private vehicle occupancy, demand restraint and promotion of public transportation. Policies here included demand restraint using administrative instrument such as limitation on vehicle use and increase in the share of public transport through expansion of urban rail network, as summarized in Table 2.

a) Transportation Demand Management (TDM)

According to MMUTIS (JICA, 1999), 22.9% of private car users was affected by the UVVRP (Unified Vehicular Volume Reduction Program), the TDM scheme implemented in Metro Manila. Only those who used public transport and those who shared a ride as alternative modes of transport to private car were considered to affect the private vehicle traffic. The reduction of 11.08%, derived from the 1996 MMUTIS Study, was applied to vehicle-kilometers of private transport modes such as gas car, gas jeepney/utility vehicle and diesel car/utility vehicle in all 98 traffic analysis zones.

b) Expansion of the Metropolitan Railway Network (Rail 2015)

In Metro Manila, there are already 45.3 kilometers of LRT/MRT lines (Line 1, Line 2 and Line 3) as of April 2003 and there also exists a heavy rail line, which is approximately 30 kilometers (Philippine National Railways (PNR) Commuter Line). In the 1996 Metro Manila Urban Transportation Integration Study (JICA, 1999), there is a master plan for the expansion of the railway network through the extension of existing LRT/MRT lines, construction of new LRT/MRT lines and busways, and upgrade of the PNR lines. By 2015, it is planned that there will be approximately 164.1 kilometers of new MRT/LRT lines and 19.7 kilometers of busways. With the expansion of the railway network, it is expected that more people will shift their transport mode from private vehicles, buses and jeepneys to rail due to a more convenient railway service. The model for demand shift from private cars to public transit was used based on the MMUTIS. The model calculated the probability of shifting as a function of difference in travel time (in minutes) and travel cost (in pesos) of the public mode and private mode of transport. This is expected to reduce the vehicle-kilometers of travel of private cars and road-based public transport.

Table 2 Policy Scenarios for Reducing Vehicle Kilometers

Scenario	*Policy and Assumptions*
Transportation Demand Management (TDM)	Vehicle-kilometers of private transport modes such as gas car, gas jeepney/utility vehicle and diesel car/utility vehicle were reduced by 11.08% in all 98 traffic analysis zones
Expansion of the Metropolitan Railway Network by 2015 (Rail2015)	Expansion of the metropolitan railway network by 2015 by approximately 164.1 kilometers of new MRT/LRT lines and 19.7 kilometers of busways according to the MMUTIS Master Plan resulting to reduced road-based traffic demand (7.28% in public transport and 14.29% in private transport)

2.3 Reducing Fuel Used Per Vehicle Kilometer

Examples of scenarios under this category include improvement of fuel economy, promotion of non-motorized transport (NMT) and ITS technologies. The policy included in the assessment is on construction of NMT systems. The Marikina City Government has started to construct exclusive bikeways in 2001. The master plan will involve construction of bikeways on 66 kilometers of roads in the city. With this, it is assumed that there will be a significant increase in the use of bicycles for work trips. The modal share of bicycles and percentage shift from non-cycling modes in Marikina City were estimated for 2004 and 2014 in the Marikina Bikeways Feasibility Study (U.P. National Center for Transportation Studies Foundation Inc., 2000). Only the internal trips were considered in the analysis. The shift in 2014 is assumed to take effect in 2015. The rate of shift (3.5% of the trips in 2015) from tricycles to cycling modes was applied as reduction rate of tricycle vehicle-kilometers of all zones.

2.4 Reducing Emissions Per Unit of Fuel Used

Scenarios under this category generally include better and advanced vehicle-engine technologies, improvement of fuel quality, improved vehicle inspection and maintenance, clean 2 and 3-wheeler technology, use of alternative fuels and switch to clean diesel.

a) Motor Vehicle Inspection System (MVIS)

The MVIS scenario assumes that the MVIS facilities provided for in the Implementing Rules and Regulation of the Clean Air Act of 1999 are established in Metro Manila. With the MVIS, it was assumed that certain percentages of the vehicle fleet are expected to comply with the emission standards. In Table 3, the category “cars” include passenger cars, utility vehicles, taxis while the category “jeepneys” means public utility jeepneys, the category “buses” means public utility buses, and the category “trucks” means trucks. The corresponding reductions in the emission factors are applied to the shares of the vehicle fleet. The scenarios for the MVIS in 2010 and 2015 are discussed as MVIS2010 and MVIS2015 below.

