From area-wide to link-based emission modeling

Development of a methodology for improving emission estimates of road transport in Guadalajara, Mexico.

by

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Statement of Academic Honesty

I hereby declare that this thesis is entirely the results of my own work except where otherwise indicated. I have only used the resources given in the list of references.

Munich, March 23rd, 2010

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Montserrat Miramontes Villarreal :

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Abstract

Air pollution is an important problem in urban areas because of the impacts on human health and its potential contribution to climate change. The transport sector is a major contributor of emissions, especially in urban areas. Given its size and economic activities, the Guadalajara Metropolitan Area (GMA) is an example of an urban area worth analyzing in terms of on-road vehicle emissions. In the development of strategies to combat the negative effects of transport on the environment, authorities in GMA have relied on emission inventories to identify and quantify emission sources. However, until today the spatial disaggregation of vehicle emissions in local inventories is not considered to be enough for the design of effective technical solutions nor policy making. In this sense, a methodology for link-based emission estimation in GMA was developed in order to produce results with a better spatial resolution. The developed methodology allows for the estimation of vehicle emissions at the street level and for smaller analysis zones. This makes it possible to identify hot spots and streets with high emission levels. Although the accuracy has not proven to be very high, the overall results appear to be reasonable when compared to other inventories. Moreover, the analysis of network characteristics shows a logical distribution of emissions according to vehicle activity by road type and vehicle groups. The methodology is relatively easy to reproduce and can be improved upon if more detailed data is available. The accuracy of final results can also be enhanced with a series of recommendations as provided at the end of this work.

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Abbreviations

AGEB	Area geoestadística básica (Basic geo-statistic area)
AH	average hour
CEIT	Centro Estatal de Investigación de la Vialidad y el Transporte del estado de Jalisco (Transport Research Center of the state of Jalisco)
CO	carbon monoxide
CO_2	carbon dioxide
EFM	Emission factor model
EI	Emissions Inventory
g	gram
GIS	geographical information system
GMA	Guadalajara metropolitan area
HC	hydrocarbon
HDV	heavy duty vehicle
HDDV	heavy-duty diesel vehicle
HDGV	heavy-duty gasoline vehicle
hr	hour
INE	Instituto Nacional de Ecología (National Institute of Ecology)
INEGI	Instituto Nacional de Estadística, Geografía e Informática (National Institute of Statistics, Geography, and Computing)
kg	kilogram
kJ	kilojoule
km	kilometers
km^2	square kilometers
km/hr	kilometers per hour
LDT	light-duty truck
LDV	light duty vehicle
LDDT	light-duty diesel truck
LDDV	light-duty diesel vehicle
LDGT	light-duty gasoline truck
LDGV	light-duty gasoline vehicle
m^2	square meters

MAR	mileage accumulation rates
Mg	megagram
mph	miles per hour
NEI	National Emissions Inventory
NO	nitric oxide
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
OH	off hour
PH	peak hour
PEMEX	Petróleos Mexicanos
PM	particulate matter
$PM_{2.5}$	particulate matter less than 2.5 micrometers in equivalent aerodynamic diameter.
PM_{10}	particulate matter less than 10 micrometers in equivalent aerodynamic diameter
QA	quality assurance
QC	quality control
RVP	Reid vapor pressure
SEMARNAT	Secretaría de Medio Ambiente y Recursos Naturales (Secretariat of the Environment and Natural Resources)
SEMADES	Secretaría del Medio Ambiente para el Desarrollo Sustentable del estado de Jalisco (Secretariat of the Environment for sustainable development of the state of Jalisco)
SO_x	sulfur oxides
TDM	travel demand model
TND	transport network database
TOG	total organic gases
U.S. EPA	United States Environmental Protection Agency
VKT	vehicle kilometers traveled
VMT	vehicle miles traveled
VOC	volatile organic compound
yr	year

Chapter 1

Introduction

This thesis presents the development of a methodology for link-based emission modeling for road transport in a particular urban area in Mexico.

Although the methodology itself is the central part of this work, the context in which this work is useful requires an introduction. This chapter focuses on the problem statement and starts by highlighting the contribution of transport to air pollution in urban areas. Thereafter, the Guadalajara Metropolitan Area is briefly introduced as the case study for this thesis. Later, the role of emission inventories in air quality management activities will be explained together with the concept of a bottom-up approach and link-based emission modeling as effective methods for emission estimation. To end this chapter, the objectives of this work and structure of the thesis are presented.

1.1 AIR POLLUTION AND TRANSPORT IN URBAN AREAS

In the last decades the world population has increased from 2.54 billion in 1950 to 6.67 billion in 2007. Of the total population today, approximately one half lives in urban areas. It is expected that in the next years the urban areas of less developed regions will absorb all of the world´s population growth. This phenomenon is leading to the development of megacities, which is a term used for metropolitan agglomerations exceeding ten million inhabitants (UN, 2008).

As explained by Molina & Molina (2004), these concentrations of people and their related activities are exerting negative impacts on the environment at urban, regional, and global levels. For instance, in recent decades air pollution became one of the most significant problems in urban areas because of its harmful influence on human health and the potential it has to contribute considerably to climate change.

Air pollution is understood as the introduction of different substances into the atmosphere which are released from a complex mixture of sources that either directly or indirectly harm the environment. Common sources are industry, households, natural processes, and traffic.

Among different sources, the transport sector currently accounts for almost a quarter of the global carbon dioxide (CO_2) emissions (IEA, 2009). Moreover, emissions from transport have risen faster than those from all other sectors and are projected to increase more rapidly in the future. Hence, greenhouse gas emissions from transport are considered an important contributor to climate change. (GTZ, 2007)

But the increasing focus on a global problem, such as climate change, should not put out of sight the importance of other emissions from motorized transport with a local impact on human health and environment. In most urban areas, motorized vehicles are the main contributors to emissions of total organic gases (TOG), carbon monoxide (CO), nitrogen oxides (NO_x), sulfur oxides (SO_x), particulate matter (PM), air toxics and visibility reducing species. (Radian International, 1996)

Concerning urban areas, it has been observed that those in developing countries are characterized by chaotic and discontinuous spatial patterns, as well as unorganized and fast development processes. Specifically, the urbanization process in Latin American cities is depicted as insufficiently planned and poorly coordinated (Xavier Barros, 2004). These and other characteristics of urban agglomerations often have negative impacts on the mobility and transport, resulting in significant contributions to air pollution.

1.2 Case study in Guadalajara Metropolitan Area

Given the location, size and continuous urban and population growth, the Guadalajara Metropolitan Area is considered an interesting example of conurbation in a developing country that is worth an analysis in terms of vehicle emissions.

The Guadalajara Metropolitan Area (GMA) after Mexico City is the biggest metropolitan area in Mexico with 4.1 million inhabitants (INEGI, 2007, p. 84) and the main center of economic and industrial activities in the region. According to UAM (2007), in the last years GMA has had rapid population, economical and industrial growth. As a consequence, transportation demand and the consumption of carbon fuels also increased, resulting in a significant contribution to air pollution.

The last emission inventory for GMA, dating from 2005, reports an overall production of 1.5 million (metric) tons of five criteria pollutants. Among the different sources considered in the inventory, transport is identified as the main contributor of carbon monoxide, nitrogen oxides and hydrocarbons with 99%, 76% and 54% of total emissions, respectively (UAM, 2007).

The above mentioned figures have already raised consciousness among residents and authorities about the problem. Consequently, some measures have already been implemented or are in the process of being implemented. Measures include emission control and car sharing programs, as well as support to the urban mobility strategy with a central focus on the implementation of the Bus Rapid Transit (BRT) system for mass public transportation (SEMADES, 2009; SEMADES, 2007)

Air quality management activities in GMA have been based upon the continuous analysis of air quality monitoring and the results from emission inventories. As such, they are considered to be technically supported. However, emissions from on-road vehicles in GMA since the last emission inventory have been estimated with an area-wide approach. That is to say, emissions are calculated and reported for the total urban area in tons per year without a further detailed allocation of emissions in space and time. This lack of detail at the spatial and temporal resolution is considered to be a limitation in the design of effective and appropriate measures for achieving the environmental goals stated in the Air Quality Program of GMA.

Saide et al. (2009) have already observed that emission inventories in developing countries are scarce and usually only report the total amount or magnitude of emissions. Saide continues (citing Davis et al., 2005) that only in a few Latin American cities is data on temporal distribution available, while spatial distribution is not even reported.

1.3 EMISSION INVENTORIES AND THEIR ROLE IN AIR QUALITY MANAGEMENT

According to Radian International (1996), in order to address appropriate measures to reduce health and environmental impacts it is necessary to develop detailed regional plans for the quantification and identification of emission sources.

Emission inventories play an important role on air quality management activities at different scales. They are used to quantify and allocate emissions in space and time. Results allow environmental planners and authorities to design and implement effective measures against air pollution, from environmental policies to technical solutions.

Continuous updating of emission inventories (EIs) is the key to assessing the implemented measures. The results provide information on how the enacted measures can be redesigned and improved upon. This will allow for a greater achievement of environmental goals, standards, or law specifications.

On a global scale, EIs are used to monitor the fulfillment of international agreements such as the Kyoto protocol and in this context they are also used in the protocol´s mechanisms processes: Clean Development Mechanism, Joint-Implementation, and Emissions Trading. (UNFCC, 1998)

For the particular case of transport, Ossés de Eicker et al. (2009) and references mention that emission inventories are used to assess the impacts of fuels and traffic technologies on the amounts and concentrations of emissions and to analyze how they are influenced by the different types of vehicles in the study area.

Regarding resolution of EIs, Saide et al. (2009) claim that inventories should also consider spatial distribution and temporal disaggregation. Therefore, the development of simple methodologies capable of finding hot spots of emissions and also of providing accurate data for air quality forecasting is encouraged.

The relevance of a detailed spatial resolution is also discussed in the work of Ossés de Eicker et al. (2009). In their work it is mentioned that if emission inventories are spatially resolved, they can be useful in assessing pollution exposure, identifying problem zones, and as input for pollution transport and chemical models.

In a previous study, Ossés de Eicker et al. (2008) compared the accuracy of spatial resolution obtained with top-down and bottom-up approaches. While the latter approach is based on a traffic model with emissions dependent on street characteristics, the top-down approach, on the other hand, is based on the total amount of traffic emissions within the city area, disaggregating emissions later based on street density. The top-down approach requires less computational, economic, and technical resources and for large scale analysis, such as city level or country, is considered to yield acceptable results. Nevertheless, the spatial accuracy is often lower than that obtained with a bottom-up approach.

Due to the above mentioned, it is considered that the bottom-up approach is more appropriate when looking for hot spots in urban areas, but it is clear that it requires more data, resources and technical skills.

Since vehicle emission estimations with a bottom-up approach are often based on traffic models, emission estimations are also described as being link-based. Link-based emission estimations are believed to provide enough spatial resolution to fulfill many of the purposes mentioned at the beginning of this section. Link-based emission modeling has been used in many urban areas around the world with different purposes. Some examples are presented in Zárate et al., 2007; Kühlwein et al., 2002 and Smit et al., 2008.

1.4 OBJECTIVES

Given the importance of emission inventories in air quality management activities, considering the limits of the current spatial resolution of emission inventories in GMA, and as illustrated by the current examples of link-based emission modeling, this thesis is motivated with the following objectives:

- To develop a methodology for improving the spatial resolution of vehicle emission estimation in GMA. To achieve a spatial resolution that is sufficient for analysis and design of technical solutions and policy making.

- As the accuracy is anticipated to be poor in this first attempt, results are expected to be used preferably to identify opportunity areas for improvement of the accuracy and detail of future emission inventories.

- To develop a methodology that can be reproduced by local authorities with available data and affordable methods. The description of the methodology and the complementary sections (Annexes) of this work are intended to be useful in the improvement of further emission inventories.

- To introduce a methodology, flexible enough and well documented that can be improved over time and with the contribution from different stakeholders and researchers.

1.5 OUTLINE

This thesis is organized in two main parts: Part I is intended to serve as a theoretical framework for the developed methodology presented in Part II. The scope of the work it is based on the information presented in the first part. Therefore, the scope is both a conclusion of the first part and the introduction of the next. Part II describes the developed methodology and continues with the presentation of results, analysis and conclusions.

1.5.1 PART I: BACKGROUND

Part I reviews basic principles about vehicle emissions and the methods for its estimation, the context of the study area for which the methodology has to be developed, and presents the methods and data that were available for link-based emission estimation in GMA. Finally the scope of the work is set given the framework presented before and links to Part II.

Chapter 2 starts with the basic concepts about vehicle emissions and carries on with the current methods, from the general equation and the variables involved to the pre-conditions for link-based emission estimation. It continues by describing appropriate sources of data and defining the appropriate approach for emission estimation in GMA. The chapter closes with examples of emission factor models used in different countries including Mexico.

Chapter 3 reviews context of the case study, from its population and urban growth to the transport and mobility characteristics. Later, two emission inventories related to GMA are analyzed in detail for mobile sources and the methods used are also briefly reviewed. The chapter closes by pointing out the opportunities for an enhanced resolution of emission inventories.

Chapter 4 presents available data and methods that are suitable to be used in the GMA context. The description of the data will be useful later to understand how it has to be pre-processed for use in emission estimation. The chapter concludes by setting the limitations of the work based on this and the previous two chapters and leading to the second part of this thesis.

1.5.2 PART II: LINK-BASED EMISSION MODELING IN GMA

Part II starts presenting the core of this work, the developed methodology. It then continues with the results and analysis, closing with the conclusions.

Chapter 5 starts out by describing the data pre-processing and continues with the description of how emission factors were modeled. It then indicates how they were used for link-based emission estimation. To conclude, the methods to analyze sensibility of methodology and the methods for quality assurance of the results are described.

Chapter 6 presents an extensive analysis of the results. Before the actual results of emissions are provided, characteristics of the network in terms of vehicle and road classification are presented in order to assess the influence of vehicle volumes and speeds on emissions. Total emissions are first presented as a general number according to vehicle and road classifications. Subsequently they are depicted in maps showing emission levels of the streets and analysis zones.

Chapter 7 is the last chapter of this thesis. Here the overall results obtained are assessed. First a general evaluation of the results will summarize the influence of some variables on the emission estimates according to the developed methodology. Next, the limitations encountered during the development of the methodology and the actual estimation will be listed and will lead to the foreseen opportunities for its improvement. Recommendations for future estimates and further emission inventories are given. Finally an overall assessment of the work will close this chapter and be the final conclusion of this thesis.

Part I Background

Chapter 2

Different approaches for vehicle emission estimation

Internationally, good practice guidance for emission inventories encourages transparency, accuracy, impartiality, comparability and consistency (UNFCCC, 1999)

Since this thesis focuses on the development of a methodology for vehicle emissions in an urban area of Mexico, it was necessary to review the guidelines for vehicle emission inventories and adhere to them as much as possible.

In Mexico, the *Guide for use and elaboration of emission inventories*, published by the National Institute of Ecology, provides a number of guidelines for emission estimation with the aim of being a tool for the standardization of development, maintenance and updating of all inventory efforts throughout the country.

The manual for *Motor Vehicle Inventory Development* is part of the Mexico Emissions Inventory Program Manuals and provides specific guidelines for emission estimation from on-road mobile sources.

The manuals are the result of careful investigation and cooperation of institutions from the United States of America (Eastern Research Group, Radian International, Western Governors' Association) and from Mexico (National Institute of Ecology and the Secretary of Environment and Natural Resources). Hence, the methodology developed in this thesis is strongly influenced by the recommendations and guidelines given in the documents mentioned above. However, in order to identify potential opportunities for improvement of vehicle emission estimation, investigation on emission modeling in other urban areas of the world has also been carried out.

This chapter starts with general concepts about vehicle emissions, from a definition of the sources, the emissions processes, pollutants, and influencing factors to be analyzed. The chapter continues with the general equation used for emission estimation and goes further by setting the pre-conditions of the input variables for a link-based calculation. Finally the sources of data are presented in order to define the appropriate approach for emission estimation in GMA. The chapter closes with a brief description of different emission factor models used in different countries including the one that is currently used in Mexico.

2.1 BASIC CONCEPTS OF VEHICLE EMISSIONS

2.1.1 DEFINITION OF SOURCES

The definition of sources may vary depending on the purpose of the emission inventory. Some EIs use the term “mobile sources” to account for any source that is considered mobile. For example, mobile sources can include on-road as well as non- road vehicles, airplanes, ships and trains.

Nevertheless, for the particular case of Mexico, where the developed methodology is to be applied, mobile sources are defined as on-road motorized vehicles that are permitted to operate on public roadways (INE, 2005).

Other mobile sources, such as aircraft, locomotives, and commercial marine vessels are included as area sources while other types of non-road mobile equipment such as electricity generators and agricultural equipment are calculated separately from on-road vehicles. Due to the magnitude of their emissions and the special consideration to estimate its volume, motorized vehicles are managed separately from area sources (Radian International, 1996).

Mobile sources for Mexican inventories include passenger cars, buses, heavy vehicles and motorcycles that run with gasoline, diesel, or gas fueled engines.

Electric and/or hybrid vehicles are a special case that it is not yet considered in vehicle emission inventories in Mexico. Only when the introduction of these cars has an important share will their influence over the total amount of travel be of importance in emission estimation.

2.1.2 EMISSION PROCESSES

Motor vehicle emissions consist of a large number of pollutants resulting from two main processes: fuel combustion and fuel volatilization.

Exhaust emissions are produced by fuel combustion during vehicle operation. These types of emissions can be classified into four categories:

- Cold start emissions: occur when the engine is started after at least twelve hours of soak.
- Hot start emissions: occur when the engine is restarted after a short period of time.
- Hot stabilized emissions: occur while the engine is running.
- Idle Emissions: occur when the engine is running, but the vehicle is standing, for example at a red light or under high traffic congestion levels.

Evaporative losses occur due to fuel volatilization and can be produced while the vehicle is running, but also after engine shut off. It is mainly affected by the fuel volatility and ambient temperatures. These types of evaporative losses can be classified as follows:

- Hot soak emissions: these are caused by volatilization of fuel in the fuel delivery system following engine shut-off. The residual engine heat volatilizes the fuel.
- Running evaporative emissions: these are liquid or vapor fuel leaks occurring while the engine is operating.
- Diurnal emissions: these are evaporative losses from the vehicle fuel tank due to higher bulk liquid temperatures and fuel vapor pressure. They result from rising ambient temperatures, heat input from the vehicle's exhaust system, or heat reflected from the road surface.
- Resting losses: result from vapor permeation and liquid leaks through various parts of the evaporative control system while the engine is not operating.

- Crankcase losses: these emissions are primarily the result of defective PCV (Positive Crankcase Ventilation) systems.

- Refueling evaporative emissions: evaporative losses displaced from the vehicle fuel tank during refueling. While the vehicle is the source of the emissions, they occur while the vehicle is stationary and at known locations, such as gasoline stations.

In Figure 2.1 both exhaust and evaporative emissions processes are schematized.

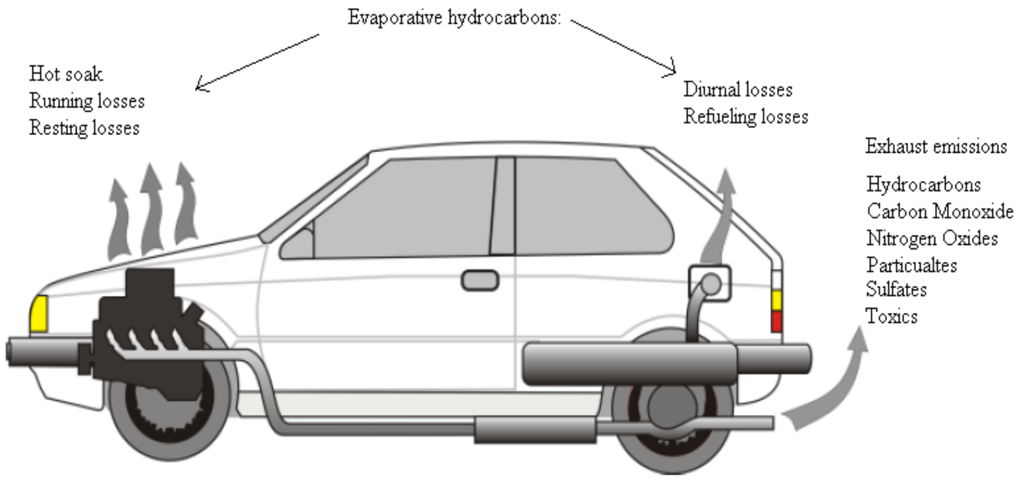

Figure 2.1-1. Motor vehicle emission processes. Adapted from INE (2005).

According to Radian International (1996), refueling losses are considered as area sources in Mexican Inventories and therefore will not be considered in this study.

Emission rates of the different processes may vary depending on the vehicle type and fuel characteristics. Some vehicle characteristics that affect emission rates are vehicle gross weight, vehicle age, and emission control technologies. For example, heavier vehicles tend to produce more emissions per distance traveled or per fuel consumed than lighter vehicles. Emission control technologies are more or less related to the vehicle age. Newer vehicles have better emission control technologies such as catalytic converters, improved engines, and better sealing systems. Thus, newer vehicles produce fewer emissions than vehicles of similar dimensions that are older. The variables that influence emission will be reviewed in more detail in Section 2.1.4

2.1.3 POLLUTANTS

With respect to motor vehicles, pollutants of frequent interest predominantly include hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_x), sulfur oxides (SO_x), and particulate matter (PM). Below, descriptions of these pollutants and other pollutants such as carbon dioxide (CO_2) and ozone (O_3) are provided. They were taken and adapted mainly from INE (2005) and complemented with descriptions found in Capiello (2002).

- Hydrocarbons: hydrocarbon emissions result from incomplete combustion or from fuel evaporation. These compounds can be grouped according to their chemical and physical properties in different groups, namely, total hydrocarbons (THC), non-methane hydrocarbons (NMHC), total organic gases (TOG), volatile organic compounds (VOC) and non-methane organic gases (NMOG). A number of exhaust hydrocarbons are toxic, with the potential to cause cancer. Hydrocarbons react in the presence of nitrogen oxides and sunlight to form ground-level ozone, a major component of smog.

- Carbon monoxide: is a colorless and odorless, but poisonous gas that results from incomplete combustion of carbon fuels. The greatest proportion of carbon monoxide in urban areas is generated by motorized vehicles. Exposure to this gas in concentrations greater than 20 parts per million (ppm) may cause alterations in nervous and cardiovascular systems.

- Nitrogen oxides: is a generic term for a group of highly reactive gases that are produced during combustion and include nitric oxide (NO), nitrogen dioxide (NO_2) and other less common nitrogen oxides. It is understood that NO does not cause adverse effects on human health in ambient concentrations, but the exposure to NO_2 may cause irritation to the respiratory tract. If NO_2 exposure is prolonged it may cause damage to the lunges. NO_x are normally eliminated from the atmosphere by wet and dry deposition processes and also react with CO to produce ozone and other photochemical oxidizers.

- Carbon dioxide: is a colorless and odorless gas that is produced in great amounts as a result of complete combustion of carbon fuels. Although it is naturally present in the atmosphere and is not considered a pollutant, CO_2 is a greenhouse gas that contributes to the potential for global warming. While emission control technologies applied to newer vehicles reduce emissions of other pollutants, carbon dioxide emissions often increase because of the improvements in the combustion process.

- Particulate matter: is a generic term for all the particles suspended in the air that come from soot, dust, aerosols, smokes or fogs. Particulate matter from motor vehicles is produced by chemical reactions of gases emitted to the atmosphere. There are many sub classifications of particles such as primary particles, secondary particles, total suspended particles (TSP), particles with diameter smaller than 10 (PM_{10}) or 2.5 micrometers ($PM_{2.5}$). These last two kinds of particles are of particular importance because of its potential damage to the lungs and respiratory system. Given their size, they may remain suspended in the atmosphere and eventually enter the lungs at which point they are deposited and may cause adverse health effects. Their presence is considered to be a cause of mortality and morbidity increase among individuals with previous cardiovascular and respiratory problems.

- Sulfur Oxides: is a generic term for oxides of sulfur which are emitted from motor vehicles burning fuel containing a high concentration of sulfur. Sulfur dioxide (SO_2) is a colorless gas with strong smell produced by vehicles. These compounds irritate the respiratory system with multiple negative effects.

- Ozone is the most abundant photochemical oxidizer present in the atmosphere. Although it is not released directly by any process of vehicle emissions, it is formed, together with other photochemical oxidizers, by chemical reactions between hydrocarbons, CO and NO_x in the presence of sunlight. Ozone irritates the eyes, damages the lungs, and aggravates respiratory problems.

According to Radian International, for Mexican vehicle emission inventories, emission factors for CO, NO_x and HC should be estimated using the emission factor model MOBILE in its Mexican version. Moreover, hydrocarbons should be reported as TOGs and emission factors for SO_x should be calculated using fuel mass balances. Finally, particle emissions should be calculated with the model PART5 until an appropriate model for Mexico is available.

2.1.4 FACTORS THAT INFLUENCE EMISSIONS

Emission rates from vehicles are influenced by a number of variables. Below, some of these variables are mentioned as a compilation from technical documentation of an emission factor model (MOBILE6). However, not all variables influencing emission rates are mentioned here. The list below corresponds only to some variables that are usually taken in account by static emission models.

- AMBIENT CONDITIONS: ambient temperature, relative air humidity, and altitude or atmospheric pressure. These variables affect the combustion process and therefore the rates of exhaust emissions. The rates of evaporative loses are especially influenced by ambient temperatures.

- FUEL CHARACTERISTICS: The concentration of some substances in exhaust emissions is highly influenced by the fuel composition (oxygen, sulfur, lead contents). The fuel volatility affects the rates of evaporative loses.

- VEHICLE CHARACTERISTICS: Emission rates from vehicles may vary according to age, mileage, vehicle gross weight, fuel economy, and emission control technologies (catalytic converters, PCV systems).

- VEHICLE ACTIVITY: Examples of vehicle activity variables are vehicle kilometers traveled, number of starts per day and time between engine starts, average trip lengths and trip length distribution, average speed, speed and acceleration patterns, driving behavior and engine loads.

Due to the large amount of variables that have to be taken in account, emissions from vehicles are usually calculated with the use of computational programs or emission factor models (Radian International, 1996).

For example, when analyzing a fleet, vehicle population distribution and annual vehicle kilometer accumulation rates (deterioration rates) as well as local vehicle inspection and maintenance (I/M) programs are also of importance.

According to Capiello (2002), the principal input to emission models are vehicle operating conditions, while ambient conditions may be introduced as secondary inputs. Herein it is also explained that given the strong influence of vehicle technology and status over the emission processes, models are normally calibrated independently for each vehicle make and model, or for homogeneous vehicle categories.

Depending on the model, the different variables will have a different level of influence on the results. Therefore, the selection of an emission factor model will depend on the data requirements as well as the purposes of the emission inventory for which the emission factors are being estimated.

In sections 2.5.1 and 2.5.2 two types of emission factor models will be presented.

2.2 GENERAL EQUATION FOR EMISSION ESTIMATION

A general method for emission estimation involves multiplying activity data by an emission factor. In the context of motor vehicles, activity data is also known as Vehicle Kilometers Traveled (VKT) or Vehicle Miles Traveled (VMT) and it refers to the total distance traveled by the vehicles within the inventory domain or study area. Parallel, emission factors indicate the amount of a certain pollutant *p* also produced by the vehicles that contribute to the activity under particular operating conditions. Thus, emissions from vehicles may be calculated as follows:

$$\boldsymbol{E_i = VKT \times EF_i} \tag{1}$$

where E_i are the emissions of contaminant *i*, *VKT* represents the activity data and EF_i is the emission factor of *i.* Activity data is normally expressed in units of length per units of time (LT^{-1}), emission factors are usually expressed in units of emitted mass per traveled distance (ML^{-1}) and finally, vehicle emissions, as a product of both variables, are expressed in units of mass per units of time (MT^{-1}).

According to Radian International (1996), the equation given above is applicable for most gaseous pollutants and particulate matter. For pollutants such as SO_x and lead, emissions can be estimated using a fuel balance, assuming that all of the sulfur or lead contained in the fuel is emitted.

For emission estimation, both variables must be representative of the particular situation that has to be analyzed. Vehicle activity, for instance, must represent the total travel in the study area while emission factors must be valid for the entire fleet that has a contribution to this activity.

In the subsequent sub-chapters the preconditions for link based modeling will be presented, followed by the methods for obtaining both variables. Emphasis will be placed on the methods appropriate for the link-based approach.

2.3 PRE-CONDITIONS FOR LINK BASED EMISSION MODELING

Links are understood as individual street segments in a transportation network that have some characteristics in common. Typical link characteristics are the number of lanes, width, surface type, inclination, speed limits and capacity. The volume of the links is a more dynamic variable restricted mainly by the capacity of the link, but at the same time influenced by travel demand.

For link-based emission modeling, both variables of equation (1) must be representative of the particular operating conditions of every single street.

Emission factors, for example, must represent the conditions of the links in terms of vehicle mix, average speed, driving cycles and road type. Similarly, vehicle activity must be related to the traffic volume and length of the link.

Such level of detail regarding the information about the links is often obtained from Travel Demand Models (TDMs). Other variables such as atmospheric conditions will be also of importance, but generally are not link related.

2.4 SOURCES OF ACTIVITY DATA

Activity data can be obtained either from fuel consumption statistics or traffic estimates. In general, direct traffic-based estimates provide a better representation of vehicle activity than those from fuel consumption statistics. The choice of the source will mainly depend on the availability and overall quality of the data (Radian International, 1996).

Traffic based activity data usually can be obtained from direct measurements or TDMs. While direct measurements are more appropriate for regional estimates, TDMs are the preferred tool in urban areas because of the high level of detail that can be achieved.

TDMs model traffic flows between zones of similar demographic characteristics. The roads in the transportation network are represented as connected links. Outputs from TDMs provide estimated travel time and traffic flows for the individual links, as well as average speeds, volume-capacity ratios, speed limits and other link-related characteristics (Oppenheim, 1995). It is worth mentioning that TDMs are not created specifically to be used as emission inventory tools. It is important that the time frame of the model represents the situations that have to be modeled and that the coverage of the model network sufficiently represents the actual street network of the study area (Radian International, 1996).

For link-based emission modeling, TDM´s are the most appropriate source of activity data since traffic volumes, speeds and other link characteristics are individually represented for each link of the transportation network and also geographically allocated. Some examples of emission estimation based on traffic models can be found in Kühlwein et al., 2002; Smit et al., 2008; Zárate et al., 2007 and Stein & Walker, 2002.

2.5 SOURCES OF EMISSION FACTORS

As explained in section 2.1.4, many different variables affect emissions. For example, changes in fuel characteristics, vehicle operating speeds, emission control technologies, and atmospheric conditions have an impact on emission rates.

Due to the complex diversity of mobile sources, motor vehicle emission factors are derived from emission factor models (EFMs). EFMs are based upon vehicle dynamometer tests under controlled conditions of temperature, fuel and driving cycles (Radian International, 1996).

Regarding the different factors that affect emission rates, Capiello (2002) explains that because of the strong influence of vehicle technology and their mechanical conditions on the emission processes, models are normally calibrated independently for each vehicle make and model, or for homogeneous vehicle categories.

There are two widely known approaches for emission modeling: dynamic emission modeling and static emission modeling. In the next two sub-chapters both types of emission models are presented as a summary of Capiello's (2002) literature review on traffic emission models. Finally, advantages and disadvantages of both approaches will be discussed in order to find the best approach for the case study of this work.

2.5.1 DYNAMIC EMISSION MODELS

Dynamic emission models are calibrated through continuous measurement of vehicle emissions during chassis dynamometer tests. Results are stored for short time intervals, usually seconds, generating a dataset of emission factors representing different speeds and accelerations.

For a given spatial domain, dynamic emissions of a species i at time t, may be calculated as follows:

$$E_i(t) = \sum_j e_i(c_j, x_j(t))$$

Where j is the vehicle identification number, c_j is the category of vehicle j, $x_j(t)$ the instantaneous variables of vehicle j at time t and $e_i\,(c_j,\, x_j\,(t))$ the emissions of species i for vehicle j at time t.

Due to the large amount of data, computational requirements for dynamic emission modeling are usually high. Given the present technology, dynamic emissions models are nowadays used only to simulate emissions from single vehicles or single network elements. Thanks to the enhanced computational capacities and the increasing data accessibility, this approach is increasingly more applicable to larger networks (Capiello, 2002)

2.5.2 STATIC EMISSION MODELS

Static emission models are based upon measurements of total emissions during a driving cycle. There are different types of driving cycles to represent speed variations over time for specific traffic situations. For example, the so called transient driving cycles are used to represent driving patterns, such as urban driving, aggressive driving, and signalized and non-signalized facilities, among others.

Results of vehicle tests are called Base Emission Rates (BERs) and normally should be statistically representative of the fleet under study (Radian International, 1996). Some models allow for use of correction factors to BERs for a better representation of "real world" conditions, such as speed, temperatures and fuel characteristics just to mention few.

According to Capiello (2002), static emissions of a species i for a given time period and a given area can be calculated:

$$E_i = \sum\nolimits_c \sum\nolimits_l VKT_l f_c \, BER_i(\bar{s}_l, c)$$

Where c is the vehicle category, l is a single link or a set of links characterized by an average speed, VKT_l represents vehicle activity in the link l, f_c is the fraction of vehicles of category c contributing to VKT_l, and BER_i $(\bar{s}_l, c)$ is the base emission rate per distance for a species i. $BERi$ $(\bar{s}_l, c)$ is determined from standard driving cycles at a particular average speed s_l, for each vehicle category c.

2.6 APPROPRIATE APPROACH FOR CASE-STUDY

According to Capiello (2002), applications of static models are generally used for large-scale analyses and cases when the average speed adequately characterizes driving conditions, for example uninterrupted flow on freeways. Because the BERs are obtained from standard driving cycles, these models may significantly misestimate the emissions. For example, under highly dynamic driving conditions, emissions are usually underestimated. For higher spatial and temporal resolution Capiello (2002) recommends the use of dynamic emissions models. However, due to the current needs of data as well as the high technology and computational requirements, this approach is still difficult for developing vehicle emission inventories in urban areas.

On the other hand, static emission models have been widely used for emission estimation by many researchers in complex transportation networks. In the next section, some examples of internationally used static emission models will be presented.

In the next two chapters the current methods used for vehicle emission estimation in GMA as well as the data availability for the improvement of spatial resolution will be described. It will be confirmed that for the case study, static emission models are the most appropriate approach.

2.7 INTERNATIONALLY USED STATIC EMISSION MODELS

There are a variety of static emission models available. In the literature these models are also called average speed-based models or inventory models. The models are developed by different agencies and for different countries or regions.

In the United States, MOBILE6 and MVEI are the most commonly used emission inventory models. While MVEI was developed by the California Air Resources Board and is only used in the state of California, MOBILE 6, on the other hand, is used in all other states.

MOBILE6 was developed by the Environmental Protection Agency to address a wide variety of air pollution modeling needs. It has been used by states as well as local and regional planning agencies to develop emission inventories and control strategies for State Implementation Plans under the Clean Air Act and other applications such as Environmental Impact Assessments (EPA, 2003).

The EPA has recently released a new emission model called MOVES2010 to replace MOBILE6. The new model is based on a greater number of emission tests, has more capabilities, improved algorithms and a friendlier user interface (EPA, 2009)

In Europe, a widely used model is COPERT 4 (Computer Program to calculate Emissions from Road Transport) which was developed by the European Environment Agency to calculate emissions from mobile sources. The model can calculate emission factors for CO, NO_x, VOC and PM as well as other unregulated pollutants and fuel consumption (Gkatzoflias et al., 2007). Examples of emission inventory development with this model or its predecessor (COPERTIII) can be found in the works of Bellasio et al., 2007; Smit et al., 2008; Ariela D'Angiola et al., 2010.

Another source of emission factors in Europe, although it is not precisely defined as an emission factor model, is the Handbook of Emission Factors for Road Transport (HBEFA). The handbook was developed by the Environmental Protection Agencies of Germany, Switzerland and Austria, but lately has been supported by other countries (Sweden, Norway, and France) as well as the JRC (European Research Center of the European Commission). HBEFA provides emission factors for different vehicle categories and for a broad range of traffic situations (http://www.hbefa.net/e/index.html, 2010).

The International Vehicle Emissions (IVE) Model was developed by the International Sustainable Systems Research Center and the University of California at Riverside to estimate emission factors for on-road mobile sources in developing countries. This model accounts for local vehicle technology distributions, power-based driving factors, vehicle soak distributions, and local meteorological factors (Davis et al., 2005b). The model has been used in many developed countries in America, Asia and Africa. Reports can be found in the web site: http://www.issrc.org/ive/

For vehicle emission estimations in Mexico, the National Institute of Ecology recommends the use of MOBILE6 in its adapted version for Mexico (Aguilar Gómez, 2009). This version has been already used for the Mexico National Emissions Inventory for 1999 (ERG, 2006).The MOBILE6-Mexico model was derived from its original version for use in the United States territory and adapted by the Eastern Research Group to represent the Mexican fleet characteristics (ERG, 2003).

Based on the adaptations made to the model, it is stated that MOBILE6-Mexico provides the most up-to-date, Mexican-specific motor vehicle emission factors for inclusion in the Mexico National Emissions Inventory (SCERP, 2005).

Due to the above mentioned, MOBILE6-Mexico was selected for the emission estimation in Guadalajara Metropolitan Area. In Chapter 4, the model capabilities and limitations will be described in detail.

Chapter 3

Case Study: Guadalajara Metropolitan Area

In this chapter the context of the case study is described. First, some general information about the study area is presented; the location of Guadalajara Metropolitan Area (GMA) and its importance as a major center of economic activities in the country. Special attention is given to the population growth and the increasing amount of private cars as a mean of transport. Next, the results of two emissions inventories, one specific for GMA and another of national scale are analyzed, emphasizing the contribution of transport to air pollution. The methods used in these inventories are briefly reviewed for a later comparison of the results obtained in this research and for analysis of divergence.

3.1 GUADALAJARA METROPOLITAN AREA

3.1.1 LOCATION

Guadalajara Metropolitan Area is located in the state of Jalisco, around 540 km northwest of Mexico City at an elevation of 1560 MASL. The geographic coordinates are 20°40′ North and 103°21′ West. In the next Figure the location of GMA in the national territory is presented.

GMA is composed mainly of 6 municipalities: Guadalajara, Zapopan, Tlaquepaque, Tonalá, Tlajomulco and El Salto. In Figure 3.1-1 it can be observed how these municipalities share a continuous urban landscape (in blue). However, two more municipalities (Juanacatlán and Ixtlahuacán de los Membrillos) are officially recognized as part of GMA (INEGI, 2007).

Figure 3.1-1. Composition of GMA and location within the state and national context.

3.1.2 POPULATION AND URBAN GROWTH

GMA is the second largest urban area in Mexico, only after the metropolitan area of Mexico City. Its population reached 4.3 million inhabitants in 2009 and is expected to reach 4.6 million inhabitants by 2015 (COEPO, 2008).

During the last twenty years, the annual average population growth rate has been around 2%. As with many other cities, this growth has not been concentrated in the center of the metropolitan area. In fact, the municipality of Guadalajara, located at the center of the metropolitan area, has experienced a decreasing population due to land use changes from housing to commercial, while the neighboring municipalities have had an increasing contribution to the urban growth over the last years (COEPO, 2008).

Although vertical housing is becoming more popular, urban growth is still dominated by horizontal housing development which means low habitation density and urban sprawl. The contribution to population growth by municipality over the last decades is shown in Figure 3.1-2.

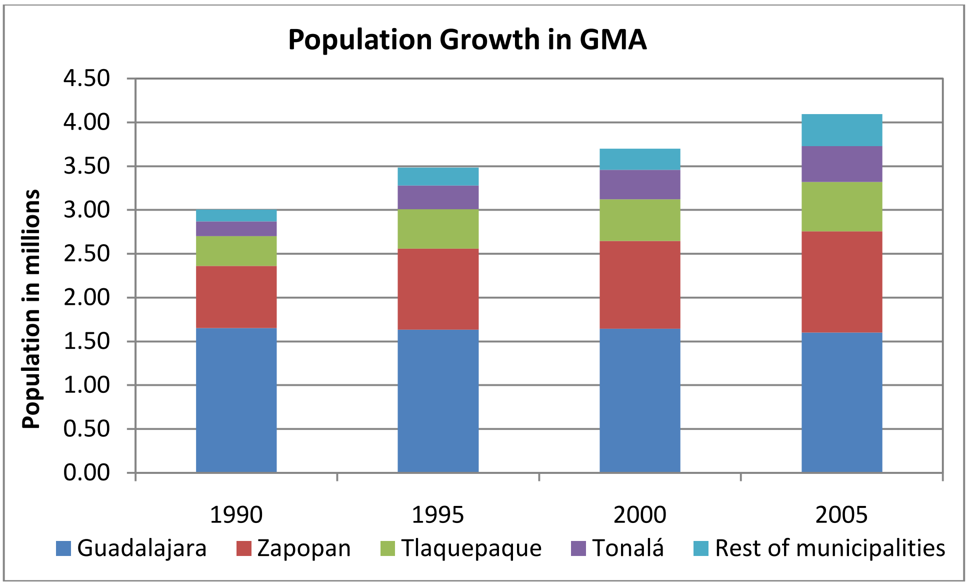

Figure 3.1-2. Population growth in GMA during the last decades (INEGI, 2007).

It is expected that population growth for the next years in the state of Jalisco will be concentrated in GMA due to migration from other regions and states of Mexico and not only due to natural growth of its current inhabitants. This concentration of growth is recognized to have an impact on the society, mobility, and environment COEPO (2008).

3.1.3 Transport and mobility

Concerning transport and mobility, during the last decade the amount of vehicles registered in GMA increased by an annual rate of 5%, a rate even higher than the population growth rate. Although this rate has been decreasing over the years, the actual amount of vehicles is still increasing as shown in Figure 3.1-3. Today there are about 1.7 million registered vehicles in GMA (CEIT, 2009). Apart from registered vehicles, there are also vehicles from other states and the so called "chocolate cars" operating in the study area. Chocolate cars is a term used for those vehicles illegally imported from the United States of America and characterized by high emission rates and low fuel economy. Therefore, these vehicles are no longer permitted to be driven in the USA. Transport authorities in Jalisco estimated that in 2000 there were about 80 000 vehicles with a plate from another state or another country that were not registered in the state of Jalisco (Ruiz Velasco, 2005).

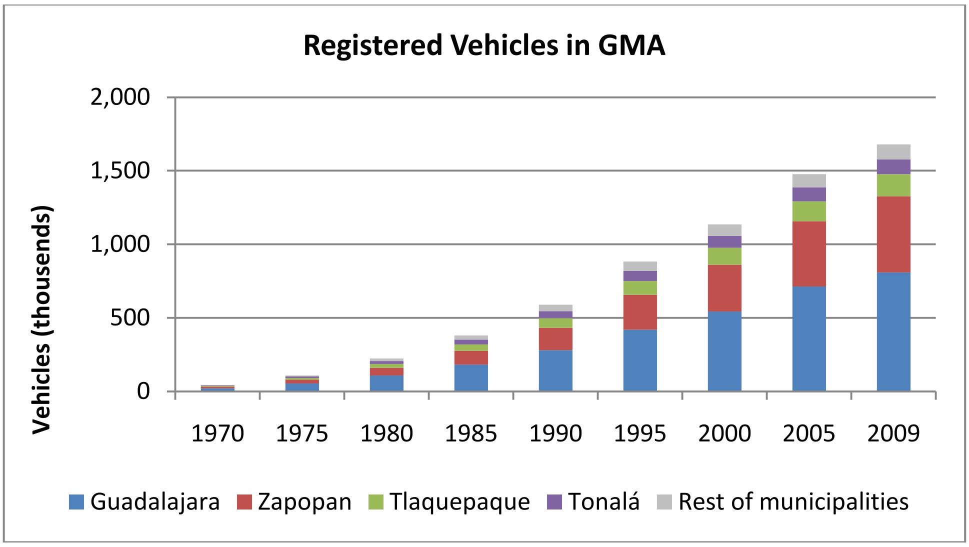

Figure 3.1-3. Registered Vehicles in GMA since 1970 (CEIT, 2009).

Regarding transport modes, the last origin destination surveys reports an average of 9.8 million trips in GMA, of which 38% are performed by walking. The rest of the trips are performed mainly with the use of private vehicles and mass public transport with 45% and 47% respectively. The remaining trips are performed by other means such as bicycle, motorcycles and other services (see Figure 3.1-4)

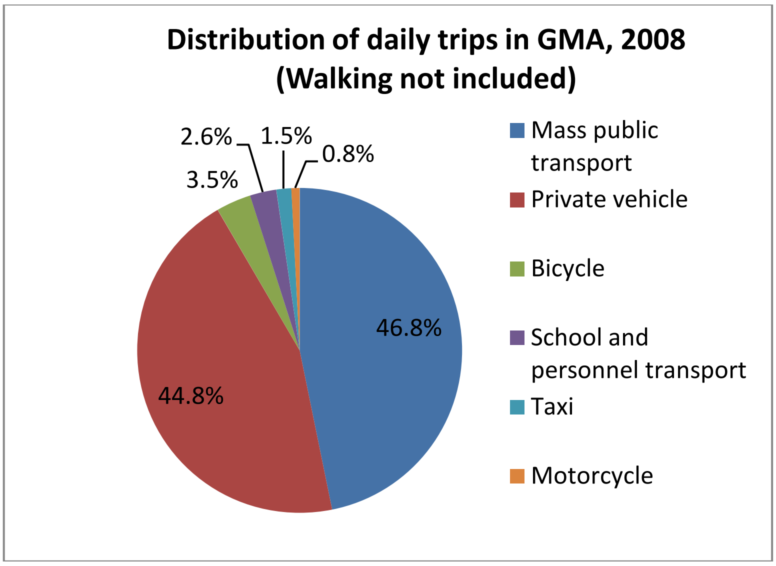

Figure 3.1-4. Modal split of daily trips in GMA (CEIT, 2008).

Worth mentioning is that in the case of motorized transport modes, the distribution of trips in 2003 was 68% in mass public transport and 32% by private vehicles. Today the share is almost the same for private vehicles and mass public transport. It is well-known that the poor quality of public transport services, the increasing affordability to purchase cars, and urban sprawl are the main reasons contributing to this annual increase (Mural, 2008).

3.2 CONTRIBUTION OF TRANSPORT TO AIR POLLUTION IN GMA

According to the long term analysis of air quality in GMA, the pollutants that most frequently exceed the air quality norms in decreasing order are: ozone, particulate matter, nitrogen dioxide, and carbon monoxide. While emissions of particulates are reported to mainly be due to changes in land use, nitrogen dioxide and carbon monoxide emissions are attributed predominantly to vehicle activity. These last two are precursors of ozone and therefore, are related to the frequency at which it exceeds regulations (SEMADES, 2007).

A closer look at emissions due to on-road transport is presented in this section as a summary of two emission inventories. The results for the state of Jalisco were taken from the Mexico National Emissions Inventory while the last emission inventory of GMA provides specific figures on vehicle emissions in the city.

A comparison between both inventories is rather difficult since each inventory was developed with different methodologies or approaches, report emissions for different spatial domains, and correspond to different years. However, it was considered important to have a look at the general figures as a means of quality control of the results generated later in this thesis. It should be noted that the results presented here are summarized for those vehicle classes and pollutants with major contributions. For a more detailed look at the sources and other pollutants the reader may refer to both inventories.

3.2.1 NATIONAL SCALE

According to the Mexico National Emissions Inventory (MNEI) from 1999 (ERG, 2006), Motor vehicle emissions for seven criteria pollutants (NO_x, SO_x, VOC, CO, PM_{10}, $PM_{2.5}$, and NH_3) were calculated using daily per capita emission rates based on travel demand models for seven representative urban areas while emission factors were generated by the MOBILE6-Mexico.

According to MNEI, motor vehicles in Jalisco produced 605,771.4 tons of the seven criteria pollutants in 1999. The distribution of these pollutants in percentage weight indicates that the major contributor is CO with 82% of the emissions, followed by VOC and NO_x with 10% and 7%, respectively. The remaining pollutants considered combine to contribute 1% in weight (see Figure 3.2-1).

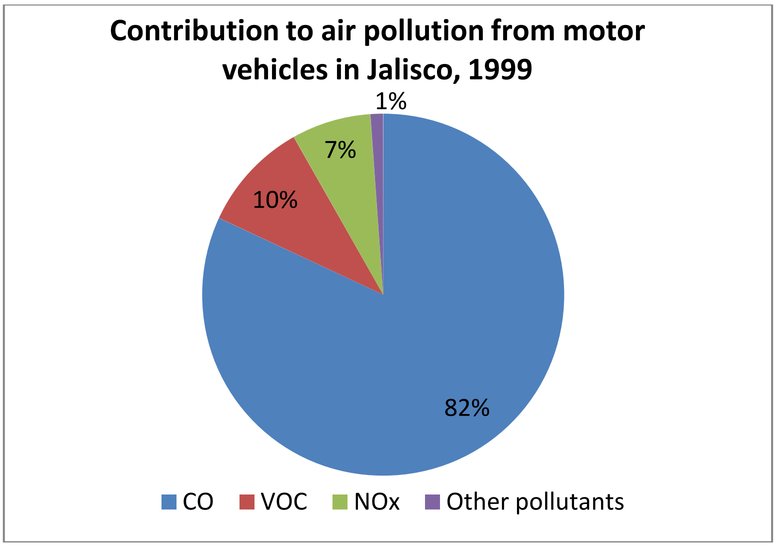

Figure 3.2-1. Contribution to vehicle emissions by pollutant in Jalisco, 1999 (ERG, 2006).

Regarding vehicles classes, results show that light duty gasoline vehicles (LDGV) and light duty gasoline trucks (LDGT) have the greatest contribution to total emissions with up to 50% and 33%, respectively. Heavy duty vehicles (HDV) are the third major contributor with around 12%. Other vehicle classes have very small contributions to emissions as is evident from Figure 3.2-4.

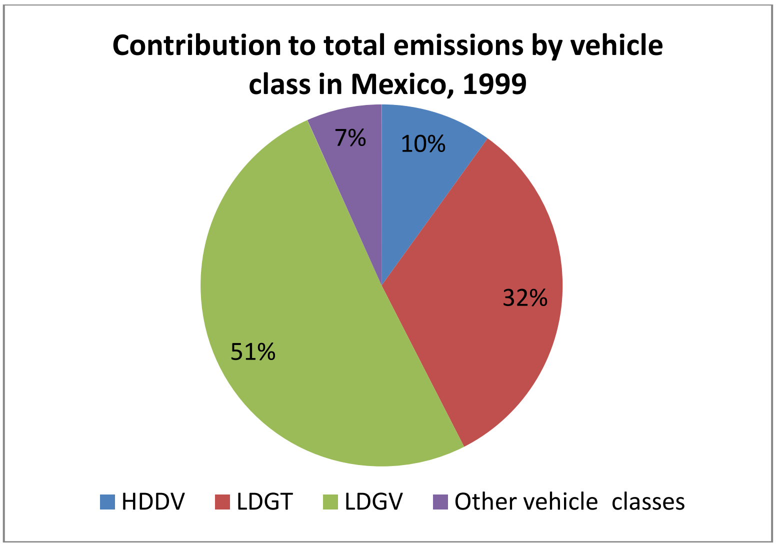

Figure 3.2-2. Contribution to emissions by vehicle class in Mexico, 1999 (ERG, 2006).

The contribution of different vehicle classes may vary if emissions are separately analyzed by pollutant. For example, light duty vehicles are major contributors of CO and VOC, while heavy duty vehicles have a larger contribution than other vehicle classes to NO_x. The individual contributions to emissions of criteria pollutants from the different vehicles classes are presented in Figure 3.2-3.

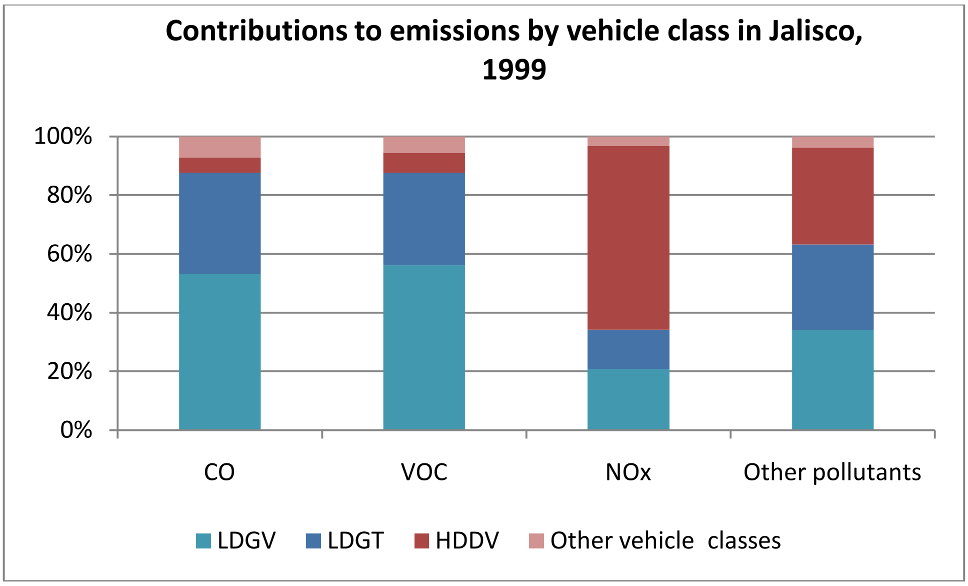

Figure 3.2-3. Contribution to emissions by vehicle class in Jalisco (ERG,2006).

3.2.2 URBAN SCALE

For the specific case of GMA, the latest emissions inventory reports emission estimates for the six main municipalities mentioned in section 3.1.1. The five criteria pollutants THC, CO, NO_x, SO_x and particulate matter (PM_{10}). Considered sources in this inventory are point, area, mobile and biogenic for the calendar year 2005.

For this year a total amount of 1.5 million tons was estimated. The most relevant emission is CO with 80% of the total emissions, followed by THC with 16%, nitrogen oxides (NO_x) 3%, and 1% composed by SO_x and PM_{10} (UAM, 2007). Motor vehicles alone produce an overall amount of 1.3 million tons per year. Among the different sources, mobile sources are major contributors of CO, NO_x and THC with 99, 76 and 54% of total emissions, respectively.

When analyzing vehicle emissions separately, the most relevant emissions are CO with 87% of total emissions, THC with almost 10%, and finally NO_x with 2.7%. Sulfur oxides and $PM_{10,}$ have an insignificant contribution as can be observed in Figure 3.2-8.

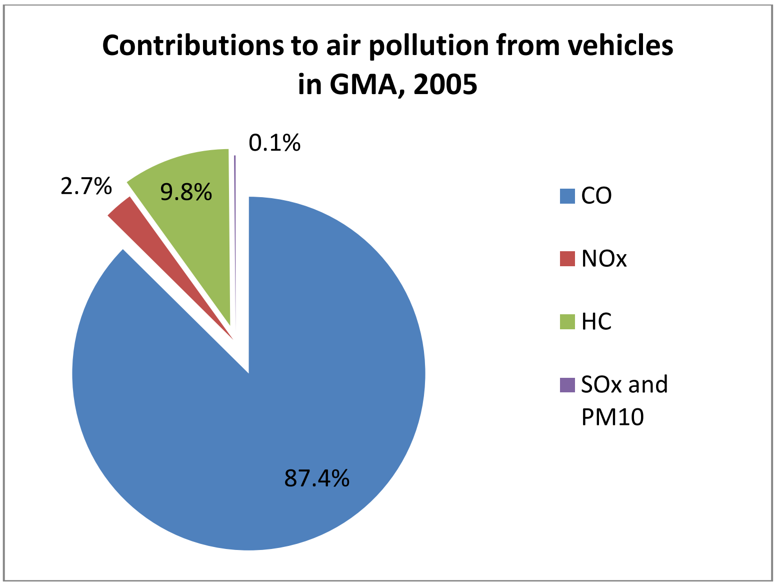

Figure 3.2-4. Contributions to emissions by pollutant in GMA, 2005 (UAM,2007).

Results for the different vehicle categories show that LDGV and LDGT have the largest contribution to total emissions with 66 and 23%, respectively while buses contribute only with 6%. It is important to note that in the urban scale, HDV have a very small contribution and therefore, are grouped with other vehicle categories such as taxis and light duty diesel trucks (LDDT). They combine for small contribution of 5% (see Figure 3.2-4).

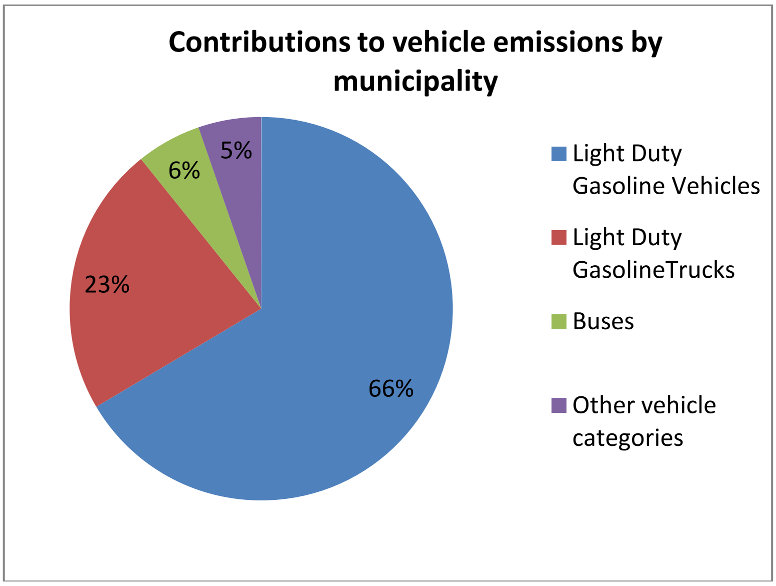

Figure 3.2-5. Contribution to emissions by vehicle type in GMA, 2005 (UAM,2007).

Finally, in the urban scale, the contribution of the municipalities to total emissions is also analyzed in the local inventory. It can be appreciated that most of the emissions are produced by the municipalities of Guadalajara and Zapopan, followed by Tlaquepaque and Tonalá.

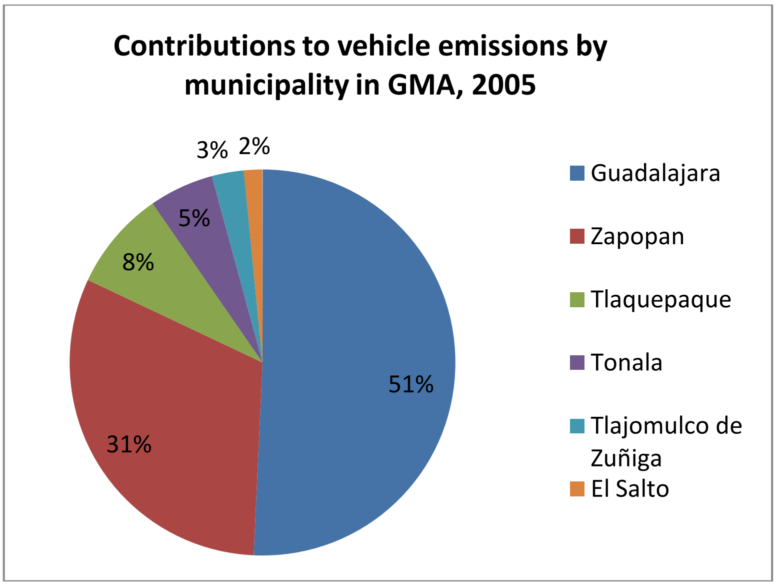

Figure 3.2-6. Contributions to vehicle emissions by municipality (UAM, 2007).

According to the documentation of the EI 2005 for GMA, emissions from motor vehicles were calculated using emission factors for CO, HC and NO_x while a fuel mass balance was used for the SO_x emission estimation.

Emission factors were calculated with the emission factor model Mobile5-Juarez, using an average annual temperature of 21°C, high altitude scenario, and an average speed of 25 km/h.

Emission factors and activity data for the different vehicle classes used for emission estimation in the GMA emission inventory are presented in Table 3.3-1.

Table 3.2-1 Emission and activity factors used for GMA emission inventory, 2005.