Table 3 Policy Scenarios for Reducing Emissions Per Unit of Fuel Used

Policy Scenario: Implementation of the Motor Vehicle Inspection System (MVIS)
Reduction of emission factors and the corresponding percentages of vehicle types with reduced emission factors **MVIS2010 = + STDS2 + I/M** * Implementation of the STDS2 scenario on top of the I/M Scenario (30% PM, NOx & SOx reduction, 40% HC & CO reduction) *further reduction of PM, NOx & SOx emission factors by 60% and of HC & CO emission factors by 75% *percent of vehicles: cars=25%, jeepneys=100%, buses=30%, trucks=30% **MVIS2015 = + STDS3 + I/M** * Implementation of the STDS3 scenario on top of the I/M Scenario *Same reduction of emission factors as in 2010 *percent of vehicles: cars=50%, jeepneys=100%, buses=100% CNG, trucks=40%
Policy Scenario: Replacement of 2-Stroke with 4-Stroke Motorcycles for Tricycles
*HC emission factor of 4-stroke tricycle = 1/8 of 2-stroke tricycle *PM emission factor of 4-stroke tricycle = 1/5 of the emission factor of 2-stroke tricycle *applied to 100% of the tricycles in all zones
Policy Scenario: Compressed Natural Gas (CNG) for Buses
100% CNG Buses by 2015 Reduction of emission factors of buses *PM – 86% * CO, HC – 40% (I/M) and 60% * NOx – no reduction

b) Switch to 4-Stroke Tricycles or Three-Wheelers (4STC)
This scenario assumes that 2-stroke tricycles, which comprise 75% of tricycles in Metro Manila, will be totally replaced with 4-stroke tricycles. Based on the study of Shah and Harshadeep (2001), the PM10 emission factor of 4-stroke motorcycles is approximately 1/5 of the emission factor of 2-stroke tricycles and this ratio was applied to all the zones.

c) Compressed Natural Gas for Buses (CNGB)
Based on the plan of the Department of Energy, the following percentages of the bus fleet powered by CNG will be running on specified roads in 2005 and 2010 (Table 4). It was also estimated that the emission factor of buses will be reduced by 86% if it will be replaced by CNG.

3. ESTIMATION OF TRANSPORTATION DEMAND

3.1 Study Area and Zoning

The modeling for the transportation demand covered Metro Manila and towns/cities of the adjoining provinces of Bulacan, Rizal, Cavite and Laguna. The 1996 MMUTIS Study (JICA, 1999) established 265 traffic analysis zones for the 17 cities/towns of Metro Manila and 51 zones for the adjoining towns and cities. These zones were combined to form 98 traffic analysis zones wherein 94 traffic analysis zones were constructed for Metro Manila and 4 other zones corresponding to the 4 adjacent provinces, as shown in Figure 1.

3.2 Socio-economic Characteristics

Transportation demand modelling for the present and the future years requires a database of socio-economic characteristics aggregated to the traffic analysis zones. The following socio-economic characteristics were considered in the modelling:

- population
- employment by residence
- employment by workplace
- school attendance by residence
- school attendance by school
- car ownership

The above data exists for the 265 zones and were derived from the 1996 household interview survey (HIS) of the MMUTIS database. Data were subsequently aggregated for the 98 zones. The socio-economic data is also available in years 2000 and 2010 (forecasted). The zonal socio-economic characteristics were calculated for the years 2002, 2010 and 2015 using a growth rate based on the data in 2000 and 2010 and applying the rate on the 1996 data from the HIS of MMUTIS database. The zonal car ownership was estimated for 2002 using the growth rate based on the 1996 and 2005 data. The zonal car ownership for 2010 and 2015 were estimated using the growth rate based on the 2005 and 2015 forecast data.

Fig. 1 Traffic Analysis Zones (TAZ) of Metro Manila and Some Towns/Cities of the Adjoining Provinces

3.3 Transportation Network Characteristics

Transportation demand modelling for the present and the future years also requires data on transportation network that consists of roads and public transport lines. The public transport network mainly consists of railway lines and buses and jeepney routes. The study utilized the MMUTIS transportation network built in 1996 and was updated to include the following roads and rail transit lines in 2005:

- Road Network
  - Primary and Secondary Road Network
  - Expressway Network
    - North Luzon Expressway
    - South Luzon Expressway
    - Manila-Cavite Expressway
    - Metro Manila Skyway (Makati-Bicutan)
- Rail-Based Mass Transit Lines
    - LRT Line 1 (Monumento – Baclaran)
    - MRT Line 3 (Monumento – Taft Avenue)
    - LRT Line 2 (Santolan – Recto)

The network consisting nodes and links is encoded in a digital map in JICA STRADA format, as displayed in Figure 2, indicating the transportation network for the BAU scenario in 2005.

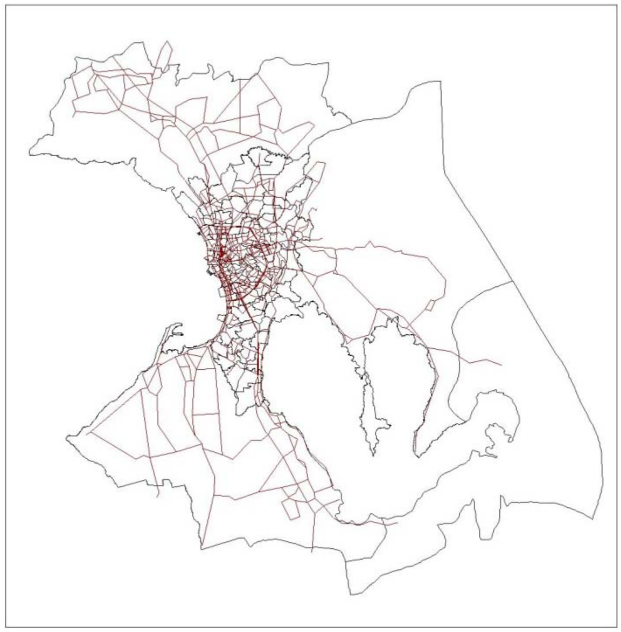

Fig. 2 Road and Railway Network for the BAU Scenario (2005)

3.4 Transportation Demand Estimation Method

a) The Four-Step Model
The 4-Step Model was used to estimate transportation demand for the baseline scenarios in 2005, 2010 and 2015, and the railway scenario in 2015. The procedure for demand forecasting used by MMUTIS was adopted by this study. The JICA STRADA (JICA System for Travel Demand Analysis), utilized in the MMUTIS Study, was used to estimate the transportation demand. The zoning system, socio-economic characteristics and transportation network which came from the MMUTIS database, served as inputs to the transportation demand modelling procedure. The 4-Step Model is discussed in the following sub-sections.

b) Trip Generation/Attraction
The trip generation/attraction step calculates the number of person trips are generated from and attracted to each traffic analysis zone. Model functions for trip generation and attraction are estimated with zonal socio-economic attributes calculated in Section 2 as explanatory variables. The trip generation model for Metro Manila is correlated with the variable “employment by workplace”. The number of person trips generated from and attracted to each of the 98 zones by private and public modes is estimated.

c) Trip Distribution
The trip distribution step estimates the number of person trips originating from a traffic analysis zone (origin zone) and ending in another traffic analysis zone (destination zone). Trips generated from and attracted to each zone are distributed among the zones generating a 98 by 98 origin-destination (O-D) matrix of person trips. In this step, two matrices (98 by 98) are generated

consisting of private and public person trips. According to the MMUTIS (JICA, 1999), the interzonal trip distribution was initially based on the Voorhees-type gravity model which distributes generated traffic in proportion to the share of attracted traffic discounted by interzonal impedance. However, the models did not show satisfactory correlation such that an adjustment factor which is the quotient of actual and theoretical number of trips in 1996 was introduced to distribute trips in the future years.

d) Modal Split

The modal split or mode choice step estimates how many of the person trips for each pair of origin and destination (O-D) zones will use private or public transport modes. However, the procedure for demand forecast in this study has already segregated the public and private trips earlier in the trip generation step.