Vehicle class	Emission Factors (g/km)			Activity	Fleet
	CO	NO	HC	(km/day)	(vehicles)
Light Duty Gasoline Vehicles	50.2	1.5	5.1	48	887,108
Light Duty Gasoline Trucks	66.2	1.1	10.4	36	296,520
Taxi (LDGV)	50.2	1.5	5.1	110	22,412
Light Duty Diesel Trucks	3.5	1.1	1.9	28	2,000
Urban and suburban buses	41.5	1.1	1.6	375	11,978
Heavy Duty vehicles	8	3	2.3	69	56,866

Finally, emissions per year were obtained assuming that all vehicles are active during each day of the year. In other words, the daily activity is multiplied by 365 and by the amount of vehicles given in the previous table. Contributions of the different municipalities were obtained by multiplying the total amount of emissions by the percentage of the corresponding vehicle population in each municipality.

3.3 OPPORTUNITIES FOR AN ENHANCED RESOLUTION OF EIS IN GMA

Although the national emission inventory uses traffic models for emission estimation, results are then divided by the population of the urban areas where TDMs were available and the emission factor per inhabitant is then extrapolated for other cities of similar characteristics. Results are finally reported in megagrams per year and the higher spatial resolution is by municipality. The Mexico National Emissions Inventory (MNEI) recognizes that additional collection and development of travel demand models, vehicle registration data, and fuel statistics among other vehicle related data can be used to improve the overall results of further emission inventories (ERG, 2006).

As is evident from the report, for the local inventory both calculation and results lack sufficient spatial and temporal resolution for the design of effective measures against pollution. In the report document the necessity of more exhaustive studies, the systematization of the procedures, and the consideration of previous results in the development of future inventories is also mentioned (UAM, 2007).

Together, transport and environment authorities in GMA have a valuable collection of data that can be used for improving the detail and accuracy of vehicle emission estimates. In Chapter 4, the available data for emission estimation in GMA and the emissions factor model Mobile6-Mexico will be presented. In spite of the model limitations and the limited data availability, it will be proven that it is possible to enhance the spatial resolution down to the street level.

Chapter 4

Available data and methods in GMA

In this chapter link-related information, the emission factor model Mobile6, and the available local data, are described. These are selected available data and methods for link-based emission modeling in GMA. Available local data is mainly used as input data for the emission factor model, while link related information is derived from a TDM.

4.1 LINK-RELATED INFORMATION

Information about traffic volumes and average speed in the transportation network was obtained mainly as an output from a TDM and its calibration.

Unfortunately, at the moment of writing this thesis no documentation on the development nor the calibration of the model was available. Therefore, the methodology and assumptions made in order to run the transportation model are unknown. However, valuable data and recommendations were provided by personnel of AU Consultores during field work and interviews which made it possible to use the output from the TDM for emission estimation in GMA.

4.1.1 OUTPUT FROM TRAVEL DEMAND MODEL

The TDM was developed by AU Consultores, as required by the Transport Research Center of the State of Jalisco (CEIT).

The transport model was done with the travel demand software VISUM. This modeling software generates a database with detailed information of the links that can be used with spreadsheets such as Microsoft Excel. Later in this document, references to this database will be made as the *transport network database* or TND.

The TND contains information of 11,049 street segments in both directions (22,098 links) and it covers the GMA area and surroundings with a radius of about 50 to 80 km. It is divided in 471 microzones and has a sub-categorization of roads in 40 types of which 27 are considered urban roads. In Table 4.1-1 more details about the transport network are provided.

Table 4.1-1. Characteristics of the transport network given by the TDM.

Characteristics	Total network	Urban Network
Number of links	22098	20510
Link types	40	27
Length (km)	4.90E+03	2.25E+03
VKT (day)	1.30E+06	1.04E+06
Average Speed (km/h)	36.2	33.2

Each individual link contains, among other parameters, the following attributes: number of the link, road type, name, length (km), volume of vehicles per day, link capacity, average speed, and speed limits (km/h). The values of link attributes are stored in cells of the database. Each of the different attributes occupies an individual column, while attributes of the same link share the same row. Annex A contains an extract of the database to illustrate its structure.

4.1.2 TRAFFIC COUNTS

The model was calibrated using 100 traffic counts all over the urban area during two consecutive weekdays between Tuesday and Thursday in January, 2008. The location of the traffic counts over the urban network is shown in Figure 4.1-1.

Vehicle volumes are reported every hour for every traffic count and also differentiate between three vehicles groups, namely, A for passenger cars and light duty vehicles; B for buses, and C for heavy duty vehicles.

The volume shares of the three vehicle groups by road type are based on observations made during the 100 traffic counts. Appropriated shares according to the road type were provided by AU-Consultores. The list of shares is given in Annex B.

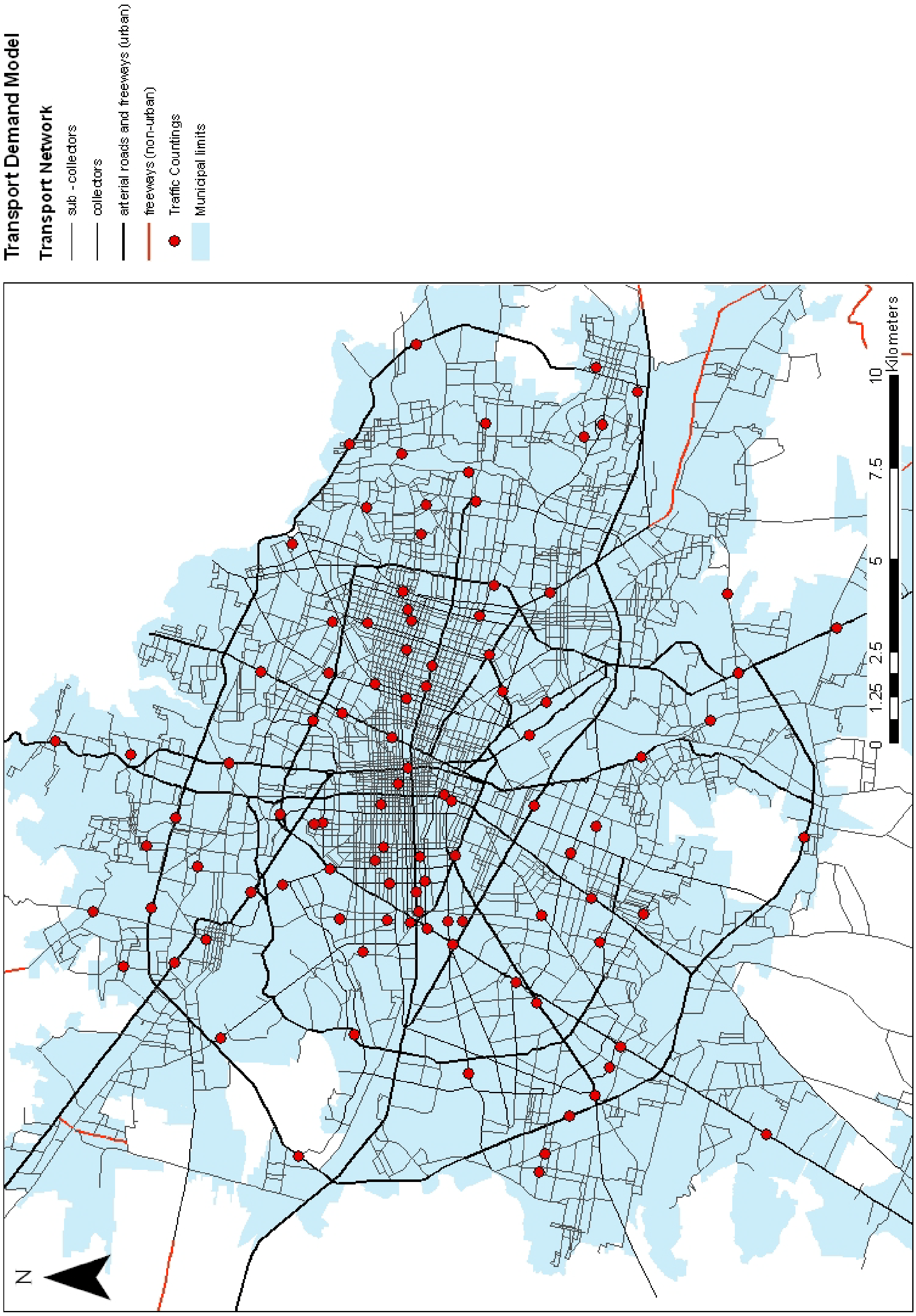

Figure 4.1-1 Transport network given by the TDM and location of traffic counts.

4.2 GEOGRAPHICAL INFORMATION AND STATISTICS

The transport network was exported as a shapefile from the travel demand software VISUM. The shapefile (geospatial vector data) provides the geographic allocation of links and related information contained in the attribute table.

An additional polygon shapefile with statistic information about GMA was provided by CEIT. The polygons represent areas used for statistical analysis by the National Institute of Geography and Statistics. Those areas are called AGEBs from its Spanish acronym of Basic Geostatistic Area.

Both shapefiles will be used later to geographically allocate the estimations of emissions per link and small analysis areas.

4.3 EMISSION FACTOR MODEL: MOBILE6-MEXICO

MOBILE6-Mexico is an adapted version of MOBILE6 especially designed to calculate emission factors within the Mexican territory. As documentation on the Mexican version is restricted to the modifications made for its adaptation, the next subchapters will first describe the general capabilities of MOBILE6. Thereafter, the specific characteristics of the adapted version will be explained.

In general, it is considered that the model can be used to estimate emission factors for any calendar year between 1952 and 2050. Its use is appropriate for the estimation of emission factors of gasoline and diesel vehicles anywhere in Mexico. (ERG, 2003)

4.3.1 GENERAL CAPABILITIES

MOBILE6 is an emission factor model developed by the Environmental Protection Agency of the United States to calculate average fleet emissions factors for HC, CO, NO_x, exhaust particulate matter (which consists of several components), tire wear particulate matter, brake wear particulate matter, sulfur dioxide (SO_2), ammonia (NH_3), six hazardous air pollutant (HAP), and carbon dioxide (CO_2) emission factors for gasoline-fueled and diesel highway motor vehicles, and for certain specialized vehicles such as natural-gas-fueled or electric vehicles that may replace them (EPA, 2003).

4.3.2 VEHICLE AND ROAD CLASSIFICATIONS

MOBILE6 calculates emission factors, VMT fractions, and fuel economy for 28 individual vehicle types. The list of 28 vehicle types is presented in Annex C. The model runs with default or user-specified data to represent local specific conditions.

According to its technical documentation, MOBILE6 provides different emission factors for different facility types, which are based on VKT estimates for different types of roadways. This is to account that the distribution of speeds associated with a particular average speed could be substantially different for different road types. The factors for freeways and arterials are based upon driving cycles developed to reflect specific levels of service (LOS) on these facilities. Although defined in terms of vehicle density, LOS also relates to speed, freedom to maneuver, interruptions, and safety. Four facility types can be explicitly modeled in MOBILE6 which are defined as freeways, arterial or collectors, freeway ramps, and locals (EPA, 1999). Table 4.3-1 presents the general description of these facilities.

Table 4.3-1. Mobile 6 facility types.

Number	Facility type	Description
1	Freeway	High-Speed, Limited-Access Roadways
2	Arterial	Arterial and Collector Roadways
3	Local	Urban Local Roadways
4	Freeway Ramp	Freeway on and off ramps

The calculation procedures are presented in technical reports posted on EPA's MOBILE6 Webpage http://www.epa.gov/otaq/models.htm.

4.3.3 SENSITIVITY ANALYSIS

As explained in section 2.1.4 emissions are influenced by a number of factors. In Mobile 6 many of the factors affecting vehicle emissions can be specified by the user with the use of commands. Some of these factors as well as a brief description of each are presented in Table 4.3-2.

Table 4.3-2. Variables that affect Emission factors in MOBILE6.

Factors	Description
External conditions	Emission factors are corrected for different external conditions such as time frame, altitude, humidity, barometric pressure, cloud cover and sun peak. Ambient temperatures are used to perform temperature corrections to exhaust HC, CO, and NO_x (and indirectly to HC-related air toxics) and some evaporative processes.
Vehicle Fleet characteristics	Vehicle fleet characteristics are used to correct basic emission rates based on the vehicle age, power source, and activity level of the vehicles.
Vehicle activity	The activity commands of the model allow users to allocate vehicle travel by time of day, day of week, type of road, speed, and other factors that affect emissions. Emissions can be modeled for different driving cycles depending on the VMT distribution by facility type and speeds.
Inspection and Maintenance programs	Emission rates can be corrected according to state programs on emission control. State program commands allow users to model the impact of state-specific emission control programs such as inspection and maintenance (I/M) programs and anti-tampering programs.
Fuel characteristics	Fuel commands allow users to model the impact of various gasoline fuel parameters such as sulfur, oxygen content and Reid vapor pressure (RVP) of gasoline, and sulfur content of diesel.

According to a sensitivity analysis the variables that have the most significant effect on emission rates are those related to average speed, fuel Reid vapor pressure, ambient temperatures, vehicle registration distribution and driving cycles. Those variables were found to have relatively large affects on the emission rates. For example, an emissions change-to-input change ratio of one or greater and at least a 20% change in emissions.

Other variables that affect emissions with less impact are humidity, altitude, mileage accumulation, and the number of starts per day. Details on the sensitivity analysis can be found in EPA (2002).

4.3.4 ADAPTATIONS FOR ITS USE IN MEXICO

The model was modified in four major areas: basic emission factors, fuel specifications, fleet age distribution, and driving patterns. Regarding base emission rates, vehicle tests were conducted for older gasoline vehicles while for newer vehicles, similar empirical data from U.S. vehicles was used to develop assumptions about the relative levels of Mexican vehicles compared to those from U.S. Another assumption is that Mexican vehicles will acquire about the same levels of pollution control as U.S. vehicles by the year 2010 (ERG, 2006).

Details on the adaptation of the model and appropriate uses are described in the *Mobile6-Mexico Documentation and User's Guide* provided by ERG (2003).

4.3.5 EXTENSIONS AND DEFAULT DATA TO ADAPT THE MODEL

In order to override some of the original model´s internal data, additional commands were created to represent the Mexican fleet. These new commands are mainly used to set the composition of the fleet according to a number of technology groups, and to set the emissions characteristics for a particular technology group. Table 4.3-3 lists the new commands.

According to the documentation of MOBILE6-Mexico, nearly all of the required input variables can be specified by the user. However, as in the original version, MOBILE6-Mexico contains default data that should be appropriate for emission factor estimation in most areas of the Mexican territory. Default assumptions for fleet demographics were developed using several data sources and detailed information can be found in the documentation of the model (ERG, 2003).

Table 4.3-3. Default data specific for Mexico.

Default data	Name of external file(s)	Description
Vehicle Registration Distribution	Mex_Regdata_1999.dat Mex_Regdata_2001.dat Mex_Regdata_2002.dat	Vehicle registration fractions (fleet demographics) for calendar years 1999, 2000, and 2001. The distributions are split for gasoline and diesel vehicles.
Mileage Accumulation Rates	Mex_MAR.dat	Mileage accumulation rates for 16 vehicle classes are provided with the model. The mileage accumulation rates are differentiated by vehicle age up to 25 years old and are updated to 2003.
Fleet penetration	Mex_P94_Imp.dat	An external data file to model 1994 and later fleet penetration fractions for light-duty gasoline vehicles under the Tier 1, NLEV (or California LEV 1), and Tier 2 emission standard programs is also provided.
Diurnal soak activity	Mex_Diurn_Soak_WeekDay.dat Mex_Diurn_Soak_WeekEnd.dat	Diurnal soak activity for Mexico.
Trip length distributions	Mex_Trip_Leng_WeekDay.dat Mex_Trip_Leng_WeekEnd.dat	Trip length distributions based on data from Aguascalientes vehicle data loggers.
Hot soak activity	Mex_Hot_Soak_WeekDay.dat Mex_Hot_Soak_WeekEnd.dat	Hot soak duration distributions for each of 14 daily periods within Mobile6

4.3.6 LIMITATIONS AND RECOMMENDATIONS

As with any other model, the accuracy of MOBILE6-Mexico results depends on the accuracy of the input data and the correctness of the assumptions made.

One of the biggest limitations of MOBILE6-Mexico is that the Basic Emission Rates are based upon less than 1,000 vehicle emission tests. This was already pointed out in the MNEI: "The basic emission rates contained in the model are based upon fairly limited vehicle testing conducted in Mexico City, Ciudad Juárez, and Aguascalientes. Additional vehicle testing would improve the quality of these basic emission rates." (ERG, 2006).

The other major limitation pertains to the fleet demographics, such as fleet age distributions, vehicle mixes, and diesel fractions. Default data for Mexican Mileage Accumulation Rates (MARs) lack values for vehicle categories from 16-27. According to MOBILE6 user's guide, the model will apply default values for any vehicle type that the user does not specify (EPA, 2003).

From the documentation of MOBILE6-Mexico it is not clear if the lack of these values implies that for the missing categories, data from the U.S. will be used by the model instead. The same applies for diesel fractions, which are not available as external default data.

Given the limitations mentioned above, it is recommended that quality assurance (QA) steps discussed in the *Motor Vehicle Inventory Development Manual* be implemented for the results obtained with the model.

4.4 AVAILABLE LOCAL DATA

Local data is mainly used to feed the model for emission factor estimation. As explained in section 2.1.4, there are many variables that affect emissions, from vehicle characteristics to atmospheric conditions. Although the model can run with default data, it is encouraged to use local data when possible. In this section local data from GMA, as obtained from environmental and transport authorities, is presented. In Chapter 5 the selection and pre-processing of data for its use in vehicle emission estimation will be described.

4.4.1 VEHICLE REGISTRATION AND MILEAGE ACCUMULATION RATES

A complete database with vehicle registration data from Jalisco classified by municipality and mileage accumulation rates were provided by SEMADES.

The vehicle registration database contains registers up to the beginning of 2009. Vehicles are classified into eleven categories and indicate the type of fuel used: gasoline, diesel, natural gas or others. The vehicle classification of this database is similar to that used by MOBILE6.

An additional file with extracted vehicle registration fractions in a format suitable for its use with MOBILE6 was provided. According to this file vehicle categories are equivalent to MOBILE6 categories as indicated in the next table.

Table 4.4-1 Vehicle categories of Jalisco database assigned to Mobile6 categories.

Jalisco Database Vehicle category	Mobile 6 category		Description
LDV	1	LDV	Light Duty Vehicles (passenger cars)
LDT1	2	LDT1	Light-Duty Trucks 2 (0 - 6,000 lbs. GVWR, 3,751-5,760 lbs. LVW[1])
LDT2	3	LDT2	Light-Duty Trucks 3 (6,001 - 8,500 lbs. GVWR, 0 -5,760 lbs. ALVW[2])
LDT3	4	LDT3	Light-Duty Trucks 4 (6,001 - 8,500 lbs. GVWR, 5751 lbs. and greater ALVW)
HDV3B_MICROBUS	7	HDV3	Class 3 Heavy Duty Vehicles (10,001 - 14,000 lbs GVWR)
GREATER THAN 3 TONS	8	HDV4	Class 4 Heavy Duty Vehicles (14,001 - 16,000 lbs GVWR[3])
	9	HDV5	Class 5 Heavy Duty Vehicles (16,001 - 19,500 lbs GVWR)
	10	HDV6	Class 6 Heavy Duty Vehicles (19,501 - 26,000 lbs GVWR)
	11	HDV7	Class 7 Heavy Duty Vehicles (26,001 - 33,000 lbs GVWR)
	12	HDV8A	Class 8a Heavy Duty Vehicles (33,001 - 60,000 lbs GVWR)
TRACTO	13	HDV8B	Class 8b Heavy Duty Vehicles (> 60,000 lbs GVWR)
AUTOBUS	14	HDBS	School Buses
	15	HDBT	Transit and Urban Buses
MOTORCYCLES	16	MC	Motorcycles (all)
MINIBUS_HDV_3B		any	
NOT DEFINED		any	

[1] Loaded vehicle weight

[2] Alternative loaded vehicle weight

[3] Gross vehicle weight rating

In this file it was found that:

- Vehicle fractions of categories LDT2 are also assigned to category LDT1 even though there are individual registers for LDT1.
- Vehicle fractions for diesel MINIBUS_HDV_3B are assigned to category HDV3 even though in this file the gasoline fraction has to be reported and not the diesel fraction.
- Vehicle fractions for gasoline AUTOBUS are assigned to categories HDBS and HDBT even though category HDBT is supposed to be all diesel fueled.

Neither documentation about the classification in the Jalisco database nor the assumptions made for the processing of data for use with Mobil6 was provided.

Regarding mileage accumulation rates (MARs), according to the source, this data is based on 2000 surveys from 2008. MARs are reported for 8 vehicle classes without differentiation among years. In general, the MARs provided with MOBILE6 as default data are considered to be more complete (see Table 4.3-3).

4.4.2 LOCAL AMBIENT DATA

Temperatures and relative humidity data were obtained from the meteorological station of JVC center. The values correspond to hourly averages for the year 2005.

Table 4.4-2 Hourly averages of Temperature and Relative Humidity for January, 2005

HOUR	Temperature (°C)	Relative Humidity (%)
0:00	16.2	64
1:00	15.2	67.5
2:00	14.1	70.1
3:00	13.2	73.1
4:00	12.3	75.2
5:00	11.7	76.6
6:00	11.2	77.9
7:00	10.8	78.4
8:00	12.2	71.2
9:00	16.3	56.6
10:00	19.7	47.5
11:00	21.6	42.4

HOUR	Temperature (°C)	Relative Humidity (%)
12:00	23.2	38.1
13:00	24.5	34.6
14:00	25.5	32.7
15:00	26.1	31.2
16:00	26.3	31
17:00	26	33.2
18:00	24.6	38.8
19:00	21.8	47.7
20:00	19.3	53.8
21:00	18.1	56.5
22:00	17.4	58.9
23:00	17	60.7

For further emission inventories, updated values from more meteorological stations may be collected and used instead. Data must represent the specific month of the year, season, or day that is to be modeled.

4.4.3 FUEL DATA

Data about fuel characteristics are given in Mexican Official Norm 086, NOM-086-SEMADES-SENER-SCFI-2005, (DIARIO OFICIAL, 2006). In Table 4.4-3 fuel characteristics valid for GMA are presented.

Table 4.4-3 Fuel characteristics valid for GMA.

Fuel characteristic	Value	Units
Reid Vapor Pressure	7.15	(psi)
Oxygen content of ether blend fuels	0.2	% Weight
Average gasoline sulfur level	300	ppm
Maximum gasoline sulfur level	500	ppm
Maximum diesel sulfur level	500	ppm

Fuel consumption statistics were provided by SEMADES (Parra Romero, 2010) and presented in Table 4.4-4. Data from 2008 will be used later for quality check of vehicle activity obtained from the TDM.

Table 4.4-4 Fuel consumption statistics for GMA.

Fuel type	Fuel consumption in GMA (Liters per year)		
	2007	2008	2009
Gasoline	1,892,087,951	1,979,963,011	1,989,036,313
Diesel	715,214,962	753,118,759	711,080,100

4.5 SCOPE OF THIS WORK

Considering the information presented in this and the two previous chapters, the scope of this work was decided upon three essential questions related to each of the chapters:

- Chapter two: What can be done and what has been done in other urban areas regarding vehicle emission modeling?
- Chapter three: What is more relevant to investigate for the case-study?
- Chapter 4: What is possible to do in GMA given the available data and methods?

The answers to these questions set the scope of this work and are presented in the following subsections.

4.5.1 SPATIAL DOMAIN AND RESOLUTION

As the case study location is GMA and the transport model provides enough information about the urban transport network, the spatial domain is the metropolitan area composed by all its municipalities and where the transportation network is defined as urban by the TDM.

Because the TDM has a very detailed representation of the transport network, it was considered that its use was suitable for link-based emission estimation. The spatial resolution can be set at the link level in order to find streets with high emission levels. Moreover, the results can also be aggregated to smaller analysis areas (AGEBs) in order to consider street density and indentify problem zones.

4.5.2 TEMPORAL DOMAIN AND RESOLUTION

Since the transport model provides activity data on a daily basis, and it was calibrated during two weekdays, the temporal domain is also one day. The data corresponds to 2008 and therefore the emission estimation is referred to this year. Extrapolations of the results to calculate annual emissions are not completely appropriate because emission rates are influenced by the average temperatures which change over the year and vehicle activity which may also change from month to month. Hourly emission estimations are also difficult to make since vehicle activity varies throughout the day. For such resolution, more detailed information on activity data is necessary. The temporal resolution is the same as the temporal domain: one day.

4.5.3 CONSIDERED POLLUTANTS

As carbon monoxide, hydrocarbons and nitrogen oxides are the most relevant pollutants in most urban areas, including GMA and in general the state of Jalisco, these pollutants were considered of interest for this study. Although carbon dioxide was not considered in the local or in the national emission inventory, it was decided to estimate emissions from this gas given the increasing concern of its influence on climate change.

Since MOBILE6-Mexico can calculate emission factors for the above mentioned pollutants, it was decided to estimate their emissions produced by the fleet operating in GMA using this model.

4.5.4 SOURCE DEFINITION AND CATEGORIZATION

Given the definition of mobile sources in section 2.1.1, the emission sources to consider in this work are on-road vehicles. However, for a more detailed identification of contributors, emissions from different vehicle classes have to be calculated separately. Although the emission factor model can distinguish between 28 vehicle classes, the traffic counts used to calibrate the Travel Demand Model only distinguish between 3 vehicle types. Therefore, the resolution of emission sources is limited by the TDM to the vehicles groups: light duty vehicles, buses and heavy duty vehicles with no distinction between gasoline or diesel powered vehicles.

Part II Link based emission modeling in GMA

Chapter 5

Methodology

In Chapter 4 the available local and link-related data as well as the emission factor model selected for emission estimation in GMA was presented. As described in section 4.3, the emission factor model (EFM) has different vehicle and road type classifications than the TDM. In order to calculate emissions per link, an integration of both variables is necessary. This chapter starts with the description of data pre-processing and continues by explaining how emission factors were modeled with MOBILE6.

The central part of the methodology comes with the presentation of equations used in the Transport Network Database (TND) to estimate emissions per link and how the results were analyzed with the use of geographical information systems. Finally, three scenarios of hypothetical traffic conditions used to test the sensibility of the developed methodology to changes in vehicle activity and speeds will be described.

5.1 DATA PRE-PROCESSING: INTEGRATION OF MODELS OUTPUTS

In order to combine the output data from the transport model and the output from the emission factor model, it was necessary to reconcile differences between both sources of data.

From the description of the link related data given in section 4.1 and the description of the capabilities of the EFM in section 4.3, differences among the vehicle and road type classification were recognized. In order to combine both sets of data the following pre-processing was done.

5.1.1 VEHICLE CLASSIFICATION

MOBILE6 estimates emission factors for 28 vehicle categories. However, the transport model only distinguishes between three vehicle groups. MOBILE6 vehicle categories were grouped into the three vehicle groups of the model. In the next table it is shown how MOBILE6 categories were grouped into the three vehicle groups from the TDM.

Table 5.1-1. Mobile 6 Vehicle Categories grouped into three TDM vehicle groups.

TDM Vehicle groups	**Mobile6 Vehicle categories**	
A (passenger cars)	LDGV	Light-Duty Gasoline Vehicles (Passenger Cars)
	LDGT1	Light-Duty Gasoline Trucks 1 (0-6,000 lbs. GVWR, 0-3,750 lbs. LVW)
	LDGT2	Light-Duty Gasoline Trucks 2 (0-6,000 lbs. GVWR, 3,751-5,750 lbs. LVW)
	LDGT3	Light-Duty Gasoline Trucks 3 (6,001-8,500 lbs. GVWR, 0-5,750 lbs. ALVW)
	LDGT4	Light-Duty Gasoline Trucks 4 (6,001-8,500 lbs. GVWR, greater than 5,751 lbs. ALVW)
	LDDV	Light-Duty Diesel Vehicles (Passenger Cars)
	LDDT12	Light-Duty Diesel Trucks 1and 2 (0-6,000 lbs. GVWR)
	LDDT34	Light-Duty Diesel Trucks 3 and 4 (6,001-8,500 lbs. GVWR)
B (Buses)	HDGB	Gasoline Buses (School, Transit and Urban)
	HDDBT	Diesel Transit and Urban Buses
	HDDBS	Diesel School Buses
C (Heavy Duty Vehicles)	HDGV2b	Class 2b Heavy-Duty Gasoline Vehicles (8,501-10,000 lbs. GVWR)
	HDGV3	Class 3 Heavy-Duty Gasoline Vehicles (10,001-14,000 lbs. GVWR)
	HDGV4	Class 4 Heavy-Duty Gasoline Vehicles (14,001-16,000 lbs. GVWR)
	HDGV5	Class 5 Heavy-Duty Gasoline Vehicles (16,001-19,500 lbs. GVWR)
	HDGV6	Class 6 Heavy-Duty Gasoline Vehicles (19,501-26,000 lbs. GVWR)
	HDGV7	Class 7 Heavy-Duty Gasoline Vehicles (26,001-33,000 lbs. GVWR)
	HDGV8a	Class 8a Heavy-Duty Gasoline Vehicles (33,001-60,000 lbs. GVWR)
	HDGV8b	Class 8b Heavy-Duty Gasoline Vehicles (>60,000 lbs. GVWR)
	HDDV2b	Class 2b Heavy-Duty Diesel Vehicles (8,501-10,000 lbs. GVWR)
	HDDV3	Class 3 Heavy-Duty Diesel Vehicles (10,001-14,000 lbs. GVWR)
	HDDV4	Class 4 Heavy-Duty Diesel Vehicles (14,001-16,000 lbs. GVWR)
	HDDV5	Class 5 Heavy-Duty Diesel Vehicles (16,001-19,500 lbs. GVWR)
	HDDV6	Class 6 Heavy-Duty Diesel Vehicles (19,501-26,000 lbs. GVWR)
	HDDV7	Class 7 Heavy-Duty Diesel Vehicles (26,001-33,000 lbs. GVWR)
	HDDV8a	Class 8a Heavy-Duty Diesel Vehicles (33,001-60,000 lbs. GVWR)
	HDDV8b	Class 8b Heavy-Duty Diesel Vehicles (>60,000 lbs. GVWR)

As explained before, no documentation of the model was provided and only the general description of the vehicles groups was used to define the groups. As a summary, the previous classification was made as follows:

- Light Duty Vehicle (LDV) and Light Duty Truck (LDT) categories were assigned to vehicle group A.
- Gasoline and Diesel bus categories were assigned to vehicle group B.
- All Heavy Duty Vehicle (HDV) categories were assigned to vehicle group C.

5.1.2 ROAD CLASSIFICATION

The transport model classifies streets into 40 types while MOBILE6 only differentiates between four types of facilities.