e) Traffic Assignment

The traffic or trip assignment step identifies the exact routes that will be taken by each of the person trips. It involves assigning traffic to a road network or a transit network. The road and transit network of Metro Manila for the baseline scenario in 2005 is shown earlier in Figure 3. Traffic is assigned to available transit or roadway routes using a mathematical algorithm that determines the amount of traffic as a function of travel time, volume, capacity, or impedance factor. The three common methods are all-or-nothing, diversion and capacity restraint. The highway-type assignment for private and public modes is adopted as the model. The JICA STRADA outputs of the traffic assignment are the following: link vehicle traffic volumes per day, link average traffic speed per day, link volume-to-capacity ratios per day and link trip lengths per day. The traffic volumes were obtained by dividing the number of person trips assigned to each route by the average vehicle occupancy. The vehicle occupancy data were obtained from the MMUTIS database.

3.5 Additional Procedures for Estimation of Transportation Demand

a) Estimation of Transportation Demand for Tricycles

The transportation demand of the local three-wheelers (a public transport mode in residential areas) called the “tricycles” was estimated separately in 2010 and 2015 and then the demand was added to the transportation demand which was earlier estimated for private and public trips. The tricycle demand was estimated separately since the outputs of the travel demand analysis software are in terms of private and public traffic volumes which did not include the tricycle mode.

b) Application Program to Aggregate Transportation
Demand From Links to Zone

The main outputs of the transportation demand analysis software are daily link-level traffic flows and average traffic speeds. An application program was developed to aggregate the outputs from links to the traffic analysis zones. The program first identified which traffic analysis zone a specific link belongs. After identifying zone membership, aggregation was done for traffic volumes and average traffic speeds to produce zone-level traffic volumes and average speeds per day.

c) Calculation of Vehicle-Kilometers and Assumptions

The daily vehicle-kilometers for the zones were calculated by multiplying traffic volumes with the length of the road links. The calculations yielded the private and public vehicle-kilometers per day for each zone. It is necessary to further classify the vehicle-kilometers in terms of vehicle types as input to the calculation of vehicle emissions. The composition of public transport vehicles was assumed to be uniform in all zones and the estimates were based on the share of the vehicle kilometers of each type, as shown in Table 4. The share in percent was multiplied by the total vehicle-kilometers of public trips to get the total vehicle-kilometers of each public transport vehicle type for each zone. Since the tricycle demand was estimated separately, it was not necessary to get its share of vehicle-kilometers of the public transport trips. For private vehicle trips, the shares from vehicle registration data of the Land Transportation Office of the Philippines in 2001 (Table 5) were multiplied to the private vehicle kilometers to get the share of vehicle-kilometers of each private vehicle type per zone.

Table 4 Share of Present Travel Distance of Buses and Jeepneys

	Vehicle Trips	Average Trip Length	Veh-Km	Share of Veh-Km
Bus	57,000	13.0	741,000	31.5%
Jeepney	460,000	3.5	1,610,000	68.5%

Source: JICA (1999) MMUTIS Technical Report No. 10: Traffic Environmental Study, Air and Noise Pollution in Metro Manila

Table 5 Share of Private Modes

Cars (Gas)	Utility Vehicles (Gas)	Utility Vehicles (Diesel)	Trucks (Diesel)
41.9%	21.7%	30.4%	6.0%

Source: Land Transportation Office (LTO), Philippines

3.6 Estimates of Vehicle-Kilometers

The total vehicle-kilometers per day by mode for all the 98 zones of Metro Manila and the adjoining provinces for the baseline scenarios in 2010, 2015 and the Railway 2015 scenarios are shown in Table 6. The transportation demand where the railway network would be in place by 2015 under the MMUTIS Master Plan would just reduce the vehicle-kilometers of road-based modes especially the private transport mode back to the 2005 level. Without improvements in road and rail network, the road-based transport demand was forecasted to increase to more than 80 million veh-km in 2005 and 2015.