According to the technical guidance for MOBILE6, the definition of facility types may vary between users. In order to group functional classes, local terminology is usually accepted as the basis for such grouping. Some caution may be needed in making such assignments, as the principal criteria for the assignment should include vehicle speeds and the nature of traffic control. Ideally, measured speed distributions for each locally defined class of roadways should be compared with the speed distributions of the MOBILE6 driving cycles to select the class that matches best (EPA, 1999).

Some of the MOBILE6 facility characteristics are provided in Table 4.3-1. It is considered that in GMA there are no ramps. Therefore, the 40 road types of the model were grouped into the three first facility types based on the characteristics of the link, number of lanes, and speed limits (in that order) given by the model. In Table 5.1-2 the road classification is presented. Given this classification and with the use of conditional functions, each link in the TND received a MOBILE6 facility type code: 1 for freeways, 2 for arterials and 3 for locals.

Table 5.1-2. Classification of road types given by the TDM into Mobile6 facility types.

ROAD TYPE	TYPE NAME	LANES	SPEED (km/h)	MOBILE6
33	Sub-collectors	1	40	LOCAL
34	Sub-collectors	1	60	
35	Sub-collectors	2	40	
36	Sub-collectors	2	60	
37	Sub-collectors	3	40	
38	Sub-collectors	3	60	
39	Sub-collectors	4	60	
41	collectors	1	60	ARTERIAL
42	collectors (tunnel)	3	40	
43	collectors	1	40	
44	collectors (tunnel)	2	40	
45	collectors	2	60	
46	collectors	3	60	
47	collectors	4	60	
55	Arterial main	6	60	
56	Arterial main (tunnel)	4	60	
57	Arterial main	2	60	
58	Arterial main	3	60	
59	Arterial main	4	60	
62	urban road	5	80	FREEWAY
63	peripheral road	2	80	
64	peripheral road	3	80	
65	peripheral road	4	80	
66	urban road	2	80	
67	urban road	3	60	
68	urban road	3	80	
69	peripheral road	5	80	

In other words, the road types were grouped into MOBILE6 facility types as follows:

- link types 62 to 99 were classified as freeways
- link types 41 to 59 were classified as arterials.
- link types 33 to 39 were classified as locals.

5.2 MODELING EMISSION FACTORS

5.2.1 INPUT DATA

Emission factors were calculated with MOBILE6-Mexico. Most of the local available data presented in section 4.1 was used. However, due to the limitations presented in section 4.4.1 regarding local registration data and mileage accumulation rates, it was decided to use default data instead.

According to the model documentation, both datasets are appropriate for its use within the Mexican territory (ERG, 2003). Nevertheless, as explained in section 38, these two variables have a significant impact on the emission rates and therefore the use of default data is considered an important source of uncertainty on the emission rates for GMA.

5.2.2 INPUT FILE

The model was run with an input file specially designed for the purposes of this work. The input file directs the model to estimate emission factors for TOG´s, CO, NO_x, and CO_2 for three facility types: Freeway, Arterial, and Local. For the first two, 26 speed scenarios were modeled from 2.5 mph to 65 mph in steps of 2.5 mph. For the facility type local, only one speed scenario was possible since MOBILE6 does not allow the user to change the speed for this facility type. Emission factors are reported in grams per mile.

The input file used to model the speed and facility scenarios mentioned above is provided in Annex D .

5.2.3 OUTPUT

The appropriate output format for its use in the following steps is the Spreadsheet Output. This format reports composite emission factors (all emission types) as well as VMT fractions and fuel economy for 28 vehicle classes.

The contribution of each vehicle class to the total VMT is based on vehicle registration data, mileage accumulation rates, calendar year, and other default data. In the current work this contribution will be defined as Fleet VMT (F-VMT)

Extract of the spreadsheet outputs of the four pollutants are presented in Annex E.

5.3 AVERAGE EMISSION FACTORS FOR GROUPS OF VEHICLE CLASSES

Emission factors for the three vehicle groups from the TDM were calculated as a weighted average of individual emission factors of the vehicle classes that belong to each group. In section 5.1.1, it is explained how vehicles classes from MOBILE6 were grouped into the three vehicles groups of the TDM.

The weighting factor is the contribution of each vehicle class to the total travel by the group, defined here as *G-VMT fraction*. Let *n* be the number of vehicle classes that belong to one group, *x* the ID of the vehicle class and *y* the ID of the group; the average emission factor (GEF) of any group can therefore be calculated as follows:

$$\mathbf{GEF_y = \sum_{x=1}^{n} EF_x \cdot G\text{-}VMT_{x,y}} \tag{2}$$

Where $G\text{-}VMT_{x,y}$ is the VMT fraction of the vehicle class *x* that belong to group *y*.

$G\text{-}VMT_{x,y}$ is actually the normalized value of the fleet VMT fraction, that is to say, $F\text{-}VMT_x$ divided by the total travel share accumulated by the group P_y:

$$\boldsymbol{G\text{-}VMT_{x,y} = \frac{F\text{-}VMT_x}{P_y}} \tag{3}$$

The travel share of groups A, B and C are obtained as the sum of *F-VMTx* of the vehicle classes that belong to that group.

In Table 5.3-1 $F\text{-}VMT_x$, as reported by Mobile6, are presented in the first column. The G-VMT values are given in the second column as they were obtained according to (3). Note that the sum of *G-VMT* in every group is 1.This is to show again that *G-VMT's* are normalized values of *F-VMT* by the travel share of the group P_y.

For example, the VMT fraction of LDGV in group A, $G\text{-}VMT_{LDGV,A}$:

$$G\text{-}VMT_{LDGV,A} = \frac{F\text{-}VMT_{LDGV}}{P_A} = \frac{0.3866}{0.8254} = 0.4684$$

Table 5.3-1. F-VMT fractions given by MOBILE6 and calculated G-VMT fractions.

GROUP	Vehicle class	F-VMT	G-VMT
A (passenger cars)	LDGV	0.3866	0.4684
	LDGT1	0.0766	0.0928
	LDGT2	0.2549	0.3088
	LDGT3	0.072	0.0872
	LDGT4	0.0331	0.0401
	LDDV	0.0006	0.0007
	LDDT12	0	0
	LDDT34	0.0016	0.0019
	P_A	0.8254	1
B (buses)	GAS BUS	0.0005	0.0847
	URB BUS	0.0019	0.322
	COM BUS	0.0035	0.5932
	P_B	0.0059	1
C (heavy vehicles)	HDGV2B	0.0208	0.1321
	HDGV3	0.0008	0.0051
	HDGV4	0.0004	0.0025
	HDGV5	0.0009	0.0057
	HDGV6	0.0019	0.0121
	HDGV7	0.0008	0.0051
	HDGV8A	0	0
	HDGV8B	0	0
	HDDV2B	0.0141	0.0895
	HDDV3	0.0038	0.0241
	HDDV4	0.0046	0.0292
	HDDV5	0.0021	0.0133
	HDDV6	0.0103	0.0654
	HDDV7	0.015	0.0952
	HDDV8A	0.0175	0.1111
	HDDV8B	0.0645	0.4095
	P_C	0.1575	1
	MC	0.0111	NOT USED
	TOTAL	1	

The GEFs for each vehicle group, pollutant, speed scenario and facility type were calculated according to (2). Since G-VMTs are dimensionless, the units of GEFs are the same as the units of EF reported by MOBILE6 (grams per mile).

5.3.1 SPEED REGRESSION EQUATIONS AND CONSTANT VALUES FOR DIFFERENT SPEED RANGES

Following the methodology presented in the work of Stein & Walker (2002), the average emission factor for each vehicle group (GEFs) were separately plotted against the speed for each facility type.

For speeds between 5 mph and 65 mph polynomial regressions were obtained. These are called speed regression equations (SREs). Following the procedures of Stein & Walker (2002), the 2.5 mph record was dropped from the regression because its inclusion tended to produce distorted curves. Therefore, for speeds lower than 2.5 mph the emission factors at 2.5 mph were assigned. This is consistent with the MOBILE6 technical guidance on modeling emissions from idling vehicles.

For speeds higher than 65 mph the actual values at 65 mph were assigned in order to avoid uncertainty from extrapolation.

Plots, SREs, and constant values for all pollutants, facility types and vehicle groups are presented in Annex F.

5.4 EMISSIONS PER LINK

Emissions per link were calculated by adding new columns to the TND and performing operations with other attributes of the links contained in cells. In the following text, the equations used for link-based emissions are presented.

Let i be any pollutant of interest, l any link, and y any vehicle group that has a travel share in the link. Emissions of any pollutant in any link $EM_{i,l}$ are calculated as the sum of emissions produced by each vehicle group that has some activity in that link $EM_{i,y,l}$:

$$\boldsymbol{EM_{i,l}} = \sum_{y}^{n} \boldsymbol{EM_{i,y,l}} \tag{4}$$

Emissions of any pollutant from any group in any link $EM_{i,y,l}$ are calculated similarly to equation (1) presented in section 2.2, where the Emission Factor is multiplied with the activity of the vehicle group whenever it has a travel share in that link:

$$\boldsymbol{EM_{i,y,l} = EF_{i,y,l} \cdot VMT_{y,l}} \tag{5}$$

As EFs in MOBILE6 are expressed in grams per mile and activity may be expressed as vehicle miles traveled per day, emissions per link can finally be expressed in grams per day.

5.4.1 EMISSION FACTORS OF ANY VEHICLE GROUP AND ANY LINK

In the transport network database, emission factors for any group and any link $EF_{y,l}$ are obtained through a conditional function that assigns either the constant values or the speed regression equation (SRE) to the link depending on the road type and speed range of the link. The constant values and SREs represent average emission factors at any speed for vehicle groups A, B and C and are presented in the corresponding tables in Annex F. These are also the same factors defined as GEFs in section 5.3.

As an example, the GEF of total organic gases for vehicle group A in any link was obtained using the following conditional function:

```
IF(E2=3,3,IF(P2<2.5,13.47,IF(P2>65,1.98,IF(E2=2,0.0000000039*P2^6 -
0.000000906*P2^5 + 0.0000850405*P2^4 - 0.0040738043*P2^3 +
0.1053318005*P2^2 - 1.4244985551*P2 +
10.5816903254,IF(E2=1,0.0000000041*P2^6 - 0.000000971*P2^5 +
0.0000917331*P2^4 - 0.0044185659*P2^3 + 0.1144269857*P2^2 -
1.5332881326*P2 + 10.942289821,"!")))))
```

In this expression, E2 is the cell with the code of the facility type (1 for freeways, 2 for arterials, 3 for locals). P2 is the cell with the record of speed in miles per hour. Note that the first condition is assigning constant values to facility types local with no dependency on the speed range. The next two conditions assign 13.47 g/mile to any facility of type arterial or freeways that have a speed less than 2.5 mph. A constant value of 1.98 g/mile is assigned to the link if speed is greater than 65 mph. Finally, if the speed is between 2.5 and 65 mph the next two conditions assign the corresponding SRE presented in Annex F. At the end the expression “!” is used to check if all conditions were met or if there was an error in the formula.

5.4.2 VEHICLE ACTIVITY OF ANY GROUP AND ANY LINK

Vehicle activity of any vehicle group and any link is given by the total volume of vehicles reported for that link V_l, the length of the link L_l, and the percentage of the travel share of the group in that link $T_{y,l}$. This is depicted in the following equation:

$$\boldsymbol{VMT_{y,l} = V_{\,l} \cdot L_l \cdot T_{y,l}} \qquad (6)$$

V_l and L_l are given for each link by the TDM and stored in cells of the TND. $T_{y,l}$ was assigned to each link according to the road type as specified in Annex B.

Reverting back to equations (4) and (5), emissions in any link can be obtained by performing the operations among the cells that contain the values of the required variables.

With these steps, the desired spatial resolution was achieved. Results are presented in section 6.3.

5.5 GEO-REFERENCED EMISSIONS

The total emissions obtained with the steps described before were exported to a format suitable for use with geographical information systems (Database IV). This is called the *Emissions Database* (ED) and at a minimum must contain the number of links as an ID attribute, the length of the links, and the total emissions obtained with equation (4).

5.5.1 EMISSIONS PER STREET

The ED was joined to the shapefile that contained the geo-referenced transport network (shapefile exported from VISUM) using the link number. In this way, emissions are now assigned to the link in the network and are geographically allocated.

The level of pollution produced in every link is represented by different colors according to the amount of contaminant released during the temporal domain (one day). However, as every link has a different length, for a correct categorization of emission level the total amounts obtained with equation (4) were first normalized with the length of the link. The units are then in kilograms per day per kilometer (kg/day-km).

Results for all pollutants are presented in section 6.4.

5.5.2 EMISSIONS PER ANALYSIS ZONE AND MUNICIPALITY

Emissions per link were also assigned to AGEBs and municipalities using the *"spatial join"* tool in ArcGIS. The following settings in ArcGIS were used: *Target Features* is the shapefile that contains emissions per link; *Join Features* is the shapefile that contains the areas of AGEBs and municipalities. *Join Operation* must be set to *one-to-one* and the *Match Option* must be *intersect*.

Finally, with the use of the *Summary Statistics* tool, also in ArcGIS, emissions of the links that belong to each AGEB and/or municipality were summed. This tool requires that the shapefile obtained with the spatial join is used as *Input Table*. Any name can be chosen for *Output Table*. *Statistics Fields* are those that contain the total emissions per link and *case field* is the one that contains the identification index for AGEBs and municipalities respectively. Each summary has to be done at once. Results are produced in tables.

For a graphic representation of area emissions, the tables produced by the summary statistics tool have to be joined to the AGEBs shapefile. Since every AGEB has a different size, emissions were normalized with the area. Emissions are then expressed in kilograms per day per square kilometer (kg/day-km^2). Results for all pollutants are presented in section 6.4.

5.6 SENSITIVITY ANALYSIS

The previously described methodology was tested for sensitivity to two variables: speed and traffic volume. These variables can easily be manipulated in the TND. Speeds are used as input to SREs to estimate emission factors. Volumes are used to estimate VMT according to equation (6).

The base scenario uses the data as given by the TDM, which are average values per day. Three additional scenarios were simulated to test how emissions would change if a specific traffic condition would take place in the study area.

It is important to note that such scenarios of traffic conditions are only rough approximations of the changes in speed and volumes that apply to the whole study area. In reality, changes in speed or volume can occur in different links at different times of the day and are influenced by many other factors beyond the scope of this thesis. For hourly emission estimations, the real volumes and speeds for a specific hour of the day at the different links should be used instead.

Assumptions of traffic volumes are based on observations made on the hourly traffic volumes registered by some of the traffic counts, with which the TDM was calibrated. The hourly volumes were expressed as a percentage of the total daily volume. Registers from 17 random traffic records were plotted against the 24 hours of the day.

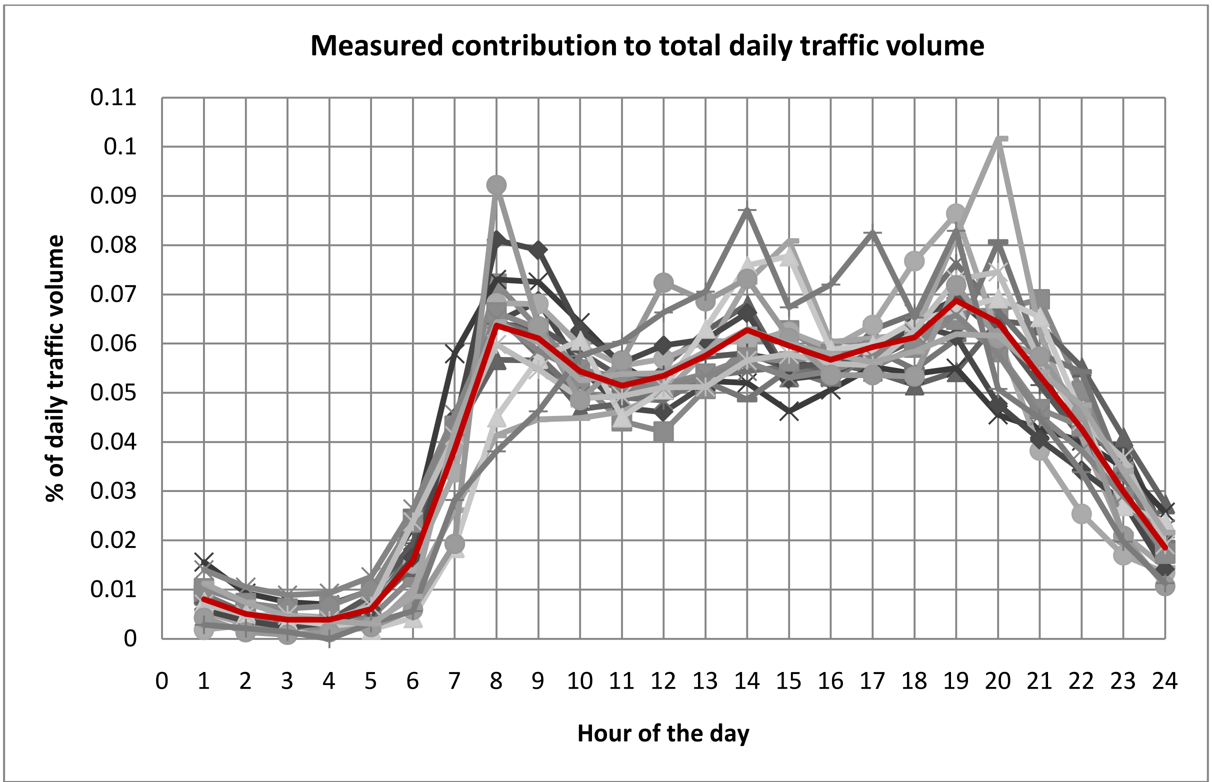

Figure 5.6-1. Percentage of daily traffic volumes observed in 17 traffic counts. Individual traffic counts are represented by grey plots while the average of them is drawn with a red line.

It is observed that for most of the traffic counts, the hours with less traffic are those between 1 and 5 am. The percentage of daily volumes during these hours is below 1%. On the other hand, peaks occur at different hours in the different links. Volume peaks around 7 am, 2 pm and 7 pm are evident for the majority of links. These peaks most likely correspond to commuting trips and school time tables. Between 7 am and 7 pm volumes remain high but vary from link to link. As the volumes peak occurs at different times in different links it was decided to plot the average percentages of the 17 traffic counts. The average values are represented by the red line.

Based on the observation of the average contribution to daily volume during different hours of the day, it was decided to assume the conditions presented in Table 5.6-1 for three hypothetical scenarios.

Table 5.6-1. Assumed speeds and volumes for traffic scenarios.

SCENARIO	Speeds are equal to:	% of total daily volume
Off hour (OH)	Speed limits	1%
Peak hour (PH)	Speeds obtained with BPR method	7%
Average hour (AH)	Daily average speed reported by the TDM	3%

The “off hour” scenario attempts to simulate those hours when the traffic volume is at a minimum e.g. between 1 and 5 am. This scenario assumes a traffic volume that is 1% of the daily volume. Due to the low traffic volumes, speeds at the “off hour” are assumed to be equal to the speed limits.

The “peak hour” scenario works to simulate those hours where the traffic volumes reach a maximum. Based on the average contributions to daily volume it was decided to represent this condition by taking 7% of the total volume. Speeds were calculated using the method of the Bureau of Public Roads (BPR method) as explained in the following subsection.

Finally, the “average hour” scenario assumes a traffic condition between the “off hour” and “peak hour”. Traffic volumes are assumed to be 3% of total daily volume and speeds the same as the average daily speeds.

For a detailed analysis, the methodology presented in this work can be reproduced for smaller areas or specific links where the actual speed and traffic volumes are known at specific times.

5.6.1 BPR METHOD

The BPR (Bureau of Public Roads) method was selected because of its simplicity and based on the recommendations of the technical guidance on development of speed distributions (EPA, 1999) within the context of emission modeling using MOBILE6.

The speed for the peak hour was calculated according to the following equation:

$$s = \frac{s_f}{1 + a\left(\frac{v}{c}\right)^b} \tag{6}$$

where S_f is the free flow speed, v is the volume for the peak hour, c is the hourly capacity, a and b are factors: a is 0.5 for signalized facilities and 0.2 for non-signalized facilities; b is 10.

Speed limits given by the TDM were used as the free flow speed. It was assumed that freeways are non signalized facilities and that arterials and locals are signalized facilities.

Roadway capacity is determined by different factors that affect driving behavior such as lane width, median width, roadway curvature, distance between side streets, etc. As traffic volumes approach roadway capacity, speeds can drop and vehicle densities can increase rapidly (EPA, 1999). Because all the variables that influence the link capacity were not included in the TDM, it was not possible to find an appropriate and available method for its calculation. Therefore, the hourly capacity was obtained by dividing the daily capacity by 18. This is according to the recommendations of the TDM developers (Iñiguez, 2009) and approved by consultants of the Transport Research Center of Jalisco (De la Cruz & López Sales, 2009).

5.7 QUALITY ASSURANCE

Following the recommendation of the technical guidance for emission inventories in Mexico, quality assurance methods were applied to assess the results. According to the manual for motor vehicle emissions inventory in Mexico, the final necessary step in developing accurate and useful emission estimates is to assess the overall accuracy of the estimates.

It is known that the development of independent assessments of the accuracy of vehicle emissions estimations is always difficult because of the large diversity and number of sources as well as differences in spatial and temporal domains. Nevertheless, results must be analyzed in terms of quality and reasonableness. In the manual for motor vehicle estimations in Mexico this is called quality assurance and quality control (QA/QC) review. This review has to be done with as many independent measures as possible because there is not a single measure for QA/QC available yet (Radian International, 1996).

The manual presents specific procedures that can be used to evaluate the accuracy of motor vehicle emission estimates. These procedures include:

- Comparison of emissions versus VKT
- Comparison of motor vehicle emissions to overall emissions inventory
- Comparison of per capita emissions
- Comparison of motor vehicle activity data to fuel consumption statistics
- Use of ambient sampling data
- Remote sensing surveys of exhaust emissions

In Chapter 6, some of these procedures will be used to analyze the results obtained for vehicle emissions in GMA with the developed methodology. Results will be compared to the results of previous emission inventories presented in Chapter 2. The emissions will also be compared with vehicle activity given by the model and check for reasonableness according to the vehicle groups and facility types. The recognized limitations and derived recommendations will be presented later in Chapter 7.

Chapter 6

Results and Analysis

Before presenting the actual results for emissions, other parameters of the transport network are analyzed in terms of the road and vehicle classifications used for emission estimation. This analysis will help later to understand the impact that vehicle activity, speed, and travel shares of the different vehicle groups have on the actual emissions.

The central theme of this chapter deals with the total emission estimates obtained within the TND as explained in Chapter 5. These will be presented and analyzed separately for different facility types and vehicle groups. Additionally, the maps of geo-referenced emissions will help to relate emission levels to vehicle activity levels and speed.

The results of the traffic scenarios are compared in order to assess the sensitivity of the method to changes in speeds and volume on the transportation network. Finally, results are compared to previous emission inventories and the overall accuracy evaluated.

6.1 NETWORK CHARACTERISTICS AND RELATED ACTIVITY

As explained in Chapter 5.1, roads were classified into three facility types and vehicles in three groups for emission estimation. In this section the network characteristics, in terms of those facility types and vehicle groups, are summarized. See Table 6.1-1:

Table 6.1-1. Characteristics of the transport network summarized by facility type and vehicle group.

Facility type	Length (km)	VKT (day)	VMT (day)	VKT/km	VMT (day)		
					LDV	Buses	HDV
Freeway	218	9.97E+06	6.19E+06	4.57E+04	5.68E+06	2.23E+05	2.88E+05
Arterial	801	1.76E+07	1.09E+07	2.20E+04	1.02E+07	3.87E+05	3.81E+05
Local	3481	7.03E+06	4.37E+06	2.02E+03	4.03E+06	1.56E+05	1.78E+05
All facilities	4500	3.46E+07	2.15E+07	7.69E+03	1.99E+07	7.66E+05	8.47E+05

From the previous table, it is observed that activity is not linearly related to the total length of the facilities. Although the actual length of freeways is very small compared to the total length of arterials or locals, most of the activity per km is presented in freeways. Locals have a total length that is 77% of the urban network, while arterials and freeways have only 18% and 5%, respectively. However, the ratio VKT/km shows that freeways have the most activity per length with more than 45,000 VKT per km, followed by arterials with almost 22,000 and finally locals with only 2,020 VKT per km. These ratios are only to show that activity is mainly concentrated in freeways and arterials.

Compared to previous emission inventories, vehicle activity is considered to be reasonable. In Table 6.1-2 a comparison to similar metropolitan areas regarding activity is presented.

Table 6.1-2 Vehicle activity per kilometer in two similar metropolitan areas.

Metropolitan Area	Temporal domain	Population (million inh.)	VKT	VKT/inh.
Monterrey[4]	1999	3.3	30693199	9.4
Guadalajara[5]	2008	4.1	34,601,797	8.4
Guadalajara[6]	2008	4.1	54,399,414	13.3

VKT from fuel consumption statistics was obtained by multiplying the fuel consumption in liters by the fuel economy in kilometers per liter. Fuel economy is given by MOBILE6 for 28 vehicle classes. An average fuel economy for diesel and gasoline was obtained using the given VMT fractions and the fuel economy for each vehicle class and grouped by fuel type.

It is also observed that VKT estimates from fuel consumption statistics are about 60% higher than those obtained from TDM. In general, VKT estimates from TDM are considered more appropriate for emission estimation (Radian International, 1996). However, the comparison to vehicle activity in another urban area of similar size indicates a reasonable estimate.

In the following subsection vehicle activity will be reviewed separately according to facility type and vehicle group.

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[4] Source of data Mexico NEI (ERG, 2006)

[5] VKT estimates from the TDM of AU consultores.

[6] VKT from fuel consumption statistics provided by SEMADES and fuel economies given by MOBILE6

6.1.1 VEHICLE ACTIVITY BY FACILITY TYPE

It was observed that arterials are the facilities with more activity, followed by freeways and then by locals. For a graphic representation, see Figure 6.1-1.

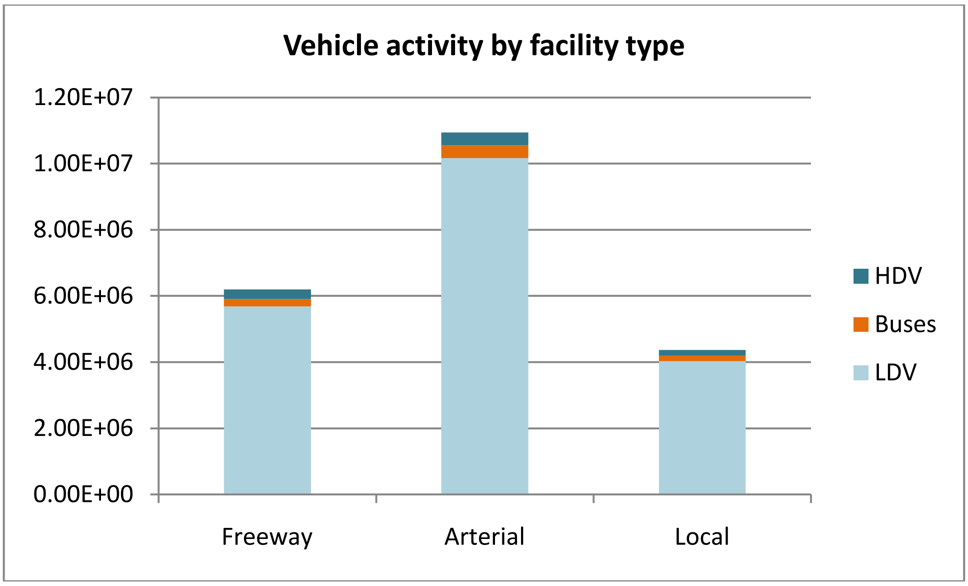

Figure 6.1-1. Contributions to vehicle activity by vehicle groups in different facility types.

It can also be observed that LDVs contribute the most to activity in all facility types. This will be analyzed in more detail in section 6.1.2.

In the next figures, the different facility types in the transport network and associated traffic volumes are represented in two maps.

In Figure 6.1-3 different categories of traffic volumes are presented. It is notorious that high levels of vehicle activity (more than 30,000 vehicles per day) occur in peripheral avenues and main roads classified as freeways and some of the arterials. Medium levels of activity (15,000 to 30,000 vehicles per day) are distributed between arterials and locals, while the lower activity (less than 15,000 vehicles per day) generally occurs only in locals (see Figure 6.1-2).

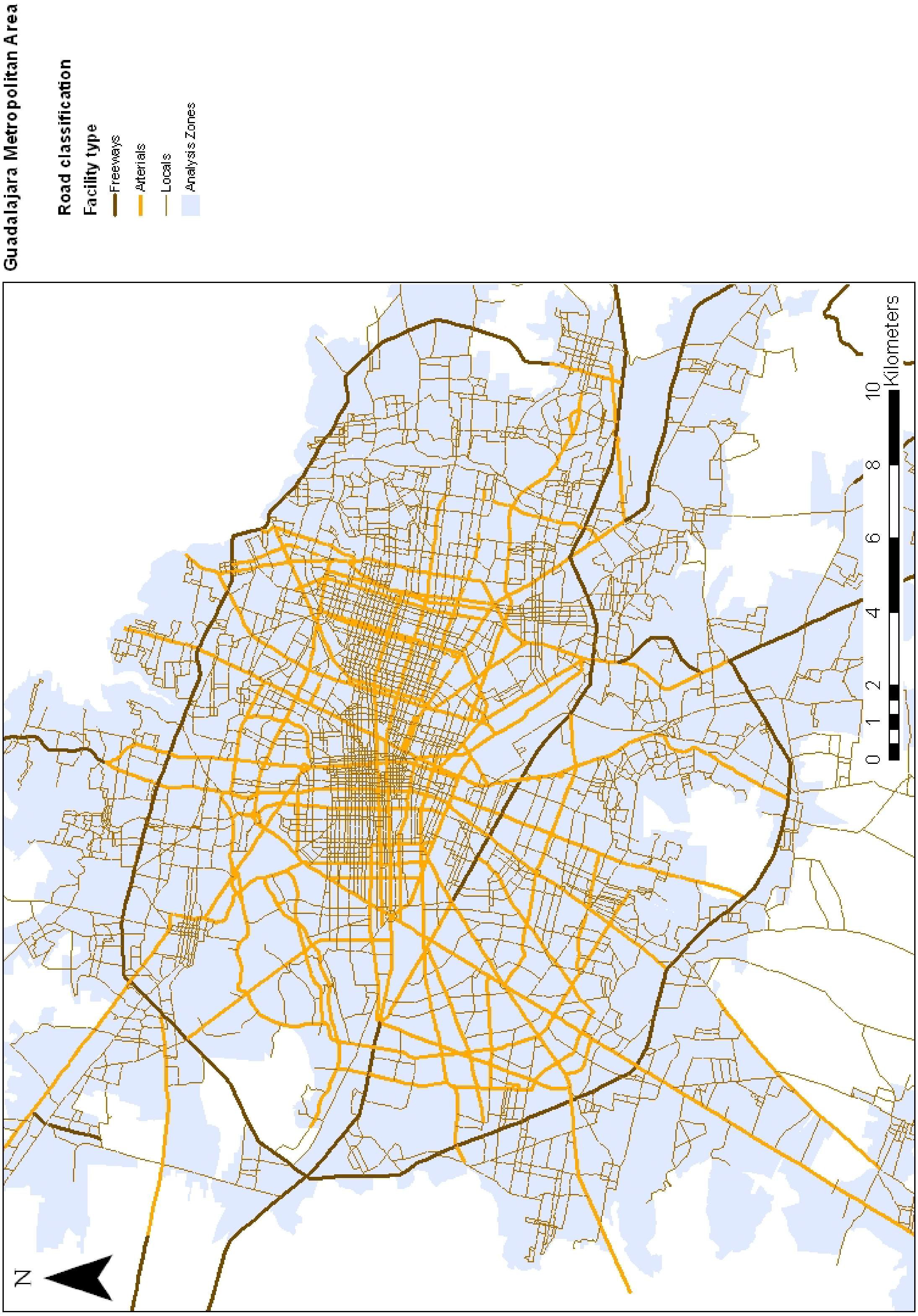

Figure 6.1-2. Transportation network showing the location of different facility types.