Table 6 Transportation Demand by Mode

Scenario	Vehicle-Kilometers Per Day			
	public	private	tricycle	total
Baseline 2005	12,249,488	52,697,058	8,568,184	73,514,730
Baseline 2010	15,978,812	57,182,985		81,729,981
Baseline 2015	15,978,812	59,699,820		84,246,816
Rail 2015	14,191,353	51,167,782		73,927,319

4. ESTIMATION OF LOCAL EMISSIONS FROM TRANSPORTATION

4.1 Local Vehicle Emission Factors

Table 7 shows the emission factors for the 7 vehicle-fuel types according to traffic speed. The study adopted the locally developed emission factors of the 1992 VECP Project (ADB, 1992) as emission factors at the 20 kph speed level and patterned the variation after the speed-specific and vehicle-specific emission factors provided by the MMUTIS Technical Report No. 10 (JICA, 1999). Tables 8-12 show the resulting emission factors according to traffic speed level that were adopted in this study.

One of the outputs of the 4-step travel demand forecasting model estimated in JICA STRADA is the average speed of each zone. When the average speed is known, the emission factor for each vehicle-fuel type is taken from Tables 8-12 as a function of traffic speed.

Table 7 Emission Factors (g/veh-km)

Fuel Type	Vehicle Type	Pollutant Type				
		PM	CO	HC	SO_x	NOx
Gasoline	Car	0.1	49.5	6.0	0.011	2.7
	Utility Vehicle	0.12	60.0	8.0	0.014	3.0
	Motorcycle	2.0	26.0	18.6	0.004	0.2
Diesel	Taxi Jeepney	0.6 0.9	1.9 2.5	0.65 0.7	0.081 0.121	2.0 1.4
	Utility Vehicle	0.9	2.5	0.7	0.115	1.4
	Truck	1.5	12.4	3.7	0.374	12.5

Source: ADB (1992) Vehicular Emission Control Planning Project

Table 8 Speed-specific PM Emission Factor (g/veh-km)

speed / vehicle-fuel	less than 10 kph	10-20 kph	greater than 20 kph
gas car	0.12	0.1	0.1
gas UV	0.14	0.13	0.12
diesel taxi/car	2.03	0.9	0.9
diesel utility vehicle/jeepney	1.89	0.99	0.9
diesel truck/bus	2.4	1.6	0.9
gas motorcycle/tricycle	2.02	2.01	2.00

Table 9 Speed-specific CO Emission Factor (g/veh-km)

speed / vehicle-fuel	less than 10 kph	10-20 kph	greater than 20 kph
gas car	58.1	49.5	39.4
gas UV	55.1	60.5	47.6
diesel taxi/car	3.0	2.5	2.3
diesel utility vehicle/jeepney	2.9	2.5	2.3
diesel truck/bus	11.3	12.4	11.3
gas motorcycle/tricycle	30.5	26.0	20.7

Table 10 Speed-specific HC Emission Factor (g/veh-km)

speed / vehicle-fuel	less than 10 kph	10-20 kph	greater than 20 kph
gas car	7.0	6.0	4.8
gas UV	6.7	7.3	5.8
diesel taxi/car	0.8	0.7	0.6
diesel utility vehicle/jeepney	0.8	0.7	0.6
diesel truck/bus	3.4	3.7	3.4
gas motorcycle/tricycle	21.8	18.6	14.8

Table 11 Speed-specific SOx Emission Factor (g/veh-km)

speed / vehicle-fuel	less than 10 kph	10-20 kph	greater than 20 kph
gas car	0.013	0.011	0.011
gas UV	0.015	0.011	0.010
diesel taxi/car	0.201	0.115	0.101
diesel utility vehicle/jeepney	0.180	0.121	0.110
diesel truck/bus	0.499	0.374	0.249
gas motorcycle/tricycle	0.005	0.004	0.004

Table 12 Speed-specific NOx Emission Factor (g/veh-km)

speed / vehicle-fuel	less than 10 kph	10-20 kph	greater than 20 kph
gas car	2.7	2.7	2.7
gas UV	4.6	3.5	3.5
diesel taxi/car	1.8	1.4	1.3
diesel utility vehicle/jeepney	1.6	1.4	1.3
diesel truck/bus	13.3	12.5	10.9
gas motorcycle/tricycle	0.2	0.2	0.2

4.2 Method for Estimation of Local Emissions

The daily emissions for each traffic analysis zone were estimated as follows (Eq. 1):

$$E = \sum_{i=1}^{6} d_i \times EFexhaust_i(v) + \sum_{i=1}^{6} T_s \times d_i \times EFidle_i \qquad (1)$$

where: E = local emissions per traffic analysis zone (g)
d_i = travel distance of vehicle type i (veh-km) per zone
v = average travel speed per zone (km/h)
$EFexhaust_i(v)$ = exhaust emission factor of vehicle type i as a function of travel speed (g/veh-km)
T_s = idle or stopping time (min/veh-km) per zone
$EFidle_i$ = idle emission factor of vehicle type i (g/min)

The stopping or idle time per zone was obtained from the "Two-Fluid Model" developed for Metro Manila by MMUTIS (JICA, 1999). Using the output of travel demand estimation, which is the travel time (min/km) in each zone, the stopping time is calculated using the equation of the Two-Fluid Model as shown below (Eq. 2):

$$T_s = T - T_m^{\frac{1}{n+1}} T^{\frac{n}{n+1}} \qquad (2)$$

where: T_s = stopping time per unit distance (min/km)
T = trip time per unit distance (min/km)
T_m = average minimum trip time per unit distance = 1.966 min/km for Metro Manila
n = 1.889 for Metro Manila

4.3 Emissions Estimates of Policy Scenarios

Table 13 shows the estimated daily emissions of 5 criteria pollutants generated by transportation. Carbon monoxide emissions primarily from passenger cars dominate the share of local emissions.

Table 13 Estimate of Baseline Daily Emissions, 2010

Criteria Pollutant	Emissions (tons/day)	Share
HC	14.1%	220.4
CO	66.6%	1,060.1
NOx	16.0%	280.1
SOx	0.4%	7.7
PM	3.0%	58.2
Total	100.0%	1,626.6

Table 14 shows the total daily emissions per pollutant for the baseline scenario in 2015.

Table 14 Estimate of Baseline Daily Emissions, 2015

2015	emissions in tons/day					
Scenario	HC	CO	PM	NOx	SOx	TOTAL
Base	226.812	1,119.456	60.910	294.972	8.154	1,710.303

Table 15 shows the percent change in total emissions per criteria pollutant of each scenario with respect to the baseline scenario in 2015.

Table 15 Change in Emissions of Each Scenario Compared to Baseline Daily Emissions, 2015

	Percent Change in Emissions (%)					
Scenario	HC	CO	PM	NOx	SOx	TOTAL
4-Stroke TC	**-30.47**	-1.26	**-20.07**	-0.37	-0.34	-5.65
MVIS	**-25.32**	**-35.21**	**-27.42**	**-32.91**	**-38.08**	**-33.24**
TDM	-5.28	-9.78	-3.84	**-11.64**	**-13.96**	-9.31
Bikeways	-1.72	-1.75	-1.24	-0.02	-0.02	-1.42
Mass Transit	-9.67	**-14.65**	**-18.23**	**-20.00**	**-22.99**	**-15.08**
CNG	-2.88	-3.22	-8.29	-2.26	-5.56	-3.20

Strategies such as the vehicle inspection and mass transit improvement contributed to higher overall emission reductions. The switch from 2-stroke to 4-stroke tricycles significantly reduces HC and PM emissions. Higher NOx and SOx emissions reductions were achieved in the TDM strategy.

Measures such as use of CNG for buses and construction of bikeways contribute to lower emissions reduction.

5. ESTIMATION OF FUEL CONSUMPTION OF TRANSPORTATION

5.1 Estimation of Fuel Consumption

The daily fuel consumption of a particular road link is calculated by:

$$FC = \sum_{i=1}^{6} d_i \cdot FCF_i \qquad (3)$$

where:

FC= fuel consumption per link (liters)
d_i = travel distance of vehicle type *i* (veh-km) per link
FCF_i = fuel consumption factor of vehicle type *i* (li/veh-km)

Table 16 Fuel Consumption Factors (FCF)