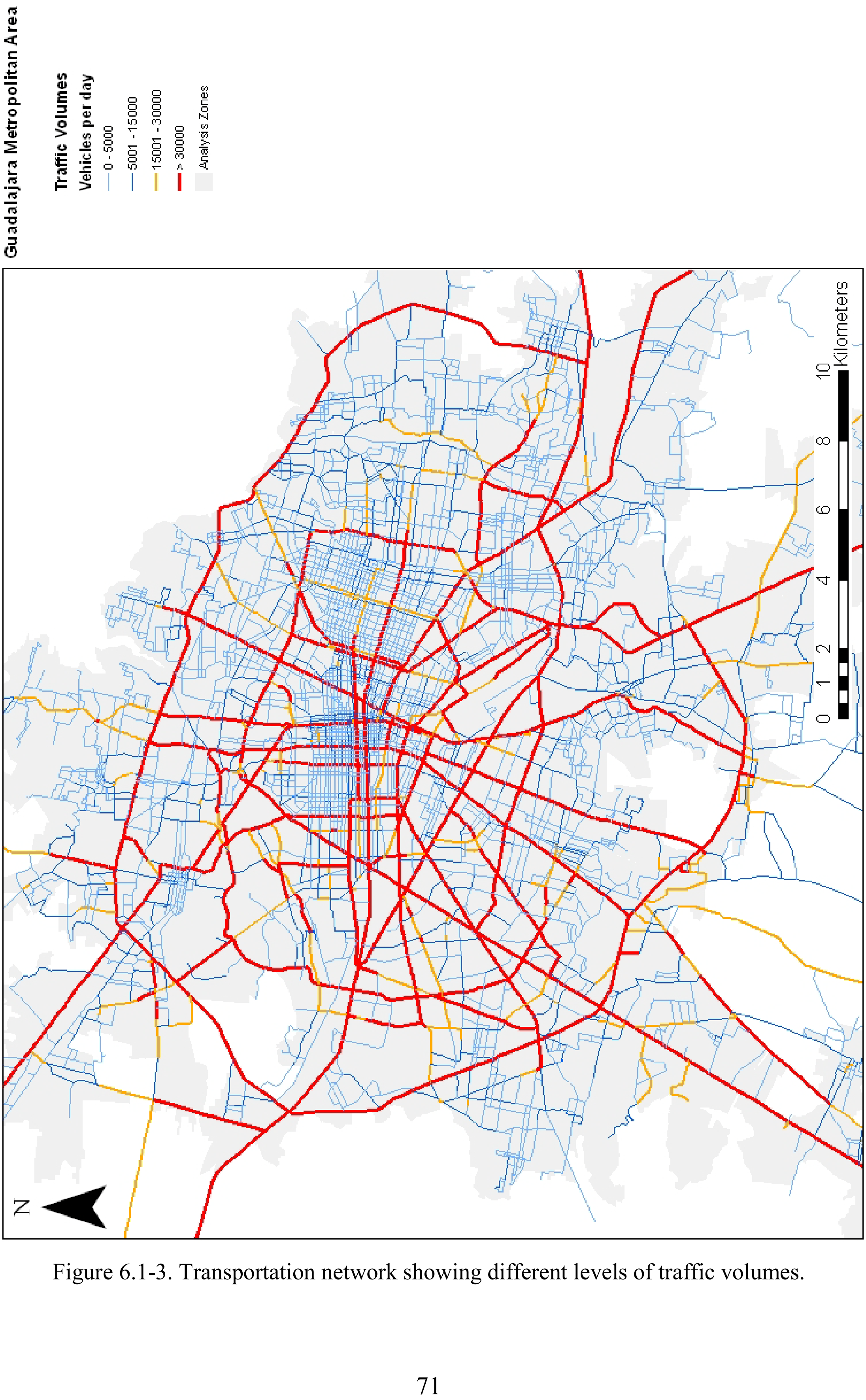

Figure 6.1-3. Transportation network showing different levels of traffic volumes.

6.1.2 VEHICLE MIX BY FACILITY TYPE

From Figure 6.1-1 it was observed that LDVs have the most significant contribution to activity. In Figure 6.1-7 it is evident that vehicle activity of different vehicle groups in different facilities is more or less equally distributed. Regardless of the facility type and leaving the rest of the activity more or less equally distributed between HDV and buses, LDV has the most of activity with more than 90%,.

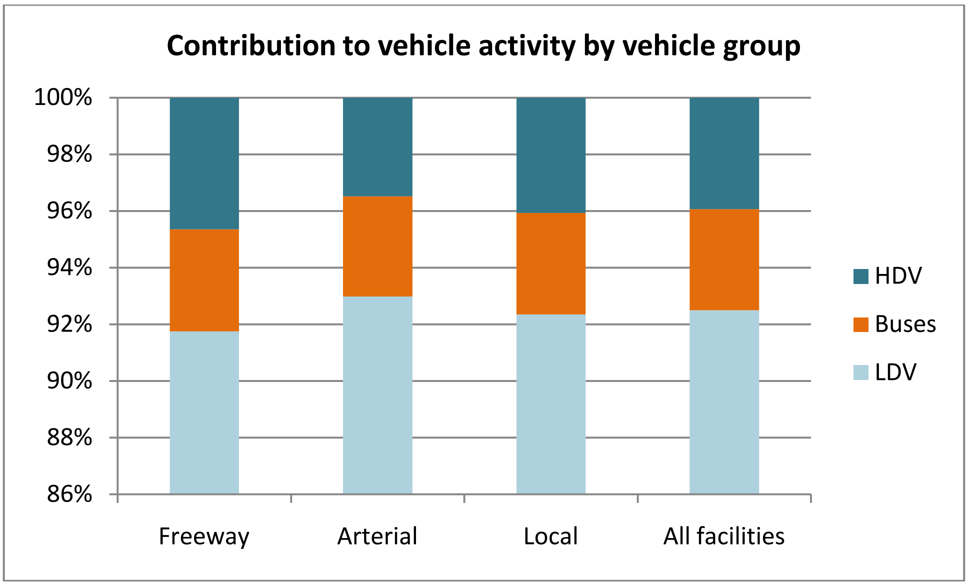

Figure 6.1-4. Contribution to activity by the vehicle groups at the different facilities.

Variations of the vehicle mix are almost indistinguishable among the different facility types, but still it can be seen that there is a slightly larger contribution of HDVs in freeways than in any other facility type.

The activity was also analyzed in terms of its distribution among the different facility types. In Figure 6.1-3 it is observed that 50% of vehicle activity occurs in arterials, while 30% and 20% are performed in freeways and locals, respectively. The high contribution of arterials to activity was also previously observed in Figure 6.1-1.

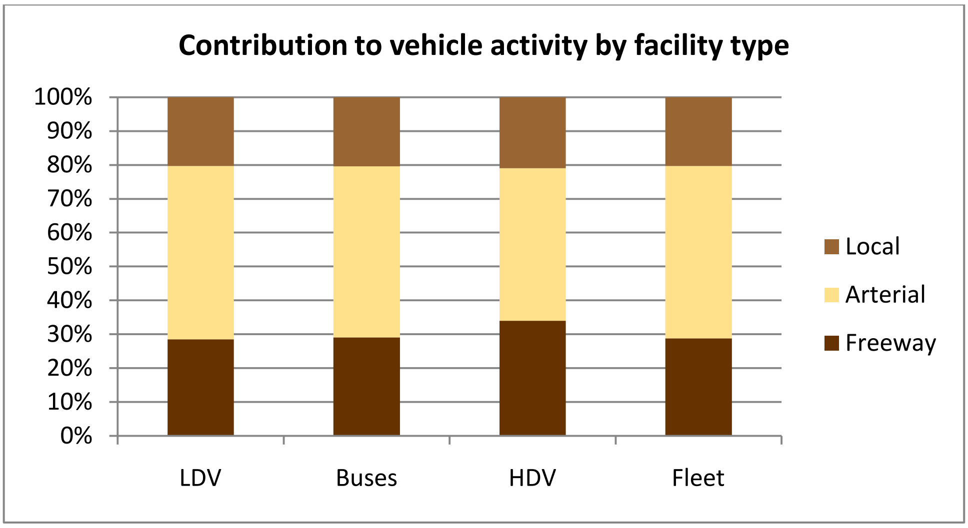

Figure 6.1-5. Contribution to vehicle activity in different facilities by vehicle groups.

It is worth noting that contribution to activity from the different vehicle groups is essentially the same in all facility types. The slightly larger contribution of HDV in freeways, as observed previously in Figure 6.1-4, is again evident. However, it is very close to the average contribution to activity of the entire fleet.

6.1.3 Speeds by Facility

As expected, average speeds are higher on freeways and smaller on arterials and locals, in that order. Daily average speeds for all facility types are slower than the speed limits. The difference is greater on freeways and locals with speeds 38% and 32% slower, respectively. The distribution of average speeds over the transportation network can be seen in Figure 6.1-9.

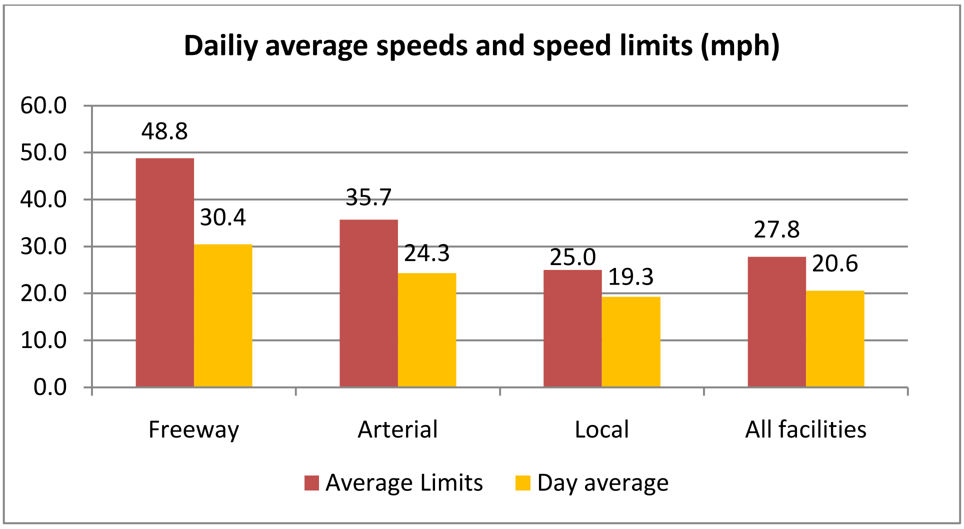

Figure 6.1-6. Average speeds and average speed limits at the different facility types.

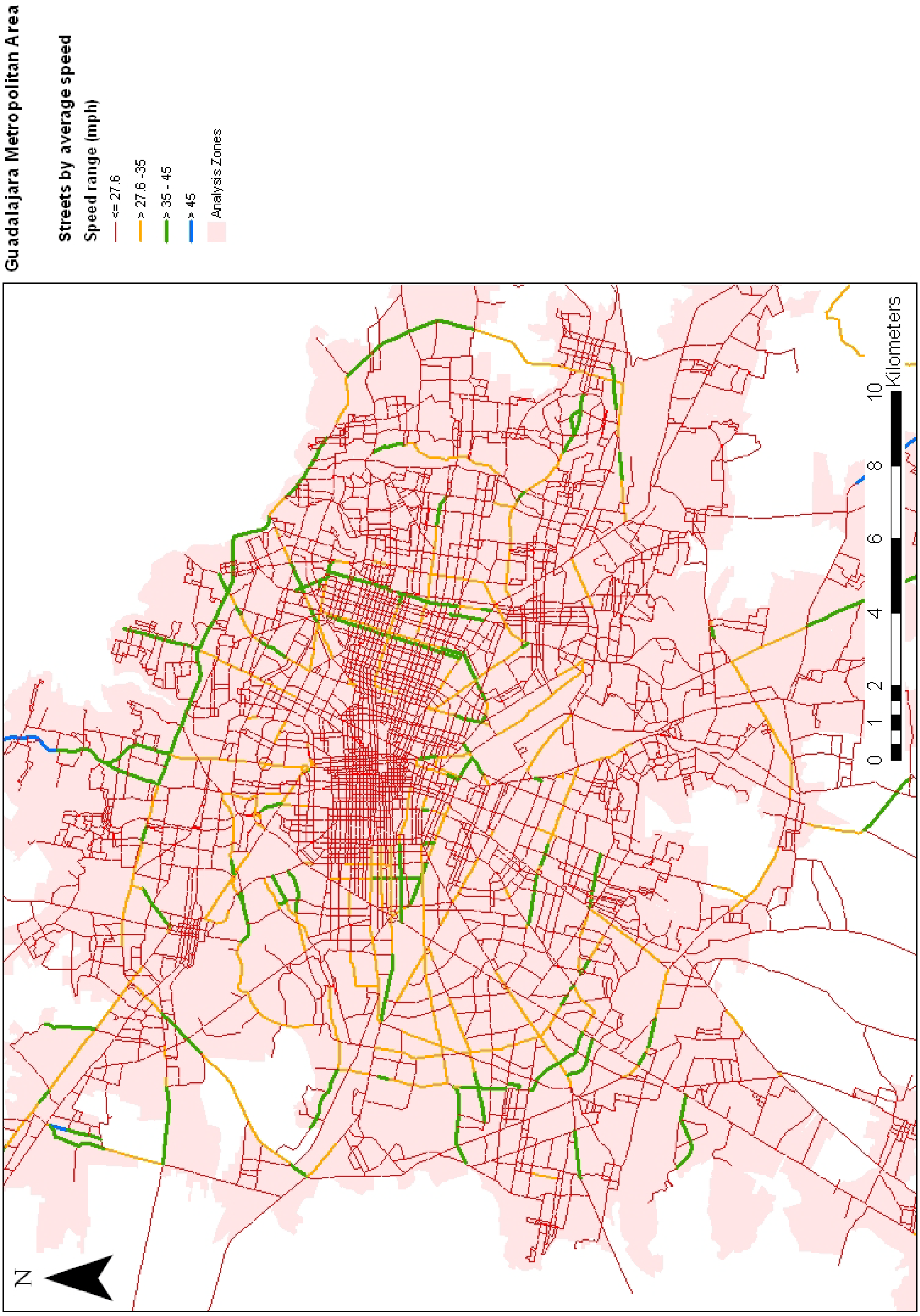

Figure 6.1-7. Representation of speed ranges in the GMA transportation network.

In the map, four speed categories are shown: faster than 45 mph, between 35 and 45mph, between 27.6 and 35 mph and slower than 27.6 mph. This last speed was used as a limit between speed categories because it is the average speed of the driving cycle that MOBILE6 uses for facilities defined as locals.

Only a few roads have speeds higher than 35 mph. The streets with speeds greater than 27.6 mph are peripheral streets or main avenues classified as freeways or arterials. Most of the streets have daily average speeds less than 27.6 mph.

6.2 AVERAGE EMISSION FACTORS

As explained in section 5.3, average emission actors are weighted averages of individual emission factors of vehicle categories of the same group. It was also explained that those individual EFs were calculated for different speed ranges and different facility types. Speed regression equations and constant values are given in Annex F.

The average emission factors were also plotted for different facility types and by vehicle groups for each criteria pollutant. These graphs are given in Annex H. In the following sub-sections the influence of speeds and facility-specific driving cycles on the average emission factors is analyzed.

6.2.1 INFLUENCE OF SPEED AND FACILITY-SPECIFIC DRIVING CYCLES

As shown in Figure 6.1-6, average speeds are lower in locals, increase gradually in arterials, and are higher on freeways.

As explained in section 5.3, emission factors of the different vehicle groups are a function of the speed. In general, EFs are higher for low speeds, decrease gradually as the speed increases, and rise again at very high speeds for some pollutants. Speed-emission curves of the four pollutants of interest are shown in detail in Annex F.

Consequently, emission factors tend to be higher in locals, slightly reduced in arterials, and even lower on freeways (See Annex H).

In general, for CO, NO_x and TOGs, the average of emission factors in local facilities is higher than those in arterial and freeway facilities. This is mainly attributed to the lower speeds presented in locals and higher speeds in arterial and freeways, in that order. In the case of CO_2, there are no differences between facility types because CO_2 emission factors in Mobile6 are independent of speed. Therefore speed in the different facility types does not affect these EFs.

6.2.2 INFLUENCE OF VEHICLE GROUP COMPOSITION

In the case of TOG and CO there is not a large difference between EFs for LDV and EFs for HDV. However differences are much higher in the case of nitrogen oxides and CO_2. This may be due to the weight of the vehicles and the particular combustion process that characterizes each vehicle group.

It can also be observed that EFs for buses are greater than those for LDV and HDV, regardless of the pollutant.

From the speed curves in Annex G it can be seen that for the same vehicle groups, emission factors in arterials and freeways are very similar, and in some cases exactly the same.

6.3 TOTAL EMISSIONS

Total emissions per link were calculated according to the methodology presented in section 5.4. Then emissions were first filtered to obtain only emissions in the urban network, in other words, emissions from links with a road type smaller than 70.

As the TND also contains individual results of emissions per vehicle group, emissions were summarized by vehicle group and facility type using a pivot table in Microsoft Excel.

First, results are presented generally and subsequently, emissions are analyzed separately for vehicle groups and facility types. Emissions are then compared to the previous analysis of vehicle activity and speeds by facility type and vehicle group given in the prior sections of this chapter. This is done for two purposes: to check for reasonableness of the results and to analyze how vehicle activity and speeds affect emissions.

From a general analysis, it was found that the major contributor to emissions in weight is carbon dioxide with more than 95% of total emissions. The rest of the emissions are mainly composed by CO with almost 80% (4% of the total) leaving the remaining 1% more or less equally distributed between NO_x and TOGs. The final results are summarized in Table 6.3-1.

Table 6.3-1. Total Emissions in GMA.

Total emissions		
Pollutant	**Mg/day**	**Mg/year**
TOG	5.76E+01	2.10E+04
CO	4.61E+02	1.68E+05
NO_X	6.33E+01	2.31E+04
CO_2	1.09E+04	3.97E+06
Total	1.15E+04	4.19E+06

Daily emissions are reported here as they were obtained from the TND. The annual values are only a simple extrapolation of the daily value (divided by 1000 and multiplied by 365 to yield Mg/year)

6.3.1 EMISSIONS BY FACILITY TYPE

In this section emissions are analyzed in terms of different facility types that MOBILE6 differentiates between. In Table 6.3-3 emissions produced by the entire fleet without distinction among vehicle groups, are presented by facility types in megagrams per day.

Table 6.3-2. Emissions produced by the fleet in the different facility types. (Mg/day)

Total emissions in (Mg/day)				
Pollutant	**Freeway**	**Arterial**	**Local**	**All facilities**
TOG	16	28	14	58
CO	132	236	92	461
NO_x	19	31	13	63
CO_2	3177	5489	2217	10884
Total	3344	5785	2337	11466

As it is shown in Figure 6.3, the distribution of emissions of all pollutants is more or less the same, regardless of the facility type. The biggest contribution to emissions occurs in arterial facilities with around 50%, leaving 30% and 20% to freeways and locals, respectively.

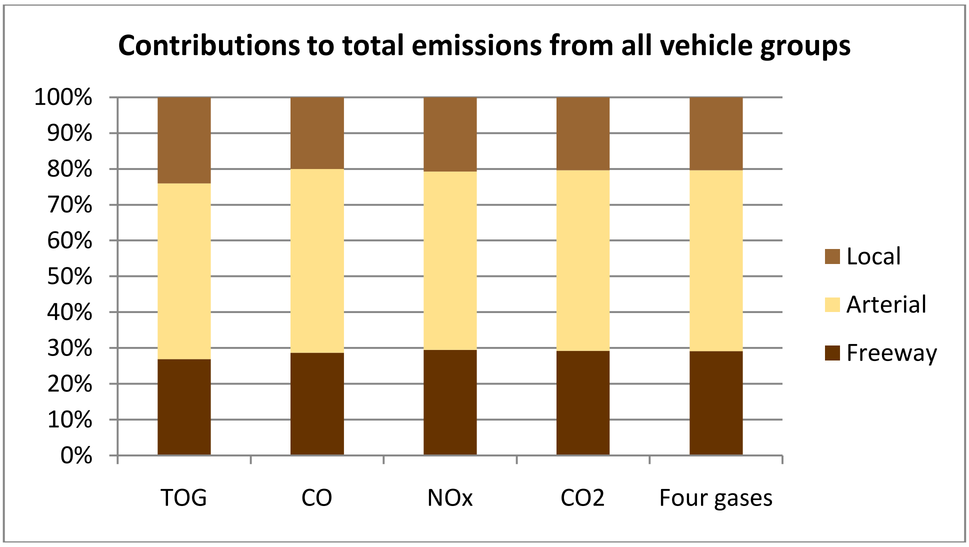

Figure 6.3-1. Contribution to emissions from the fleet by facility type.

This distribution of emissions is much related to the vehicle activity by facility type as it is shown in Figure 6.1-1, where also activity is distributed in the same fashion.

Emissions of the different pollutants are then distributed more or less equally in between the different facilities as is evident in the next graph. In terms of weight, carbon dioxide is the main pollutant with almost 95% of total emissions, followed by carbon monoxide with 4%, and NO_x and TOG with 1%.

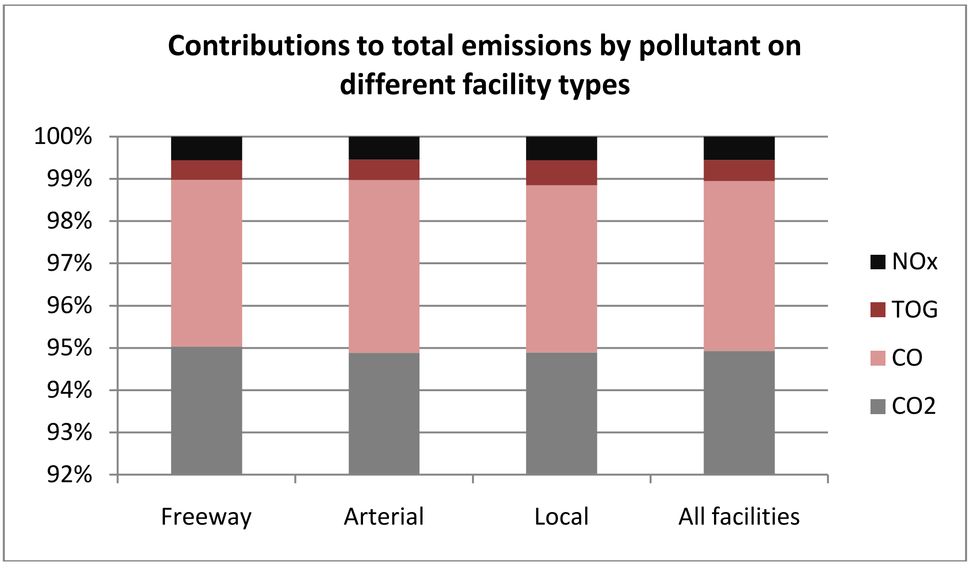

Figure 6.3-2. Contribution to emissions by pollutant on the different facility types.

6.3.2 EMISSIONS BY VEHICLE GROUP

Results per vehicle group show that LDVs are the largest contributor to emissions. In Table 6.3-3 the total emissions produced by the different vehicle groups in the entire network are summarized.

Table 6.3-3. Total emissions produced in the urban network by vehicle groups (Mg /day).

Total emissions (Mg/day)				
POLL	LDV	Buses	HDV	Fleet
TOG	52	3	3	58
CO	416	25	20	461
NOX	40	12	12	63
CO2	8402	1377	1105	10884
4 gases	8909	1418	1139	11466

In the case of CO and TOG, LDVs contribute around 90% of the emissions. In the case of CO_2 and NO_x there is a greater contribution of HDV and buses, with the distribution being more or less equal. However, LDVs are still larger contributors of carbon dioxide (78%) and nitrogen oxide (62%) of total emissions. See Figure 6.3-3

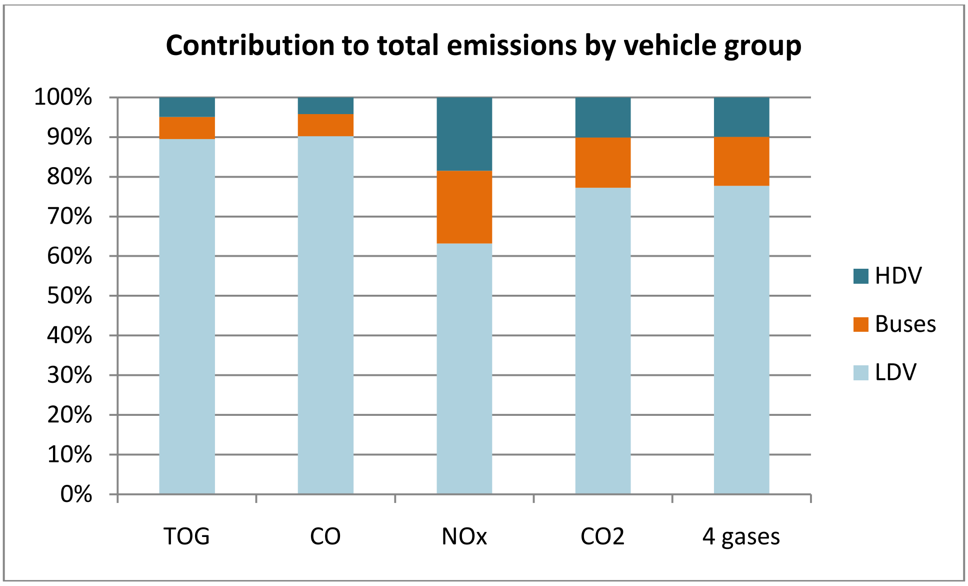

Figure 6.3-3. Contribution to total emissions by vehicle group.

The contribution to emissions by pollutants from the different vehicle groups was also analyzed. In Figure 6.3-4 the contributions to the different pollutants is shown individually for each vehicle group and also for the fleet.

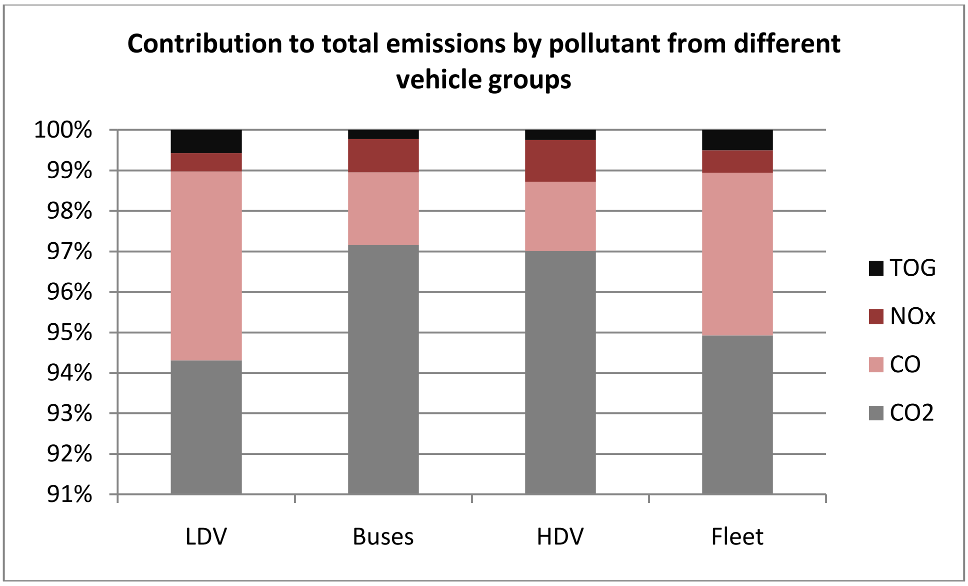

Figure 6.3-4. Contribution to total emissions by pollutant.

Here again it is evident that carbon dioxide is the main contributor, irrespective of vehicle group. Carbon monoxide has important contributions from LDVs. Although HDVs and buses have a stronger contribution to NO_x emissions than to other pollutants, emissions from LDVs are still larger because their activity is also much greater as it can be observed in Figure 6.1-5.

6.3.3 General observations

From the previous analysis it is evident that most of the emissions are produced by LDVs and the most important contributor to emissions is CO_2 followed by CO. The higher emission rates of HDVs and buses compared to LDVs do not have a strong influence over emissions because more than 90% of the activity corresponds to this last vehicle group.

6.4 Spatial disaggregation of emissions

In the next two figures, total emissions per street in GMA urban transportation will be presented, as well as the aggregated results per analysis zone. Separated results for each pollutant are given in Annex H.

Emission levels of the streets are normally high for freeways and arterials. When compared to the map for speeds (Figure 6.1-2) and the one with the traffic volumes (Figure 6.1-3) it is possible to see that high emission levels are more related to high volume levels than to low speeds. For example, those streets with more activity (>30,000 vehicles per day) are in the highest range of emissions per kilometer. On the other hand, if compared to the speed maps, it can be seen that although peripheral streets have higher speeds, emissions on those links are still high. Moreover, even though most of the local streets have average speeds slower than 27.6 mph, emissions are still low.

When looking at the aggregated emission per analysis area, emissions appear to be higher in central zones, even though many links there are in the lower category of emissions per kilometer. This can be attributed to the link density, meaning that the sum of emissions per area is higher. In the same map, the road classification by facility type is also shown. It can be appreciated that many areas with high emission levels lie next to freeways and arterials. This is not always true for freeways in peripheral zones, but again this is related to the low density of links per area.

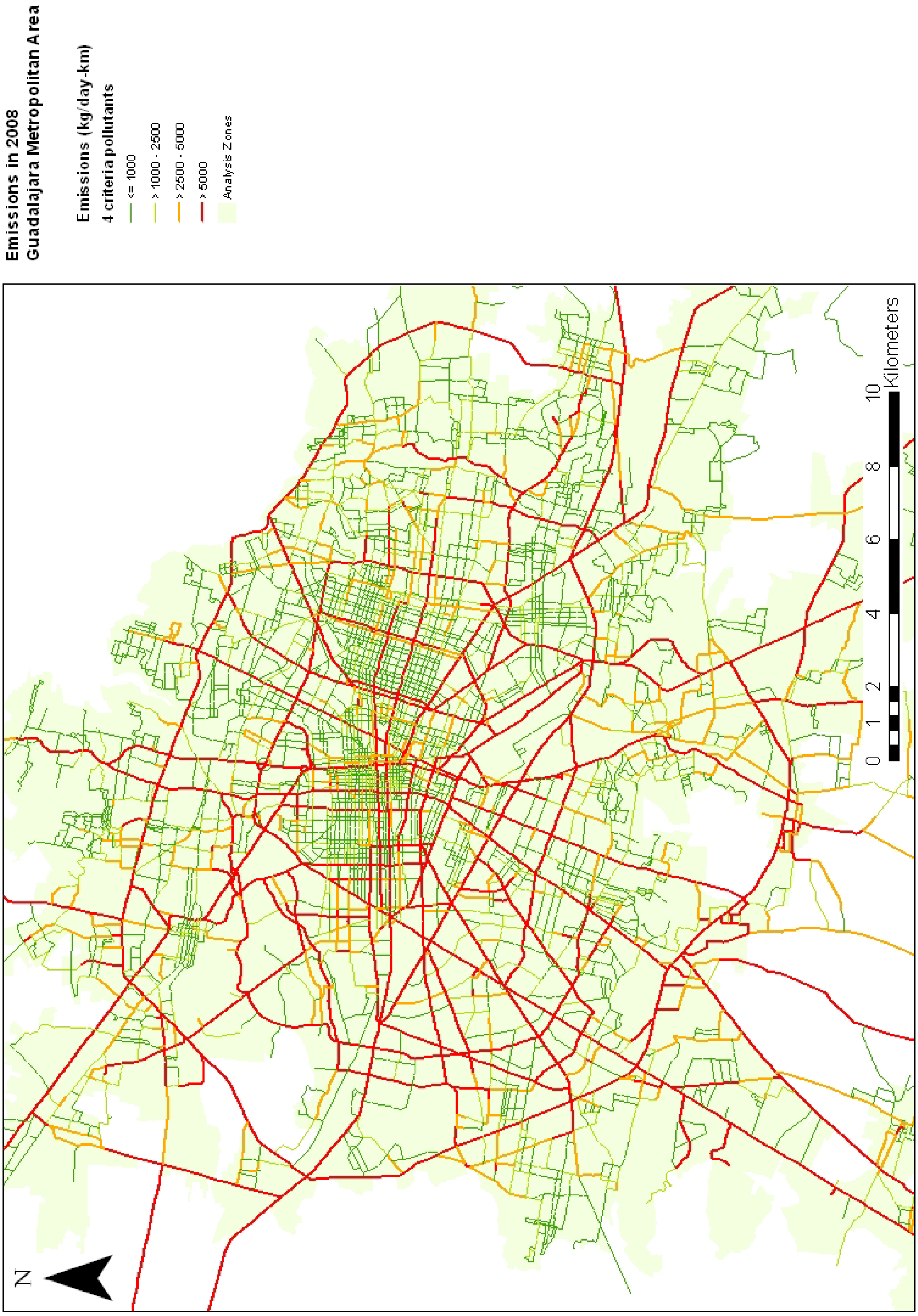

Figure 6.4-1. Different levels of vehicle emissions per link in GMA.

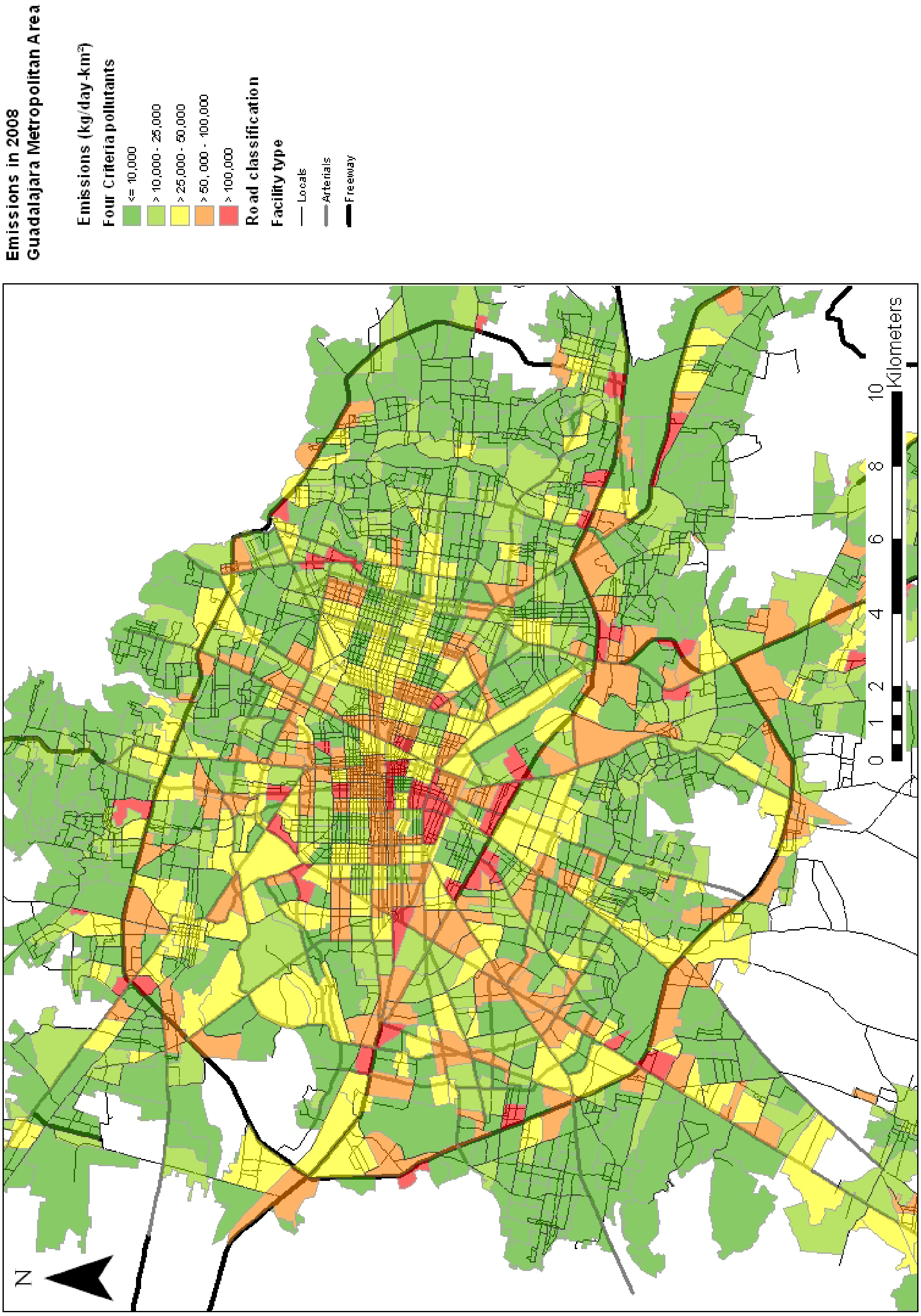

Figure 6.4-2. Different levels of emissions per analysis areas in GMA.

6.5 TRAFFIC SCENARIOS

To start this section, it is important to note again that these "traffic scenarios" are only to assess the sensibility of the methodology to changes in volumes and speeds over the results. The rough assumptions made to represent such scenarios are not based on any traffic engineering analysis. For example, as it was explained in section 5.6, volumes and speeds of all scenarios assume that the traffic condition changes equally in the whole network, which in reality may not happen.

6.5.1 VEHICLE ACTIVITY FOR TRAFFIC SCENARIOS

From the description of the traffic scenarios given in section 5.6, vehicle activity is only a fraction of daily VMT and therefore, the distribution of activity in the different facility types is the same as the distribution of daily activity presented in Figure 6.1-4. The sum of VMT by facility type for each scenario is shown in Figure 6.5-1.

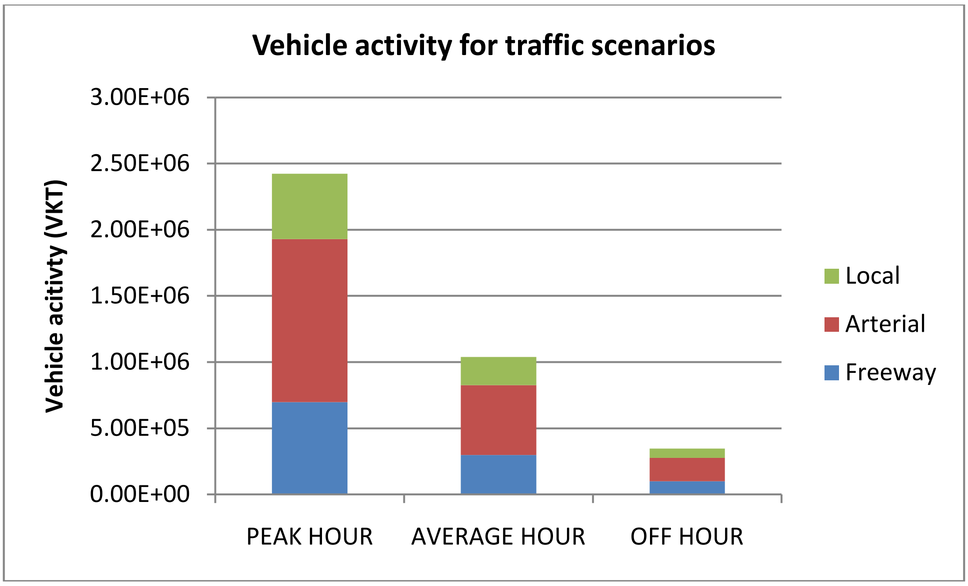

Figure 6.5-1. Vehicle activity for traffic scenarios.

Because the percentages used for these scenarios are 7%, 3% and 1% of daily activity for PH, AH and OH scenarios respectively, it is obvious that activity for the PH scenario is higher than the activity in AH and OH scenarios.

6.5.2 CALCULATED SPEEDS FOR DIFFERENT SCENARIOS

The average values of calculated speeds per facility type are presented in Figure 6.5-1.

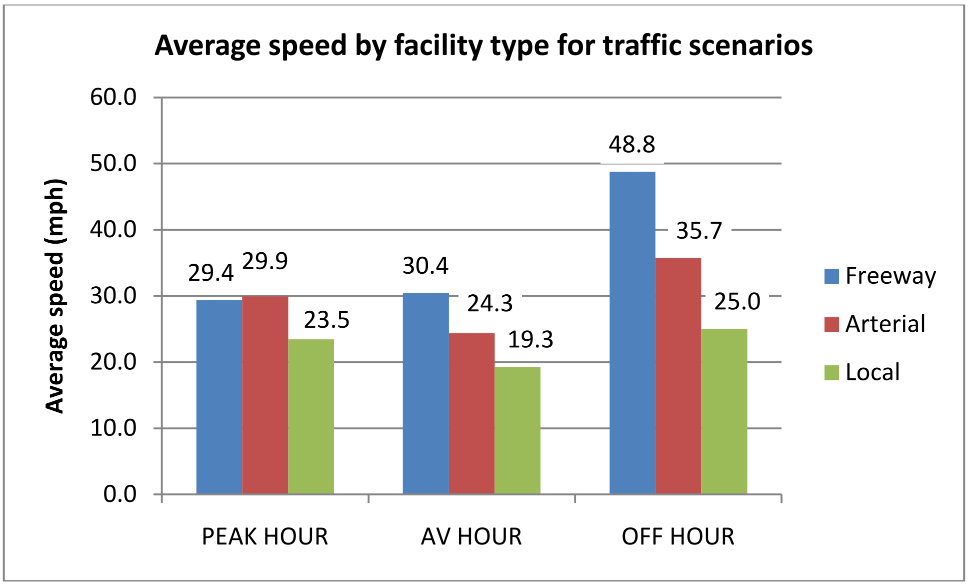

Figure 6.5-2 Average speeds for traffic scenarios by facility type

It is observed that speeds are higher in the "off hour" scenario than the other two scenarios, regardless of the facility type. It can also be observed that there are no significant differences in average speeds between "peak hour" and "average hour" scenarios. Actually, contrary to what was expected, average speeds in arterials and locals are higher for the PH scenario and slightly smaller at freeways.

The reason for higher speeds in the PH scenario compared to the AH scenario may be due to the fact that volumes reported by the TDM in some streets are low. Even when assuming 7% of the daily volume at a particular hour, the level of service of some streets continues to be high. As such, the BPR method can estimate speeds that are even higher than the average speed reported by the TDM when the volume capacity ratio is small.

6.5.3 EMISSIONS FOR DIFFERENT SCENARIOS

In Figure 6.5-3 the emissions estimates for the three speed scenarios are presented.

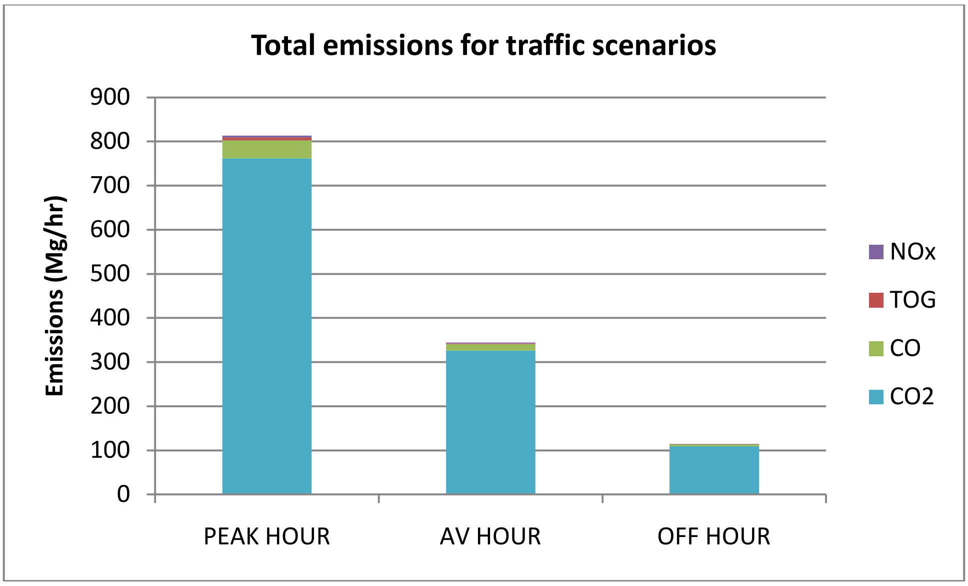

Figure 6.5-3. Total emissions estimates for traffic scenarios.

It can be observed, as expected, that for the total emissions, quantities are higher for the PH scenario followed by AH and OH scenarios. Additionally, it is evident that CO emissions, as was for the base scenario, are higher than those for the other pollutants, which are almost not visible in Figure 6.5-3 .

6.5.4 SENSIBILITY OF THE METHOD TO INPUT VARIABLES

The emission estimation for the three traffic scenarios shows that the model is sensitive to changes in the input variables. However, in section 6.5.2 it was observed that speeds are not very different for PH and AH scenarios. Referring back to section 6.5.1, it can be observed that emissions are strongly influenced by the vehicle activity.

In Table 6.5-1 the contributions to total emissions and activity by facility type show that there is a strong relation between emission estimations and vehicle activity.

Table 6.5-1. Contribution of emissions and vehicle activity by facility type under different traffic scenarios.

	activity	Emissions		
		PH	AH	OH
Freeway	28.81%	29.49%	29.14%	29.21%
Arterial	50.87%	50.11%	50.42%	50.38%
Local	20.32%	20.39%	20.44%	20.42%
All facilities	100.00%	100.00%	100.00%	100.00%

However, if looking in detail, the proportions are not exactly the same. This is also indicative of the influence of changes in speeds.

6.6 COMPARISON TO PREVIOUS INVENTORIES

In Chapter 3, section 3.2, previous emission inventories at the national and urban scales were briefly analyzed as well as the methods used. A comparison of the results obtained with the developed methodology is difficult because of the differences among spatial domains, vehicle classifications, and methods used. In Table 6.6-1 these differences are summarized. Results obtained in this work are referred to as *GMA, 2008*.

Despite the differences, the general numbers were compared in order to prove the reasonableness of the results obtained in this work. In the following subsections comparison among inventories, in terms of total contributions by vehicle groups, some pollutants, and municipalities, will be presented and analyzed.

Table 6.6-1. Comparison of inventory's characteristics.

Inventory characteristics		**INEM, 1999**	**GMA, 2005**	**GMA, 2008**
Temporal Domain		1999	2005	2008
Temporal Resolution		year	year	day
Spatial Domain		Mexico, Jalisco	GMA	GMA
Spatial Resolution	State	yes	no	no
	Municipality	yes	yes (6 municipalities	yes (8 municipalities)
	AGEB	no	no	yes
	Street	no	no	yes
Vehicle classification	HDDV	yes	yes (grouped as HDV)	yes (grouped as HDV)
	HDGV	yes		
	LDGV	yes	yes	yes (grouped as LDV)
	LDGT	yes	yes	
	LDDV	yes	no	
	LDDT	yes	yes	
	Buses	(not explicitly)	yes	yes
	Motorcycles	yes	no	no
	Taxi	no	yes	included in LDV
Pollutants	hydrocabons as VOC	yes (as VOC)	yes (as THC)	yes (as TOGs)
	CO	yes	yes	yes
	NOx	yes	yes	yes
	CO2	no	no	yes
	NH_3	yes	no	no
	PM10	yes	yes	no
	PM2.5	yes	no	no
	SOx	yes	yes	no
Emission factor model		MOBILE6-Mexico	MOBILE5-Juarez	MOBILE6-Mexico

Comparison between inventories is possible for those characteristics in common. For example, in the case of vehicle classes, comparison was done by grouping similar classes into bigger groups as shown in the previous table. Comparison among pollutants was possible only for those that were reported in common.

6.6.1 SIMILAR VEHICLE CLASSES

The individual results per vehicle group and pollutant from all inventories are expressed as percentages of total emissions.

In Table 6.6-1the contribution to total emissions by vehicle group are presented.

Table 6.6-2. Comparison of contribution to total emission by vehicle group.

Contribution to total emissions					
INEM 1999		GMA 2005		GMA 2008	
LDV	83%	LDV	94%	LDV	78%
HDV	16%	Buses	5%	Buses	12%
Others	1%	HDV	1%	HDV	10%

From Table 6.6-2 it is apparent that in all emission inventories, LDVs are reported as the largest contributors to total emissions. Differences may come from different definitions of vehicle sub-categories, methods for estimation, and of course the differences at the spatial and temporal domains. Results for 2008 seem to be reasonable when compared to other inventories.

6.6.2 COMPARABLE POLLUTANTS

Since each inventory considers a different number of criteria pollutants, only those in common are compared. The contributions are normalized to the sum of the three most relevant toxic pollutants: CO, NO_x and hydrocarbons. Important to note is that hydrocarbon emissions are expressed differently for each inventory (see Table 6.6-1). As such, the comparisons are not completely correct.

The contribution to total emissions by pollutant in each inventory is presented below:

Table 6.6-3. Comparison of contribution to total emissions by pollutant.

Pollutant	INEM, 1999	GMA, 2005	GMA, 2008
CO	82%	87%	79%
NO_X	10%	3%	11%
Hydrocarbons	8%	10%	10%

From these analyses, it is possible to identify carbon monoxide as the predominant contributor to emissions. Results for 2008 also seem to be reasonable when compared to other inventories.

A comparison among the total amount of emissions of carbon monoxide and nitrogen oxides in GMA among the two local inventories is presented in Table 6.6-3. Results are compared by municipality.

Table 6.6-4. Comparison of total emissions by vehicle group in two local inventories.

Municipality	**GMA,2005 (Gg/year)**		**GMA, 2008 (Gg/year)**		**Difference with respect to 2005**		**% of 2008 with respect to 2005**	
	CO	**NO_X**	**CO**	**NO_X**	**CO**	**NO_X**	**CO**	**NO_X**
Guadalajara	590.30	17.90	64.85	8.11	-525	-10	-810%	-121%
Zapopan	363.73	11.03	50.60	6.96	-313	-4	-619%	-58%
Tlaquepaque	97.36	2.95	25.84	3.83	-72	1	-277%	23%
Tonalá	62.76	1.90	12.27	1.94	-50	0	-412%	2%
El Salto	18.03	0.55	3.62	0.68	-14	0	-398%	19%
Tlajomulco	31.08	0.94	10.82	1.88	-20	1	-187%	50%
Ixtlahuacán de los M.	n.r.[7]	n.r.	1.46	0.30	-	-	-	-
Juanacatlán	n.r.	n.r.	0.26	0.05	-	-	-	-
other municipalities	n.r.	n.r.	45.67	9.74	-	-	-	-
Total	1,163.3	35.3	215.4 [8]	33.5 [2]	-948	-2	-440%	-5%

It was observed that reported emissions for carbon monoxide in 2008 are much less than those from 2005 with differences up to -440% for the total study area. Results for nitrogen oxides are different for some municipalities; however the total amount has a small error of 5%.

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[7] n.r. means "not reported"

[8] The differences among the quantities presented here and those presented in section 6.3 are because the last were calculated using the TND considering only the urban network while the quantities presented in the previous table are aggregated results for all the streets included in the analysis zones which may contain rural streets as well.

The large differences among the two inventories resulted in the need to refer back to the methods used in each inventory and find out the origin of the discrepancies. In Table 6.6-5, emission factors used for the emission inventory of 2005 are presented. Note that their estimation was done with another version of MOBILE, assuming an average speed of 25 km/h as explained in section 3.2.2. Another difference is that the emission factors for nitrogen oxides in 2005 are only for nitric oxide.

Table 6.6-5. Emission factors used for emission inventory in 2005.

Vehicle class	MOBILE5-Juarez Emission Factors (g/km)		
	CO	NO	HC
Light Duty Gasoline Vehicles	50.2	1.5	5.1
Light Duty Gasoline Trucks	66.2	1.1	10.4
Taxi (LDGV)	50.2	1.5	5.1
Light Duty Diesel Trucks	3.5	1.1	1.9
Urban and suburban buses	41.5	1.1	1.6
Heavy Duty vehicles	8	3	2.3

In Table 6.6-6, averages of the emission factors, as they were calculated in TND, are presented. As explained in section 5.2, these factors were calculated for different speeds and different facility types. Here, the averages of values for the entire network are summarized by vehicle group.

Table 6.6-6. Average of emission factors used for emission inventory in 2008.

Vehicle group	Average of MOBILE6-Mexico emission factors (g/km)		
	CO	NO_X	TOG
LDV	16.8	1.4	2.5
Buses	25.9	10.0	3.2
HDV	17.5	9.0	2.5

Note that the large discrepancy between results is probably related to the difference in the emission factors. For example, emission factors of carbon monoxide for LDV and buses used in 2005 are much higher than those used in 2008.

Nevertheless, for vehicle emission estimations the activity factor also plays a role. In Table 6.6-7 the vehicle activity considered in each emission inventory is presented.

Table 6.6-7 Comparison of vehicle activity data used for local inventories.

Vehicle group	Activity (MVKT/day)		Difference with respect to 2005	% of 2008 respect to 2005
	GMA,2005	GMA, 2008		
LDV	55.78	32.05	-23.73	-74%
Buses	4.49	1.22	-3.27	-267%
HDV	3.92	1.33	-2.59	-195%
TOTAL	64.19	34.60	-29.59	-86%

Note that TDM on the whole calculates a much lower activity for all vehicle groups. In general, TDM has an activity 86% smaller compared to the activity considered in 2005. It is commonly considered that VKT estimated from TDMs is more reliable than values obtained from other sources, such as the estimates from 2005.

6.6.3 GENERAL REMARKS

From the previous analysis it is still difficult to assess the accuracy of the emission estimates, but at least it is possible to find two major similarities:

- Light duty vehicles are the greater contributors to total emissions than other vehicle classes with around 80%
- Carbon monoxide is the main contributor of toxic pollutants with around 80%; the rest vary among inventories.

Chapter 7

Conclusions

In this final chapter the overall results of the developed methodology are evaluated. First, the general evaluation of the results will be presented. Next, a discussion about the limitations encountered during this work will be briefly described and will lead to the recommendations for further development of emission inventories. Finally, the overall assessment of the work, based on the objectives outlined at the beginning, will conclude this thesis.

7.1 EVALUATION OF RESULTS

According to the analysis of results presented in the previous chapter, a strong relationship of vehicle activity to total emissions was observed. On the other hand, the input of speed in TND had less influence on the final estimates.

The comparison to previous inventories was difficult because of their different characteristics. However, general results coincide approximately with the contribution to total emissions by vehicle classes and by pollutant. For instance, LDVs are reported in the different inventories as major contributors to total emissions with around 80%. Moreover, they are also major contributors of carbon monoxide, also with 80% of total emissions.

A sound assessment of overall accuracy of results obtained with the developed methodology was, within the limits of this work, not possible. Although the reasons for the enormous differences among local inventories were identified, it would not be completely correct to state that the emission factors and vehicle activity data used in the previous local inventory are wrong. However, MOBILE6-Mexico is an improved version of the emission factor model and therefore, is considered to have emission factors that are more realistic than those calculated with MOBILE5-Juarez. Also, vehicle activity estimates from TDMs are generally more appropriate than other methods, such as those used for estimates in 2005.

Moreover, the use of TDM allowed for the allocation of emissions over the GMA transportation network. Spatial resolution was then successfully increased to the street level and to smaller analysis zones with the use of geographic information systems. The maps with geo-referenced emissions per link and area for all pollutants show reasonableness and a logical relation to high traffic levels and street density.

The vehicle mixes by road type provided by AU Consultores were also a key factor for increasing the detail of emission estimates within the TND. Thanks to this data, it was possible to obtain emission estimates for three different vehicle groups. This made it possible to identify LDVs as major contributors.

Due to the above mentioned, it is generally considered that emissions obtained with the developed methodology are more accurate than those emission estimates from the previous inventory, but not necessarily the best. Actually, there is still a lot of work to do regarding vehicle emission estimation in GMA. In the next sub-section, the limitations encountered during this work will be mentioned followed by postulated ideas for improvement of further emission inventories.

7.2 LIMITATIONS

One of the biggest limitations for accurate estimates is the availability of local data. According to the documentation of MOBILE6-Mexico, the emission factor model is based on limited vehicle tests. Furthermore, according to personal observations, the model still relies on default data from the U.S. In this sense, a greater quantity as well as updated default data for Mexico is necessary in order to obtain more realistic emission factors, VMT distributions, and fuel economy rates.

Apart from improving the model itself, local input data has to be improved and developed for GMA. Improvements should be made, especially for vehicle registration data and mileage accumulation rates because emission factors in MOBILE6 are highly influenced by these variables. The vehicle registration database provided by SEMADES is very suitable for its use with MOBILE6. Only the vehicle classification for LDTs and buses has to be reviewed and updated.

Another limitation is the limited traffic engineering knowledge of the author. The use of a TDM and related data, for instance, was limited to brief training on the travel modeling software and data processing. From the same weakness other limitations are derived. For example, the integration of TDM and EFM, that is to say, the road and vehicle classifications are based on assumptions made with a limited background of traffic engineering.

7.3 OPPORTUNITIES

The developed methodology allows for the use of the emission factors of other pollutants. Whether they come from MOBILE6 or not, emission factors for particles, SO_x and other pollutants can easily be introduced into TND either as constant values or as functions of speed. Then, combined with vehicle activity data, it is possible to estimate total emissions of other pollutants.

Furthermore, TND allows for the estimation of hourly emissions if adequate traffic volumes and speeds are assigned to each link for the hour of interest. MOBILE6 can also estimate emission factors at different hours if appropriate input data are available.

The contribution of more vehicle classes per link can be evaluated if the vehicle mix per link is given.

The methodology can be used for estimation of fuel consumption on a link basis. Fuel economy rates per vehicle class can be obtained with MOBILE6-Mexico and then the same procedure as with emission factors can be done for estimation of fuel consumption by vehicle groups with a share on vehicle activity per link.

Increasing the accuracy as well as spatial and temporal resolution of emission estimates with the use of better data, can potentially allow for the use of emission estimates as input to air quality and photochemical models.

7.4 RECOMMENDATIONS

Given the existing opportunities for improvement of vehicle emission estimation in GMA and considering the existing limits, some recommendations can be provided for future emission inventory developers and further research.

The dynamic approach proposed by Capiello (2002) is still difficult. As such, it is probably better to focus on improving the static approach before moving to something more complicated that requires more computational resources and technical skills. In general, the static approach is still used even in the developed world with good results and therefore, it is considered to be satisfactory for vehicle emission estimation in GMA.

The integration of models (EFM and TDM) must be reviewed by local transport authorities in order to assure a correct vehicle and road classification.

The emission factor model can be improved upon, either as an updated version of MOBILE6-Mexico or perhaps by adapting the new EPA model, MOVES2010. The use of other models for developing countries such as IVE is also possible, but must be proven for a correct representation of the Mexican fleet. A development of a new model for Mexico is considered difficult, but not impossible.

Local data must be updated and reviewed. For instance, data pertaining to the fleet characteristics can be improved upon by reviewing the vehicle classification and generating local diesel fractions as input to MOBILE6-Mexico. Fleet activity and deterioration rates should also be updated and increased in detail. Data regarding inspection and maintenance programs as well as fleet penetration will be an important input for more realistic estimates.