Vehicle Type	Fuel Type	FCF (li/km)	Fuel Economy (km/li)	Source
passenger car	gasoline	0.133	7.50	DOE
passenger car	diesel	0.102	9.79	MMUTIS
utility vehicle	gasoline	0.133	7.50	DOE
utility vehicle	diesel	0.176	5.69	
motorcycle	gasoline	0.034	29.29	
truck	diesel	0.224	4.47	MMUTIS)
taxi	gasoline	0.133	7.50	
taxi	LPG	0.144	6.94	DOE
tricycle (2-stroke)	gasoline	0.041	24.41	Biona et al. (2007)
tricycle (4-stroke)	gasoline	0.034	29.29	
jeepney	diesel (B1)	0.176	5.69	UPD-COE (2009)
bus	diesel (B2)	0.375	2.67	DOTC-MMPTPSS (2010)
AUV	diesel (B2)	0.173	5.77	DOTC-MMPTS (2007)
jeepney	LPG	0.298	3.36	
bus	LPG	0.635	1.58	
bus	CNG*	0.326	3.07	

5.2 Fuel Consumption of Policy Scenarios

Table 17 shows the baseline fuel consumption in 2010 and 2015. The baseline consumption in 2010 was compared with annual fuel consumption in 2007 as per Department of Energy (DOE) data adjusted for Metro Manila and the difference is between 3-5% for diesel and gasoline fuels.

Table 17 Baseline Fossil Fuel and Alternative Fuel Consumption, Metro Manila, 2010 and 2015

Base-line	Daily Fuel Consumption				
	Diesel (li/day)	Gasoline (li/day)	LPG (li/day)	CNG (kg/day)	CME (li/day)
Base 2010	7,711,019	4,166,282	545,404	5,776	157,368
Base 2015	7,892,483	4,334,850	569,410	5,776	161,071

Table 18 shows the percent change in fuel consumption with respect to the baseline in 2015 of the policy scenarios. The expansion of the mass transit network is the single policy scenario that contributed to higher overall reduction in petroleum and alternative fuel consumption levels. This is followed by the vehicle restraint (TDM) policy. The implementation of all-CNG bus policy contributed to the significant reduction of diesel fuel consumption. The public utility buses consumed the largest share (28%) of diesel fuel consumed in Metro Manila in 2010It can be observed that the MVIS policy did not contribute to significant reduction in fuel consumption. The policy assumed that there will only be a 5% improvement in fuel efficiency of vehicles that will be covered under the MVIS2015 scenario.

Table 18 Change in Fossil Fuel and Alternative Fuel Consumption of Each Scenario Compared to Baseline, 2015

Scenario	Reduction in Daily Fuel Consumption				
	Diesel	Gasoline	LPG	CNG	CME
4-Stroke TC	0%	-1%	0%	0%	0%
MVIS	-3%	-3%	-5%	-5%	-3%
TDM	-6%	**-10%**	**-11%**	0%	-6%
Bikeways	0%	0%	0%	0%	0%
Mass Transit	**-13%**	**-13%**	**-14%**	**-11%**	**-13%**
CNG	**-28%**	0%	0%	high	**-28%**

6. CONCLUSIONS

Transport and environment policy measures such as the vehicle inspection (MVIS) and mass transit network expansion contributed to higher overall local emissions reductions. Travel demand management (TDM) measure ranked third in overall emissions reduction (9%). The switch to 4-stroke tricycles contributed to significant reductions in HC and PM emissions, however, overall emissions reduction was less than 10%.

The switch to CNG buses, followed closely by mass transit network expansion, contributed to significant reduction in fuel (diesel, gasoline, LPG) consumption. The TDM measure ranked third.

It can be concluded that the expansion of the mass transit system, particularly, rail-based systems resulted of reduction in emissions as well as reduction in energy demand. It can be coupled with measures on vehicle restraint (TDM) by the metropolitan and local governments.

In order to assess existing and future transport and environment policies, it is necessary to improve transport emissions inventories and energy utilization using transportation demand forecast models and traffic simulation models. Estimates of transportation demand models and traffic simulation models can be greatly improved through the development of emission factors and fuel consumption factors for a wide range of vehicle, fuel and operating characteristics together with the development of vehicle database to include basic vehicle fleet data such as annual mileage and engine age.

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