Although vehicle data from TDM is considered to be sufficient, more traffic measurements and fuel consumption statistics should be used to corroborate this data.

Local ambient data should be obtained from more meteorological stations and represent more accurately the month or hour that is to be modeled.

A programming software such as Matlab would be useful to faster perform some of the steps in emission estimation, especially the operations in the TND and the transfer of data between the emission factor model and the TND.

7.5 OVERALL ASSESSMENT

In relation to the objectives set at the beginning of this work and based on the analysis of the results presented in the previous chapter, it is possible to conclude that:

- The spatial resolution was successfully increased to the street level and to smaller analysis zones. It is considered that the developed methodology can be used for the design of technical solutions and policy making by identifying problem zones and streets with higher pollution levels. However, as the accuracy is limited, a detailed analysis has to be done in smaller areas with better data.

- In general, the use of databases is considered to be technically available and does not require excessive training. The developed methodology, until TND, is easy to reproduce by local authorities with available data and affordable methods. The detailed description given in the methodology chapter should be enough for reproduction of this work in further emission estimates. The use of geographic information systems requires, on the other hand, software that is less available as well as more technical skills.

- The methodology is considered to be flexible and well documented. The sources given in this work and the annexes should be enough for its reproduction and further improvement. Moreover, the methodology can be used to estimate emissions of other pollutants independently, whether or not emission factors are from MOBILE6. That means that the same methodology can be used outside of Mexico whenever a traffic model exits. The simplicity in evaluating the contribution of more vehicle classes, and specific traffic situations when proper data is available proves the flexibility of the methodology for further improvement.

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Annexes

Annex A Extract of the Transport Network Database

LINK_NO	TYPENO	LENGTH	NUMLANES	CAPPRT	V0PRT	VOLVEHPRT(AH)	VC_RATIO	VEHKMTRAVPRT	VCUR_KMH	VCUR_MPH	VKT
5	35	0.578	2	18000	40	8899	49	5143445	34	21.1276	5143.622
5	35	0.578	2	18000	40	9676	54	5592215	32	19.8848	5592.728
7	59	0.299	4	60000	60	61176	102	18314438	26	16.1564	18291.62
7	59	0.299	4	60000	60	61473	102	18403315	26	16.1564	18380.43
10	68	0.893	3	58000	80	54251	94	48450202	51	31.6914	48446.14
10	68	0.893	3	58000	80	68485	118	61162342	37	22.9918	61157.11
12	59	0.325	4	60000	60	33371	56	10843725	50	31.07	10845.58
12	59	0.325	4	60000	60	34509	58	11213551	49	30.4486	11215.43
19	66	0.118	2	30000	80	8826	29	1037584	79	49.0906	1041.468
19	66	0.118	2	30000	80	8288	28	974311	79	49.0906	977.984
21	47	0.243	2	24000	60	8584	36	2089541	56	34.7984	2085.912
21	47	0.243	2	24000	60	13164	55	3204341	47	29.2058	3198.852
27	64	0.541	3	58000	80	38641	67	20891933	62	38.5268	20904.78
27	64	0.541	3	58000	80	57710	99	31202214	40	24.856	31221.11
28	64	0.302	3	58000	80	49816	86	15028436	49	30.4486	15044.43
28	64	0.302	3	58000	80	56418	97	17020174	42	26.0988	17038.24
31	64	0.267	3	58000	80	39771	69	10619400	60	37.284	10618.86
31	64	0.267	3	58000	80	61312	106	16371085	37	22.9918	16370.3
32	64	0.437	3	58000	80	35623	61	15572932	65	40.391	15567.25
32	64	0.437	3	58000	80	43687	75	19097890	56	34.7984	19091.22
34	64	0.756	3	58000	80	59131	102	44673403	39	24.2346	44703.04
34	64	0.756	3	58000	80	56844	98	42945881	41	25.4774	42974.06
35	64	0.276	3	58000	80	63073	109	17417638	35	21.749	17408.15
35	64	0.276	3	58000	80	64251	111	17742758	34	21.1276	17733.28
39	64	0.368	3	58000	80	60168	104	22144355	38	23.6132	22141.82

Annex B Travel shares of TDM vehicle groups by road type

road type	Vehicle group		
	A	B	C
33	0.925	0.042	0.033
34	0.933	0.047	0.021
35	0.957	0.021	0.022
36	0.973	0.005	0.023
37	0.923	0.041	0.036
38	0.953	0.028	0.018
39	0.962	0.026	0.012
41	0.933	0.047	0.021
43	0.923	0.041	0.036
45	0.925	0.042	0.033
46	0.939	0.046	0.015
47	0.956	0.033	0.011
48	0.953	0.028	0.018
49	0.962	0.026	0.012
55	0.967	0.017	0.016
56	0.983	0.014	0.003
57	0.956	0.033	0.011
58	0.941	0.038	0.020
59	0.940	0.030	0.030
62	0.958	0.019	0.022
63	0.902	0.059	0.039

road type	Vehicle group		
	A	B	C
64	0.928	0.019	0.053
65	0.940	0.030	0.030
66	0.861	0.064	0.075
67	0.790	0.063	0.147
68	0.790	0.063	0.147
69	0.928	0.019	0.053
72	0.862	0.034	0.105
72	0.862	0.034	0.105
74	0.862	0.034	0.105
75	0.862	0.034	0.105
76	0.862	0.034	0.105
76	0.862	0.034	0.105
77	0.862	0.034	0.105
78	0.862	0.034	0.105
79	0.862	0.034	0.105
88	0.824	0.024	0.152
89	0.824	0.024	0.152
97	0.719	0.056	0.225
98	0.719	0.056	0.225
99	0.719	0.056	0.225

Annex C : MOBILE6 Vehicle classification

Number	Abbreviation	Description
1	LDGV	Light-Duty Gasoline Vehicles (Passenger Cars)
2	LDGT1	Light-Duty Gasoline Trucks 1 (0-6,000 lbs. GVWR, 0-3,750 lbs. LVW)
3	LDGT2	Light-Duty Gasoline Trucks 2 (0-6,000 lbs. GVWR, 3,751-5,750 lbs. LVW)
4	LDGT3	Light-Duty Gasoline Trucks 3 (6,001-8,500 lbs. GVWR, 0-5,750 lbs. ALVW)
5	LDGT4	Light-Duty Gasoline Trucks 4 (6,001-8,500 lbs. GVWR, greater than 5751 lbs. ALVW)
6	HDGV2b	Class 2b Heavy-Duty Gasoline Vehicles (8,501-10,000 lbs. GVWR)
7	HDGV3	Class 3 Heavy-Duty Gasoline Vehicles (10,001-14,000 lbs. GVWR)
8	HDGV4	Class 4 Heavy-Duty Gasoline Vehicles (14,001-16,000 lbs. GVWR)
9	HDGV5	Class 5 Heavy-Duty Gasoline Vehicles (16,001-19,500 lbs. GVWR)
10	HDGV6	Class 6 Heavy-Duty Gasoline Vehicles (19,501-26,000 lbs. GVWR)
11	HDGV7	Class 7 Heavy-Duty Gasoline Vehicles (26,001-33,000 lbs. GVWR)
12	HDGV8a	Class 8a Heavy-Duty Gasoline Vehicles (33,001-60,000 lbs. GVWR)
13	HDGV8b	Class 8b Heavy-Duty Gasoline Vehicles (>60,000 lbs. GVWR)
14	LDDV	Light-Duty Diesel Vehicles (Passenger Cars)
15	LDDT12	Light-Duty Diesel Trucks 1and 2 (0-6,000 lbs. GVWR)
16	HDDV2b	Class 2b Heavy-Duty Diesel Vehicles (8,501-10,000 lbs. GVWR)
17	HDDV3	Class 3 Heavy-Duty Diesel Vehicles (10,001-14,000 lbs. GVWR)
18	HDDV4	Class 4 Heavy-Duty Diesel Vehicles (14,001-16,000 lbs. GVWR)
19	HDDV5	Class 5 Heavy-Duty Diesel Vehicles (16,001-19,500 lbs. GVWR)
20	HDDV6	Class 6 Heavy-Duty Diesel Vehicles (19,501-26,000 lbs. GVWR)
21	HDDV7	Class 7 Heavy-Duty Diesel Vehicles (26,001-33,000 lbs. GVWR)
22	HDDV8a	Class 8a Heavy-Duty Diesel Vehicles (33,001-60,000 lbs. GVWR)
23	HDDV8b	Class 8b Heavy-Duty Diesel Vehicles (>60,000 lbs. GVWR)
24	MC	Motorcycles (Gasoline)
25	HDGB	Gasoline Buses (School, Transit and Urban)
26	HDDBT	Diesel Transit and Urban Buses
27	HDDBS	Diesel School Buses
28	LDDT34	Light-Duty Diesel Trucks 3 and 4 (6,001-8,500 lbs. GVWR)

Annex D Input file used for emission factor modeling.

*INPUT FILE FOR LINK BASED EMISSION ESTIMATION
*This input file is to model emission factors on facilities defined as FREEWAYS and ARTERIALS in Mobile6 under 26 speed scenarios from 2.5 to 65 mph in steps of 2.5mph.
****
HEADER SECTION
****
MOBILE6 INPUT FILE :
Input Extensions : INTL EFS HI-EM TECHFRAC
> 2003/6/25 Example input file - All M6Mexico options enabled.
POLLUTANTS : HC CO NOx CO2
SPREADSHEET :
RUN DATA :
EXPRESS HC AS TOG :
NO CLEAN AIR ACT :
NO 2007 HDDV RULE :
NO REFUELING :
****
FUELS
****
FUEL RVP : 7.15 !Fuel RVP is estimated from the average vapor pressure of gasolines MAGNA and PREMIUM that are distributed in Guadalajara (SEMADES)
OXYGENATED FUELS : 1.000 .000 .020 .000 1 !taken from NOM-086-SEMARNAT-SENER-2005 (SEMADES)
FUEL PROGRAM : 4 !Sulfur content in gasoline from NOM-086-SEMARNAT-SENER-2005 average = 300 Maximum = 500 (SEMADES)
300.0 300.0 300.0 300.0 300.0 300.0 300.0 300.0
300.0 300.0 300.0 300.0 300.0 300.0 300.0 300.0
500.0 500.0 500.0 500.0 500.0 500.0 500.0 500.0
500.0 500.0 500.0 500.0 500.0 500.0 500.0 500.0
****
FLEET AND ACTIVITY DATA
****
Intl Fleet File : MexFleet2002.inc
We Da Tri Len Di : Mex_Trip_Leng_WeekDay.dat
We En Tri Len Di : Mex_Trip_Leng_WeekEnd.dat
****
LOCAL AMBIENT DATA
****
*Average temperatures in 2005 from JVC center meteorological station
HOURLY TEMPERATURES: 52.1 51.5 54.0 61.3 67.4 70.9 73.8
76.1 77.9 79.1 79.4 78.8
76.3 71.2 66.7 64.6 63.4 62.7 61.2 59.4 57.5 55.8 54.2 53.0
****
SCENARIO SECTION
****
SCENARIO RECORD : LOCAL
CALENDAR YEAR : 2008
DIESEL SULFUR : 500.00 ! Maximum Sulfur content in Diesel from *NOM-086-SEMARNAT-SENER-2005
PARTICULATE EF : PMGZML.CSV PMGDR1.CSV PMGDR2.CSV PMDZML.CSV PMDDR1.CSV PMDDR2.CSV
PARTICLE SIZE : 2.5
ALTITUDE : 2
SOAK DISTRIBUTION : Mex_Soak_Dist.dat
HOT SOAK ACTIVITY : Mex_Hot_Soak_WeekDay.dat
DIURN SOAK ACTIVITY: Mex_Diurn_Soak_WeekDay.dat
* Alternate soak activity for weekends.
*HOT SOAK ACTIVITY : Mex_Hot_Soak_WeekEnd.dat
*DIURN SOAK ACTIVITY: Mex_Diurn_Soak_WeekEnd.dat
VMT BY FACILITY : VMTLocal.def
* Average relative humidity values from JVC center meteorological station
RELATIVE HUMIDITY : 77.9 78.4 71.2 56.6 47.5 42.4 38.1
34.6 32.7 31.2 31.0 33.2
38.8 47.7 53.8 56.5 58.9 60.7 64.0 67.5 70.1 73.1 75.2 76.6
****
SCENARIO RECORD : 2.5 NON-RAMP
CALENDAR YEAR : 2008
DIESEL SULFUR : 500.00 ! Maximum Sulfur content in Diesel from *NOM-086-SEMARNAT-SENER-2005
PARTICULATE EF : PMGZML.CSV PMGDR1.CSV PMGDR2.CSV PMDZML.CSV PMDDR1.CSV PMDDR2.CSV
PARTICLE SIZE : 2.5
ALTITUDE : 2
SOAK DISTRIBUTION : Mex_Soak_Dist.dat
HOT SOAK ACTIVITY : Mex_Hot_Soak_WeekDay.dat
DIURN SOAK ACTIVITY: Mex_Diurn_Soak_WeekDay.dat
* Alternate soak activity for weekends.
*HOT SOAK ACTIVITY : Mex_Hot_Soak_WeekEnd.dat
*DIURN SOAK ACTIVITY: Mex_Diurn_Soak_WeekEnd.dat
AVERAGE SPEED : 2.5 NON-RAMP

* Average relative humidity values from JVC center meteorological station
RELATIVE HUMIDITY : 77.9 78.4 71.2 56.6 47.5 42.4 38.1
34.6 32.7 31.2 31.0 33.2
38.8 47.7 53.8 56.5 58.9 60.7 64.0 67.5 70.1 73.1 75.2 76.6

****
SCENARIO RECORD : 5 NON-RAMP
CALENDAR YEAR : 2008
DIESEL SULFUR : 500.00 ! Maximum Sulfur content in Diesel from *NOM-086-SEMARNAT-SENER-2005
PARTICULATE EF : PMGZML.CSV PMGDR1.CSV PMGDR2.CSV PMDZML.CSV PMDDR1.CSV PMDDR2.CSV
PARTICLE SIZE : 2.5
ALTITUDE : 2
SOAK DISTRIBUTION : Mex_Soak_Dist.dat
HOT SOAK ACTIVITY : Mex_Hot_Soak_WeekDay.dat
DIURN SOAK ACTIVITY: Mex_Diurn_Soak_WeekDay.dat
* Alternate soak activity for weekends.
*HOT SOAK ACTIVITY : Mex_Hot_Soak_WeekEnd.dat
*DIURN SOAK ACTIVITY: Mex_Diurn_Soak_WeekEnd.dat
AVERAGE SPEED : 5 NON-RAMP
* Average relative humidity values from JVC center meteorological station
RELATIVE HUMIDITY : 77.9 78.4 71.2 56.6 47.5 42.4 38.1
34.6 32.7 31.2 31.0 33.2
38.8 47.7 53.8 56.5 58.9 60.7 64.0 67.5 70.1 73.1 75.2 76.6

(SAME CODE FOR THE OTHER 24 SPEED SCENARIOS UNTIL 65 mph in steps of 2.5mph)
(After modeling all non ramps scenarios, the same sequence for arterials was used. The input file end as follows:)

****
SCENARIO RECORD : 65 ARTERIAL
CALENDAR YEAR : 2008
DIESEL SULFUR : 500.00 !Maximum Sulfur content in Diesel from *NOM-086-SEMARNAT-SENER-2005
PARTICULATE EF : PMGZML.CSV PMGDR1.CSV PMGDR2.CSV PMDZML.CSV PMDDR1.CSV PMDDR2.CSV
PARTICLE SIZE : 2.5
ALTITUDE : 2
SOAK DISTRIBUTION : Mex_Soak_Dist.dat
HOT SOAK ACTIVITY : Mex_Hot_Soak_WeekDay.dat
DIURN SOAK ACTIVITY: Mex_Diurn_Soak_WeekDay.dat
* Alternate soak activity for weekends.
*HOT SOAK ACTIVITY : Mex_Hot_Soak_WeekEnd.dat
*DIURN SOAK ACTIVITY: Mex_Diurn_Soak_WeekEnd.dat
AVERAGE SPEED : 65 ARTERIAL
* Average relative humidity values from JVC center meteorological station
RELATIVE HUMIDITY : 77.9 78.4 71.2 56.6 47.5 42.4 38.1
34.6 32.7 31.2 31.0 33.2
38.8 47.7 53.8 56.5 58.9 60.7 64.0 67.5 70.1 73.1 75.2 76.6

******************** END OF RUN ********************
END OF RUN

Annex E Spreadsheet Outputs generated by M6-Mexico

Due to the size of the spreadsheets, only the most important fields are presented here.

The first column contain the name of the pollutant, then emission factors in g/mile for some of the 28 vehicle classes reported by MOBILE6-Mexico are given, finally the average speed and description of the scenario to which the emission factors correspond.

Spreadsheet outputs are presented in the following order: total organic gases, carbon monoxide, nitrogen oxides and carbon dioxide.

Poll	LDGV	LDGT1	LDGT2	LDGT3	LDGT4	HDGV2E	HDGV3	HDGV4	HDGV5	HDGV6	HDGV7	HDGV8A	LDDT12
TOG	3.014	2.771	2.771	3.682	3.682	5.459	7.528	15.106	9.386	8.849	10.925	13.425	4.535
TOG	13.068	13.078	13.078	16.446	16.446	20.162	25.49	47.485	30.711	29.081	34.522	41.829	5.631
TOG	5.574	5.479	5.479	6.989	6.989	10.561	14.513	28.401	17.804	16.819	20.739	25.363	5.294
TOG	4.126	3.947	3.947	5.117	5.117	7.889	10.923	21.624	13.487	12.731	15.746	19.299	4.944
TOG	3.402	3.181	3.181	4.181	4.181	6.553	9.127	18.236	11.329	10.686	13.25	16.267	4.769
TOG	3.065	2.801	2.801	3.73	3.73	5.533	7.632	15.311	9.513	8.969	11.076	13.61	4.542
TOG	2.84	2.548	2.548	3.429	3.429	4.852	6.636	13.362	8.303	7.824	9.627	11.839	4.391
TOG	2.699	2.399	2.399	3.249	3.249	4.261	5.766	11.664	7.247	6.825	8.36	10.292	4.233
TOG	2.593	2.286	2.286	3.114	3.114	3.818	5.113	10.391	6.456	6.076	7.41	9.132	4.115
TOG	2.521	2.217	2.217	3.026	3.026	3.465	4.587	9.351	5.815	5.47	6.639	8.187	4.002
TOG	2.464	2.162	2.162	2.956	2.956	3.183	4.167	8.519	5.302	4.986	6.021	7.43	3.911
TOG	2.415	2.115	2.115	2.897	2.897	2.955	3.828	7.852	4.89	4.596	5.525	6.823	3.829
TOG	2.374	2.076	2.076	2.848	2.848	2.765	3.545	7.295	4.546	4.271	5.111	6.316	3.76
TOG	2.33	2.031	2.031	2.791	2.791	2.612	3.32	6.855	4.273	4.012	4.784	5.916	3.7
TOG	2.292	1.992	1.992	2.742	2.742	2.482	3.128	6.478	4.039	3.791	4.503	5.572	3.648
TOG	2.267	1.965	1.965	2.709	2.709	2.377	2.976	6.183	3.855	3.617	4.283	5.304	3.604
TOG	2.246	1.942	1.942	2.681	2.681	2.286	2.843	5.926	3.694	3.465	4.091	5.07	3.565
TOG	2.225	1.919	1.919	2.652	2.652	2.215	2.741	5.73	3.571	3.348	3.944	4.892	3.534
TOG	2.206	1.898	1.898	2.627	2.627	2.151	2.65	5.557	3.461	3.244	3.814	4.733	3.505
TOG	2.186	1.876	1.876	2.599	2.599	2.101	2.58	5.426	3.378	3.165	3.716	4.615	3.484
TOG	2.168	1.855	1.855	2.573	2.573	2.056	2.518	5.308	3.303	3.094	3.628	4.508	3.464
TOG	2.15	1.833	1.833	2.546	2.546	2.024	2.475	5.228	3.252	3.045	3.569	4.437	3.45
TOG	2.134	1.814	1.814	2.521	2.521	1.994	2.437	5.155	3.206	3.001	3.516	4.373	3.438
TOG	2.119	1.795	1.795	2.497	2.497	1.98	2.42	5.126	3.186	2.983	3.495	4.347	3.431
TOG	2.105	1.778	1.778	2.476	2.476	1.966	2.404	5.099	3.168	2.965	3.476	4.324	3.425
TOG	2.093	1.762	1.762	2.455	2.455	1.967	2.411	5.117	3.177	2.974	3.49	4.342	3.425
TOG	2.081	1.747	1.747	2.435	2.435	1.969	2.418	5.134	3.186	2.982	3.503	4.358	3.425
TOG	13.068	13.078	13.078	16.446	16.446	20.162	25.49	47.485	30.711	29.081	34.522	41.829	5.631
TOG	5.574	5.479	5.479	6.989	6.989	10.561	14.513	28.401	17.804	16.819	20.739	25.363	5.294
TOG	4.176	4.021	4.021	5.195	5.195	7.889	10.923	21.624	13.487	12.731	15.746	19.299	4.944
TOG	3.477	3.292	3.292	4.298	4.298	6.553	9.127	18.236	11.329	10.686	13.25	16.267	4.769
TOG	3.15	2.925	2.925	3.861	3.861	5.533	7.632	15.311	9.513	8.969	11.076	13.61	4.542
TOG	2.932	2.681	2.681	3.569	3.569	4.852	6.636	13.362	8.303	7.824	9.627	11.839	4.391
TOG	2.763	2.49	2.49	3.345	3.345	4.261	5.766	11.664	7.247	6.825	8.36	10.292	4.233
TOG	2.636	2.346	2.346	3.177	3.177	3.818	5.113	10.391	6.456	6.076	7.41	9.132	4.115
TOG	2.549	2.252	2.252	3.063	3.063	3.465	4.587	9.351	5.815	5.47	6.639	8.187	4.002
TOG	2.478	2.177	2.177	2.972	2.972	3.183	4.167	8.519	5.302	4.986	6.021	7.43	3.911
TOG	2.423	2.123	2.123	2.905	2.905	2.955	3.828	7.852	4.89	4.596	5.525	6.823	3.829
TOG	2.377	2.078	2.078	2.85	2.85	2.765	3.545	7.295	4.546	4.271	5.111	6.316	3.76
TOG	2.331	2.031	2.031	2.791	2.791	2.612	3.32	6.855	4.273	4.012	4.784	5.916	3.7
TOG	2.292	1.992	1.992	2.742	2.742	2.482	3.128	6.478	4.039	3.791	4.503	5.572	3.648
TOG	2.267	1.965	1.965	2.709	2.709	2.377	2.976	6.183	3.855	3.617	4.283	5.304	3.604
TOG	2.246	1.942	1.942	2.681	2.681	2.286	2.843	5.926	3.694	3.465	4.091	5.07	3.565
TOG	2.225	1.919	1.919	2.652	2.652	2.215	2.741	5.73	3.571	3.348	3.944	4.892	3.534
TOG	2.206	1.898	1.898	2.627	2.627	2.151	2.65	5.557	3.461	3.244	3.814	4.733	3.505
TOG	2.186	1.876	1.876	2.599	2.599	2.101	2.58	5.426	3.378	3.165	3.716	4.615	3.484
TOG	2.168	1.855	1.855	2.573	2.573	2.056	2.518	5.308	3.303	3.094	3.628	4.508	3.464
TOG	2.15	1.833	1.833	2.546	2.546	2.024	2.475	5.228	3.252	3.045	3.569	4.437	3.45
TOG	2.134	1.814	1.814	2.521	2.521	1.994	2.437	5.155	3.206	3.001	3.516	4.373	3.438
TOG	2.119	1.795	1.795	2.497	2.497	1.98	2.42	5.126	3.186	2.983	3.495	4.347	3.431
TOG	2.105	1.778	1.778	2.476	2.476	1.966	2.404	5.099	3.168	2.965	3.476	4.324	3.425
TOG	2.093	1.762	1.762	2.455	2.455	1.967	2.411	5.117	3.177	2.974	3.49	4.342	3.425
TOG	2.081	1.747	1.747	2.435	2.435	1.969	2.418	5.134	3.186	2.982	3.503	4.358	3.425

HDDV2E	HDDV3	HDDV4	HDDV5	HDDV6	HDDV7	HDDV8A	GAS BUS	URB BUS	COM BU	LDDT34	Avg Spc	Description
1.842	2.147	2.461	2.593	3.238	3.953	4.672	19.026	6.018	4.237	1.303	27.6	LOCAL
3.041	3.546	4.063	4.281	5.347	6.528	7.715	63.28	9.937	6.996	1.919	2.5	2.5 NON-RAMP
2.673	3.116	3.571	3.762	4.699	5.736	6.779	38.106	8.732	6.148	1.729	5	5 NON-RAMP
2.29	2.669	3.059	3.223	4.025	4.914	5.808	28.45	7.481	5.267	1.533	7.5	7.5 NON-RAMP
2.098	2.446	2.803	2.953	3.689	4.503	5.322	23.622	6.855	4.827	1.434	10	10.0 NON-RAMP
1.85	2.156	2.471	2.603	3.252	3.97	4.691	19.325	6.043	4.255	1.307	12.5	12.5 NON-RAMP
1.684	1.963	2.25	2.37	2.96	3.614	4.271	16.46	5.502	3.873	1.222	15	15.0 NON-RAMP
1.511	1.762	2.019	2.127	2.656	3.243	3.833	13.962	4.937	3.476	1.133	17.5	17.5 NON-RAMP
1.381	1.61	1.846	1.944	2.429	2.965	3.504	12.089	4.513	3.178	1.066	20	20.0 NON-RAMP
1.258	1.466	1.68	1.77	2.211	2.699	3.19	10.553	4.109	2.893	1.003	22.5	22.5 NON-RAMP
1.158	1.351	1.548	1.631	2.037	2.486	2.938	9.324	3.785	2.665	0.952	25	25 NON-RAMP
1.068	1.245	1.427	1.504	1.878	2.293	2.71	8.339	3.49	2.457	0.905	27.5	27.5 NON-RAMP
0.993	1.158	1.327	1.398	1.746	2.131	2.519	7.518	3.245	2.285	0.867	30	30 NON-RAMP
0.927	1.081	1.238	1.305	1.63	1.99	2.351	6.87	3.029	2.132	0.833	32.5	32.5 NON-RAMP
0.87	1.015	1.163	1.225	1.53	1.868	2.208	6.314	2.843	2.002	0.804	35	35 NON-RAMP
0.822	0.958	1.098	1.157	1.445	1.764	2.085	5.883	2.686	1.891	0.779	37.5	37.5 NON-RAMP
0.78	0.909	1.042	1.097	1.371	1.673	1.978	5.505	2.547	1.793	0.757	40	40 NON-RAMP
0.745	0.868	0.995	1.048	1.31	1.599	1.889	5.22	2.434	1.713	0.739	42.5	42.5 NON-RAMP
0.714	0.832	0.954	1.005	1.255	1.532	1.811	4.966	2.333	1.642	0.723	45	45 NON-RAMP
0.69	0.804	0.922	0.971	1.213	1.481	1.75	4.778	2.254	1.587	0.711	47.5	47.5 NON-RAMP
0.668	0.779	0.893	0.941	1.175	1.434	1.695	4.609	2.184	1.537	0.7	50	50 NON-RAMP
0.653	0.762	0.873	0.92	1.149	1.402	1.657	4.496	2.134	1.503	0.692	52.5	52.5 NON-RAMP
0.64	0.746	0.854	0.9	1.124	1.373	1.622	4.393	2.09	1.471	0.685	55	55 NON-RAMP
0.632	0.737	0.845	0.89	1.112	1.357	1.604	4.354	2.066	1.455	0.681	57.5	57.5 NON-RAMP
0.626	0.729	0.836	0.881	1.1	1.343	1.587	4.319	2.044	1.439	0.678	60	60 NON-RAMP
0.626	0.729	0.836	0.881	1.1	1.343	1.587	4.35	2.044	1.439	0.678	62.5	62.5 NON-RAMP
0.626	0.729	0.836	0.881	1.1	1.343	1.587	4.379	2.044	1.439	0.678	65	65 NON-RAMP
3.041	3.546	4.063	4.281	5.347	6.528	7.715	63.28	9.937	6.996	1.919	2.5	2.5 ARTERIAL
2.673	3.116	3.571	3.762	4.699	5.736	6.779	38.106	8.732	6.148	1.729	5	5 ARTERIAL
2.29	2.669	3.059	3.223	4.025	4.914	5.808	28.45	7.481	5.267	1.533	7.5	7.5 ARTERIAL
2.098	2.446	2.803	2.953	3.689	4.503	5.322	23.622	6.855	4.827	1.434	10	10.0 ARTERIAL
1.85	2.156	2.471	2.603	3.252	3.97	4.691	19.325	6.043	4.255	1.307	12.5	12.5 ARTERIAL
1.684	1.963	2.25	2.37	2.96	3.614	4.271	16.46	5.502	3.873	1.222	15	15.0 ARTERIAL
1.511	1.762	2.019	2.127	2.656	3.243	3.833	13.962	4.937	3.476	1.133	17.5	17.5 ARTERIAL
1.381	1.61	1.846	1.944	2.429	2.965	3.504	12.089	4.513	3.178	1.066	20	20.0 ARTERIAL
1.258	1.466	1.68	1.77	2.211	2.699	3.19	10.553	4.109	2.893	1.003	22.5	22.5 ARTERIAL
1.158	1.351	1.548	1.631	2.037	2.486	2.938	9.324	3.785	2.665	0.952	25	25 ARTERIAL
1.068	1.245	1.427	1.504	1.878	2.293	2.71	8.339	3.49	2.457	0.905	27.5	27.5 ARTERIAL
0.993	1.158	1.327	1.398	1.746	2.131	2.519	7.518	3.245	2.285	0.867	30	30 ARTERIAL
0.927	1.081	1.238	1.305	1.63	1.99	2.351	6.87	3.029	2.132	0.833	32.5	32.5 ARTERIAL
0.87	1.015	1.163	1.225	1.53	1.868	2.208	6.314	2.843	2.002	0.804	35	35 ARTERIAL
0.822	0.958	1.098	1.157	1.445	1.764	2.085	5.883	2.686	1.891	0.779	37.5	37.5 ARTERIAL
0.78	0.909	1.042	1.097	1.371	1.673	1.978	5.505	2.547	1.793	0.757	40	40 ARTERIAL
0.745	0.868	0.995	1.048	1.31	1.599	1.889	5.22	2.434	1.713	0.739	42.5	42.5 ARTERIAL
0.714	0.832	0.954	1.005	1.255	1.532	1.811	4.966	2.333	1.642	0.723	45	45 ARTERIAL
0.69	0.804	0.922	0.971	1.213	1.481	1.75	4.778	2.254	1.587	0.711	47.5	47.5 ARTERIAL
0.668	0.779	0.893	0.941	1.175	1.434	1.695	4.609	2.184	1.537	0.7	50	50 ARTERIAL
0.653	0.762	0.873	0.92	1.149	1.402	1.657	4.496	2.134	1.503	0.692	52.5	52.5 ARTERIAL
0.64	0.746	0.854	0.9	1.124	1.373	1.622	4.393	2.09	1.471	0.685	55	55 ARTERIAL
0.632	0.737	0.845	0.89	1.112	1.357	1.604	4.354	2.066	1.455	0.681	57.5	57.5 ARTERIAL
0.626	0.729	0.836	0.881	1.1	1.343	1.587	4.319	2.044	1.439	0.678	60	60 ARTERIAL
0.626	0.729	0.836	0.881	1.1	1.343	1.587	4.35	2.044	1.439	0.678	62.5	62.5 ARTERIAL
0.626	0.729	0.836	0.881	1.1	1.343	1.587	4.379	2.044	1.439	0.678	65	65 ARTERIAL

Poll	LDGV	LDGT1	LDGT2	LDGT3	LDGT4	HDGV2B	HDGV3	HDGV4	HDGV5	HDGV6	HDGV7	HDGV8A	LDDT12
CO	17.364	19.82	19.82	25.903	25.903	67.419	105.48	210.37	129.82	122.92	158.26	193.34	15.488
CO	62.256	55.802	55.802	71.523	71.523	156.64	245.06	488.77	301.62	285.59	367.69	449.21	21.1
CO	36.181	35.343	35.343	44.801	44.801	125.16	195.81	390.53	241	228.19	293.79	358.93	19.18
CO	27.403	28.365	28.365	35.893	35.893	97.232	152.12	303.39	187.23	177.27	228.24	278.84	17.413
CO	23.014	24.876	24.876	31.439	31.439	83.269	130.28	259.83	160.34	151.82	195.46	238.8	16.53
CO	20.916	23.186	23.186	29.338	29.338	68.427	107.05	213.51	131.76	124.76	160.62	196.23	15.547
CO	19.517	22.06	22.06	27.938	27.938	58.532	91.574	182.64	112.71	106.72	137.4	167.86	14.891
CO	19.138	21.784	21.784	27.577	27.577	49.925	78.108	155.78	96.135	91.024	117.19	143.18	14.297
CO	18.854	21.577	21.577	27.307	27.307	43.47	68.009	135.64	83.705	79.255	102.04	124.66	13.852
CO	18.677	21.456	21.456	27.138	27.138	38.27	59.873	119.41	73.691	69.773	89.833	109.75	13.478
CO	18.535	21.359	21.359	27.004	27.004	34.109	53.364	106.43	65.68	62.188	80.067	97.819	13.179
CO	18.428	21.298	21.298	26.91	26.91	30.928	48.388	96.507	59.555	56.389	72.6	88.697	12.94
CO	18.339	21.247	21.247	26.833	26.833	28.278	44.241	88.235	54.451	51.556	66.378	81.095	12.741
CO	18.37	21.373	21.373	26.944	26.944	26.388	41.284	82.339	50.812	48.111	61.942	75.676	12.59
CO	18.396	21.481	21.481	27.039	27.039	24.769	38.751	77.286	47.694	45.158	58.141	71.031	12.46
CO	18.745	21.908	21.908	27.492	27.492	23.783	37.209	74.212	45.797	43.362	55.828	68.206	12.368
CO	19.05	22.282	22.282	27.889	27.889	22.921	35.861	71.522	44.137	41.79	53.805	65.734	12.289
CO	19.396	22.706	22.706	28.339	28.339	22.651	35.438	70.68	43.617	41.298	53.171	64.96	12.244
CO	19.704	23.082	23.082	28.739	28.739	22.411	35.063	69.931	43.155	40.861	52.608	64.272	12.204
CO	20.048	23.504	23.504	29.186	29.186	22.801	35.673	71.147	43.905	41.571	53.522	65.389	12.197
CO	20.358	23.883	23.883	29.588	29.588	23.152	36.221	72.241	44.581	42.21	54.346	66.395	12.192
CO	20.7	24.303	24.303	30.034	30.034	24.261	37.956	75.701	46.716	44.232	56.949	69.575	12.223
CO	21.012	24.684	24.684	30.438	30.438	25.269	39.533	78.847	48.657	46.07	59.315	72.466	12.251
CO	21.353	25.102	25.102	30.882	30.882	27.288	42.692	85.147	52.545	49.751	64.055	78.257	12.324
CO	21.665	25.485	25.485	31.288	31.288	29.139	45.588	90.923	56.109	53.126	68.399	83.565	12.391
CO	22.005	25.901	25.901	31.73	31.73	32.447	50.764	101.25	62.48	59.158	76.166	93.053	12.515
CO	22.319	26.285	26.285	32.138	32.138	35.501	55.542	110.78	68.361	64.726	83.335	101.81	12.63
CO	62.256	55.802	55.802	71.523	71.523	156.64	245.06	488.77	301.62	285.59	367.69	449.21	21.1
CO	36.181	35.343	35.343	44.801	44.801	125.16	195.81	390.53	241	228.19	293.79	358.93	19.18
CO	28.405	29.141	29.141	36.852	36.852	97.232	152.12	303.39	187.23	177.27	228.24	278.84	17.413
CO	24.516	26.04	26.04	32.878	32.878	83.269	130.28	259.83	160.34	151.82	195.46	238.8	16.53
CO	22.59	24.466	24.466	30.927	30.927	68.427	107.05	213.51	131.76	124.76	160.62	196.23	15.547
CO	21.306	23.417	23.417	29.627	29.627	58.532	91.574	182.64	112.71	106.72	137.4	167.86	14.891
CO	20.346	22.663	22.663	28.688	28.688	49.925	78.108	155.78	96.135	91.024	117.19	143.18	14.297
CO	19.626	22.098	22.098	27.984	27.984	43.47	68.009	135.64	83.705	79.255	102.04	124.66	13.852
CO	19.153	21.755	21.755	27.542	27.542	38.27	59.873	119.41	73.691	69.773	89.833	109.75	13.478
CO	18.774	21.481	21.481	27.189	27.189	34.109	53.364	106.43	65.68	62.188	80.067	97.819	13.179
CO	18.56	21.365	21.365	27.013	27.013	30.928	48.388	96.507	59.555	56.389	72.6	88.697	12.94
CO	18.381	21.269	21.269	26.866	26.866	28.278	44.241	88.235	54.451	51.556	66.378	81.095	12.741
CO	18.389	21.383	21.383	26.959	26.959	26.388	41.284	82.339	50.812	48.111	61.942	75.676	12.59
CO	18.396	21.481	21.481	27.039	27.039	24.769	38.751	77.286	47.694	45.158	58.141	71.031	12.46
CO	18.745	21.908	21.908	27.492	27.492	23.783	37.209	74.212	45.797	43.362	55.828	68.206	12.368
CO	19.05	22.282	22.282	27.889	27.889	22.921	35.861	71.522	44.137	41.79	53.805	65.734	12.289
CO	19.396	22.706	22.706	28.339	28.339	22.651	35.438	70.68	43.617	41.298	53.171	64.96	12.244
CO	19.704	23.082	23.082	28.739	28.739	22.411	35.063	69.931	43.155	40.861	52.608	64.272	12.204
CO	20.048	23.504	23.504	29.186	29.186	22.801	35.673	71.147	43.905	41.571	53.522	65.389	12.197
CO	20.358	23.883	23.883	29.588	29.588	23.152	36.221	72.241	44.581	42.21	54.346	66.395	12.192
CO	20.7	24.303	24.303	30.034	30.034	24.261	37.956	75.701	46.716	44.232	56.949	69.575	12.223
CO	21.012	24.684	24.684	30.438	30.438	25.269	39.533	78.847	48.657	46.07	59.315	72.466	12.251
CO	21.353	25.102	25.102	30.882	30.882	27.288	42.692	85.147	52.545	49.751	64.055	78.257	12.324
CO	21.665	25.485	25.485	31.288	31.288	29.139	45.588	90.923	56.109	53.126	68.399	83.565	12.391
CO	22.005	25.901	25.901	31.73	31.73	32.447	50.764	101.25	62.48	59.158	76.166	93.053	12.515
CO	22.319	26.285	26.285	32.138	32.138	35.501	55.542	110.78	68.361	64.726	83.335	101.81	12.63

HDDV2E	HDDV3	HDDV4	HDDV5	HDDV6	HDDV7	HDDV8A	GAS BUS	URB BUS	COM BU	LDDT34	Avg Spd	Description
9.483	10.923	12.667	13.013	16.304	20	26.834	342.14	30.586	20.644	4.103	27.6	LOCAL
20.47	23.578	27.344	28.09	35.193	43.171	57.923	794.91	66.023	44.563	7.346	2.5	2.5 NON-RAMP
16.71	19.247	22.321	22.931	28.729	35.242	47.284	635.15	53.897	36.378	6.237	5	5 NON-RAMP
13.251	15.263	17.701	18.185	22.782	27.947	37.497	493.43	42.741	28.848	5.216	7.5	7.5 NON-RAMP
11.522	13.271	15.391	15.811	19.809	24.3	32.603	422.57	37.163	25.083	4.705	10	10.0 NON-RAMP
9.598	11.055	12.82	13.171	16.501	20.241	27.158	347.25	30.956	20.894	4.137	12.5	12.5 NON-RAMP
8.315	9.577	11.107	11.41	14.295	17.536	23.527	297.04	26.818	18.101	3.759	15	15.0 NON-RAMP
7.152	8.237	9.553	9.814	12.295	15.083	20.237	253.36	23.067	15.569	3.415	17.5	17.5 NON-RAMP
6.279	7.233	8.388	8.617	10.796	13.243	17.768	220.6	20.253	13.67	3.158	20	20.0 NON-RAMP
5.548	6.39	7.411	7.613	9.538	11.701	15.699	194.21	17.895	12.078	2.942	22.5	22.5 NON-RAMP
4.963	5.716	6.63	6.811	8.533	10.467	14.044	173.1	16.008	10.804	2.769	25	25 NON-RAMP
4.495	5.178	6.005	6.169	7.728	9.48	12.72	156.96	14.499	9.786	2.631	27.5	27.5 NON-RAMP
4.105	4.728	5.484	5.634	7.058	8.658	11.616	143.5	13.241	8.937	2.516	30	30 NON-RAMP
3.808	4.386	5.087	5.226	6.547	8.032	10.776	133.91	12.283	8.291	2.428	32.5	32.5 NON-RAMP
3.554	4.093	4.747	4.877	6.11	7.495	10.056	125.7	11.462	7.737	2.353	35	35 NON-RAMP
3.376	3.888	4.509	4.632	5.803	7.119	9.552	120.7	10.888	7.349	2.301	37.5	37.5 NON-RAMP
3.22	3.708	4.301	4.418	5.535	6.79	9.11	116.32	10.385	7.009	2.255	40	40 NON-RAMP
3.131	3.607	4.183	4.297	5.383	6.604	8.86	114.95	10.099	6.817	2.229	42.5	42.5 NON-RAMP
3.053	3.516	4.078	4.189	5.248	6.438	8.638	113.73	9.846	6.646	2.205	45	45 NON-RAMP
3.04	3.502	4.061	4.172	5.227	6.412	8.603	115.71	9.806	6.619	2.202	47.5	47.5 NON-RAMP
3.029	3.489	4.046	4.157	5.208	6.388	8.571	117.49	9.77	6.594	2.198	50	50 NON-RAMP
3.09	3.559	4.128	4.241	5.313	6.517	8.744	123.12	9.967	6.727	2.216	52.5	52.5 NON-RAMP
3.146	3.623	4.202	4.317	5.408	6.634	8.901	128.23	10.146	6.848	2.233	55	55 NON-RAMP
3.288	3.787	4.392	4.512	5.653	6.935	9.304	138.48	10.605	7.158	2.275	57.5	57.5 NON-RAMP
3.419	3.938	4.567	4.691	5.878	7.21	9.674	147.87	11.027	7.442	2.313	60	60 NON-RAMP
3.663	4.219	4.893	5.027	6.298	7.725	10.365	164.66	11.815	7.974	2.386	62.5	62.5 NON-RAMP
3.888	4.479	5.194	5.336	6.685	8.201	11.003	180.16	12.542	8.465	2.452	65	65 NON-RAMP
20.47	23.578	27.344	28.09	35.193	43.171	57.923	794.91	66.023	44.563	7.346	2.5	2.5 ARTERIAL
16.71	19.247	22.321	22.931	28.729	35.242	47.284	635.15	53.897	36.378	6.237	5	5 ARTERIAL
13.251	15.263	17.701	18.185	22.782	27.947	37.497	493.43	42.741	28.848	5.216	7.5	7.5 ARTERIAL
11.522	13.271	15.391	15.811	19.809	24.3	32.603	422.57	37.163	25.083	4.705	10	10.0 ARTERIAL
9.598	11.055	12.82	13.171	16.501	20.241	27.158	347.25	30.956	20.894	4.137	12.5	12.5 ARTERIAL
8.315	9.577	11.107	11.41	14.295	17.536	23.527	297.04	26.818	18.101	3.759	15	15.0 ARTERIAL
7.152	8.237	9.553	9.814	12.295	15.083	20.237	253.36	23.067	15.569	3.415	17.5	17.5 ARTERIAL
6.279	7.233	8.388	8.617	10.796	13.243	17.768	220.6	20.253	13.67	3.158	20	20.0 ARTERIAL
5.548	6.39	7.411	7.613	9.538	11.701	15.699	194.21	17.895	12.078	2.942	22.5	22.5 ARTERIAL
4.963	5.716	6.63	6.811	8.533	10.467	14.044	173.1	16.008	10.804	2.769	25	25 ARTERIAL
4.495	5.178	6.005	6.169	7.728	9.48	12.72	156.96	14.499	9.786	2.631	27.5	27.5 ARTERIAL
4.105	4.728	5.484	5.634	7.058	8.658	11.616	143.5	13.241	8.937	2.516	30	30 ARTERIAL
3.808	4.386	5.087	5.226	6.547	8.032	10.776	133.91	12.283	8.291	2.428	32.5	32.5 ARTERIAL
3.554	4.093	4.747	4.877	6.11	7.495	10.056	125.7	11.462	7.737	2.353	35	35 ARTERIAL
3.376	3.888	4.509	4.632	5.803	7.119	9.552	120.7	10.888	7.349	2.301	37.5	37.5 ARTERIAL
3.22	3.708	4.301	4.418	5.535	6.79	9.11	116.32	10.385	7.009	2.255	40	40 ARTERIAL
3.131	3.607	4.183	4.297	5.383	6.604	8.86	114.95	10.099	6.817	2.229	42.5	42.5 ARTERIAL
3.053	3.516	4.078	4.189	5.248	6.438	8.638	113.73	9.846	6.646	2.205	45	45 ARTERIAL
3.04	3.502	4.061	4.172	5.227	6.412	8.603	115.71	9.806	6.619	2.202	47.5	47.5 ARTERIAL
3.029	3.489	4.046	4.157	5.208	6.388	8.571	117.49	9.77	6.594	2.198	50	50 ARTERIAL
3.09	3.559	4.128	4.241	5.313	6.517	8.744	123.12	9.967	6.727	2.216	52.5	52.5 ARTERIAL
3.146	3.623	4.202	4.317	5.408	6.634	8.901	128.23	10.146	6.848	2.233	55	55 ARTERIAL
3.288	3.787	4.392	4.512	5.653	6.935	9.304	138.48	10.605	7.158	2.275	57.5	57.5 ARTERIAL
3.419	3.938	4.567	4.691	5.878	7.21	9.674	147.87	11.027	7.442	2.313	60	60 ARTERIAL
3.663	4.219	4.893	5.027	6.298	7.725	10.365	164.66	11.815	7.974	2.386	62.5	62.5 ARTERIAL
3.888	4.479	5.194	5.336	6.685	8.201	11.003	180.16	12.542	8.465	2.452	65	65 ARTERIAL

Poll	LDGV	LDGT1	LDGT2	LDGT3	LDGT4	HDGV2E	HDGV3	HDGV4	HDGV5	HDGV6	HDGV7	HDGV8A	LDDT12
NOX	1.63	2.169	2.169	2.234	2.234	3.324	3.879	4.546	4.386	4.393	4.987	5.456	2.695
NOX	2.996	3.648	3.648	3.729	3.729	3	3.501	4.102	3.958	3.964	4.5	4.923	3.727
NOX	2.639	3.274	3.274	3.35	3.35	3.078	3.592	4.208	4.061	4.067	4.617	5.051	3.4
NOX	2.191	2.791	2.791	2.861	2.861	3.182	3.713	4.351	4.198	4.204	4.773	5.222	3.071
NOX	1.966	2.549	2.549	2.617	2.617	3.234	3.774	4.422	4.267	4.273	4.851	5.307	2.907
NOX	1.775	2.342	2.342	2.408	2.408	3.328	3.883	4.55	4.391	4.397	4.991	5.461	2.704
NOX	1.647	2.204	2.204	2.268	2.268	3.39	3.956	4.635	4.473	4.479	5.085	5.563	2.569
NOX	1.653	2.214	2.214	2.278	2.278	3.479	4.06	4.757	4.591	4.597	5.219	5.71	2.44
NOX	1.657	2.222	2.222	2.286	2.286	3.546	4.138	4.848	4.679	4.685	5.319	5.819	2.343
NOX	1.66	2.227	2.227	2.291	2.291	3.633	4.239	4.967	4.793	4.8	5.449	5.962	2.264
NOX	1.661	2.231	2.231	2.296	2.296	3.702	4.32	5.062	4.885	4.891	5.553	6.076	2.201
NOX	1.662	2.235	2.235	2.299	2.299	3.787	4.419	5.178	4.997	5.004	5.681	6.215	2.16
NOX	1.663	2.237	2.237	2.302	2.302	3.858	4.502	5.275	5.091	5.098	5.787	6.332	2.127
NOX	1.66	2.237	2.237	2.301	2.301	3.942	4.6	5.39	5.201	5.209	5.913	6.469	2.119
NOX	1.657	2.236	2.236	2.3	2.3	4.014	4.684	5.488	5.296	5.304	6.021	6.588	2.112
NOX	1.664	2.244	2.244	2.308	2.308	4.097	4.781	5.602	5.406	5.414	6.146	6.724	2.135
NOX	1.669	2.251	2.251	2.315	2.315	4.17	4.866	5.702	5.502	5.51	6.255	6.844	2.155
NOX	1.679	2.263	2.263	2.328	2.328	4.253	4.963	5.815	5.611	5.619	6.379	6.979	2.21
NOX	1.689	2.275	2.275	2.339	2.339	4.326	5.048	5.915	5.708	5.716	6.489	7.1	2.26
NOX	1.699	2.287	2.287	2.352	2.352	4.408	5.144	6.027	5.817	5.825	6.612	7.235	2.354
NOX	1.708	2.299	2.299	2.364	2.364	4.482	5.23	6.128	5.914	5.922	6.723	7.356	2.439
NOX	1.719	2.312	2.312	2.377	2.377	4.564	5.326	6.24	6.022	6.03	6.846	7.49	2.584
NOX	1.729	2.324	2.324	2.389	2.389	4.638	5.412	6.342	6.12	6.128	6.957	7.612	2.715
NOX	1.741	2.338	2.338	2.403	2.403	4.72	5.507	6.453	6.227	6.236	7.079	7.745	2.926
NOX	1.752	2.35	2.35	2.416	2.416	4.794	5.595	6.555	6.326	6.335	7.191	7.868	3.12
NOX	1.763	2.364	2.364	2.429	2.429	4.875	5.689	6.666	6.433	6.442	7.313	8.001	3.428
NOX	1.774	2.376	2.376	2.442	2.442	4.95	5.777	6.768	6.532	6.541	7.425	8.124	3.712
NOX	2.996	3.648	3.648	3.729	3.729	3	3.501	4.102	3.958	3.964	4.5	4.923	3.727
NOX	2.64	3.274	3.274	3.35	3.35	3.078	3.592	4.208	4.061	4.067	4.617	5.051	3.4
NOX	2.354	2.97	2.97	3.043	3.043	3.182	3.713	4.351	4.198	4.204	4.773	5.222	3.071
NOX	2.211	2.819	2.819	2.889	2.889	3.234	3.774	4.422	4.267	4.273	4.851	5.307	2.907
NOX	2.054	2.65	2.65	2.719	2.719	3.328	3.883	4.55	4.391	4.397	4.991	5.461	2.704
NOX	1.949	2.538	2.538	2.605	2.605	3.39	3.956	4.635	4.473	4.479	5.085	5.563	2.569
NOX	1.873	2.457	2.457	2.524	2.524	3.479	4.06	4.757	4.591	4.597	5.219	5.71	2.44
NOX	1.816	2.396	2.396	2.463	2.463	3.546	4.138	4.848	4.679	4.685	5.319	5.819	2.343
NOX	1.771	2.349	2.349	2.415	2.415	3.633	4.239	4.967	4.793	4.8	5.449	5.962	2.264
NOX	1.735	2.311	2.311	2.376	2.376	3.702	4.32	5.062	4.885	4.891	5.553	6.076	2.201
NOX	1.705	2.28	2.28	2.345	2.345	3.787	4.419	5.178	4.997	5.004	5.681	6.215	2.16
NOX	1.68	2.254	2.254	2.318	2.318	3.858	4.502	5.275	5.091	5.098	5.787	6.332	2.127
NOX	1.668	2.244	2.244	2.309	2.309	3.942	4.6	5.39	5.201	5.209	5.913	6.469	2.119
NOX	1.657	2.236	2.236	2.3	2.3	4.014	4.684	5.488	5.296	5.304	6.021	6.588	2.112
NOX	1.664	2.244	2.244	2.308	2.308	4.097	4.781	5.602	5.406	5.414	6.146	6.724	2.135
NOX	1.669	2.251	2.251	2.315	2.315	4.17	4.866	5.702	5.502	5.51	6.255	6.844	2.155
NOX	1.679	2.263	2.263	2.328	2.328	4.253	4.963	5.815	5.611	5.619	6.379	6.979	2.21
NOX	1.689	2.275	2.275	2.339	2.339	4.326	5.048	5.915	5.708	5.716	6.489	7.1	2.26
NOX	1.699	2.287	2.287	2.352	2.352	4.408	5.144	6.027	5.817	5.825	6.612	7.235	2.354
NOX	1.708	2.299	2.299	2.364	2.364	4.482	5.23	6.128	5.914	5.922	6.723	7.356	2.439
NOX	1.719	2.312	2.312	2.377	2.377	4.564	5.326	6.24	6.022	6.03	6.846	7.49	2.584
NOX	1.729	2.324	2.324	2.389	2.389	4.638	5.412	6.342	6.12	6.128	6.957	7.612	2.715
NOX	1.741	2.338	2.338	2.403	2.403	4.72	5.507	6.453	6.227	6.236	7.079	7.745	2.926
NOX	1.752	2.35	2.35	2.416	2.416	4.794	5.595	6.555	6.326	6.335	7.191	7.868	3.12
NOX	1.763	2.364	2.364	2.429	2.429	4.875	5.689	6.666	6.433	6.442	7.313	8.001	3.428
NOX	1.774	2.376	2.376	2.442	2.442	4.95	5.777	6.768	6.532	6.541	7.425	8.124	3.712

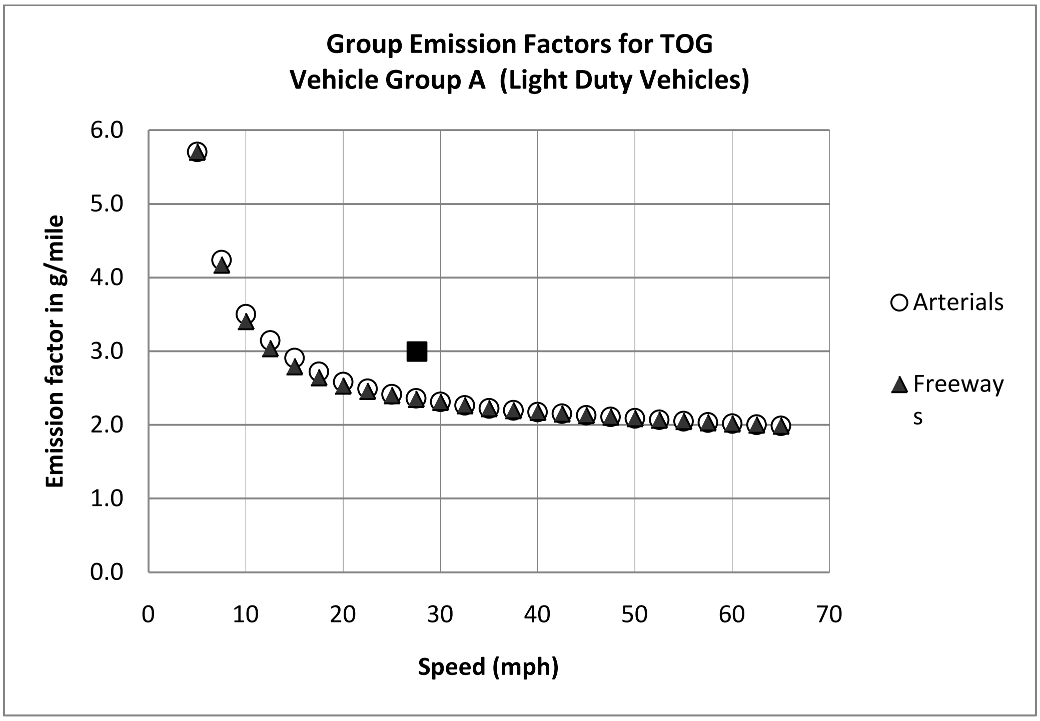
HDDV2E	HDDV3	HDDV4	HDDV5	HDDV6	HDDV7	HDDV8A	GAS BUS	URB BUS	COM BU	LDDT34	Avg Spd	Description
6.919	8.162	9.488	10.239	12.356	15.025	18.45	5.336	24.205	16.064	1.572	27.6	LOCAL
10.173	12.001	13.95	15.055	19.127	23.26	30.844	4.815	35.731	23.714	2.277	2.5	2.5 NON-RAMP
9.144	10.786	12.539	13.531	17.28	21.014	28.077	4.94	32.085	21.294	2.054	5	5 NON-RAMP
8.105	9.561	11.115	11.995	15.416	18.747	25.285	5.107	28.407	18.853	1.829	7.5	7.5 NON-RAMP
7.586	8.949	10.403	11.226	14.484	17.614	23.889	5.191	26.568	17.633	1.716	10	10.0 NON-RAMP
6.947	8.195	9.527	10.281	13.337	16.22	22.171	5.341	24.305	16.131	1.578	12.5	12.5 NON-RAMP
6.521	7.693	8.943	9.65	12.573	15.291	21.026	5.441	22.796	15.129	1.486	15	15.0 NON-RAMP
6.114	7.212	8.384	9.048	11.842	14.402	19.931	5.584	21.354	14.172	1.398	17.5	17.5 NON-RAMP
5.808	6.852	7.965	8.596	11.294	13.735	19.109	5.692	20.272	13.454	1.331	20	20.0 NON-RAMP
5.56	6.558	7.624	8.227	10.847	13.192	18.44	5.831	19.39	12.869	1.277	22.5	22.5 NON-RAMP
5.36	6.324	7.351	7.933	10.49	12.757	17.905	5.942	18.685	12.401	1.234	25	25 NON-RAMP
5.233	6.173	7.175	7.743	10.26	12.478	17.561	6.079	18.232	12.1	1.207	27.5	27.5 NON-RAMP
5.126	6.047	7.029	7.586	10.069	12.245	17.274	6.192	17.854	11.849	1.184	30	30 NON-RAMP
5.1	6.017	6.994	7.548	10.023	12.19	17.206	6.327	17.764	11.79	1.178	32.5	32.5 NON-RAMP
5.079	5.991	6.965	7.516	9.984	12.142	17.147	6.443	17.687	11.738	1.173	35	35 NON-RAMP
5.151	6.076	7.063	7.622	10.113	12.3	17.341	6.576	17.942	11.908	1.189	37.5	37.5 NON-RAMP
5.214	6.151	7.15	7.716	10.226	12.437	17.511	6.693	18.165	12.056	1.203	40	40 NON-RAMP
5.39	6.358	7.391	7.976	10.542	12.821	17.983	6.826	18.788	12.469	1.241	42.5	42.5 NON-RAMP
5.546	6.542	7.605	8.207	10.823	13.162	18.404	6.944	19.342	12.837	1.275	45	45 NON-RAMP
5.844	6.894	8.014	8.648	11.358	13.813	19.205	7.076	20.398	13.537	1.339	47.5	47.5 NON-RAMP
6.112	7.21	8.382	9.045	11.839	14.398	19.926	7.194	21.348	14.168	1.397	50	50 NON-RAMP
6.567	7.747	9.005	9.718	12.655	15.39	21.149	7.325	22.958	15.237	1.496	52.5	52.5 NON-RAMP
6.98	8.234	9.572	10.329	13.396	16.292	22.26	7.445	24.421	16.208	1.585	55	55 NON-RAMP
7.647	9.021	10.487	11.317	14.594	17.748	24.054	7.575	26.785	17.777	1.73	57.5	57.5 NON-RAMP
8.259	9.743	11.326	12.222	15.692	19.083	25.698	7.695	28.951	19.215	1.862	60	60 NON-RAMP
9.23	10.888	12.657	13.658	17.434	21.201	28.308	7.825	32.389	21.496	2.073	62.5	62.5 NON-RAMP
10.125	11.945	13.885	14.984	19.042	23.157	30.717	7.946	35.562	23.602	2.267	65	65 NON-RAMP
10.173	12.001	13.95	15.055	18.391	22.364	28.635	4.815	35.731	23.714	2.277	2.5	2.5 ARTERIAL
9.144	10.786	12.539	13.531	16.544	20.117	25.867	4.94	32.085	21.294	2.054	5	5 ARTERIAL
8.105	9.561	11.115	11.995	14.68	17.851	23.075	5.107	28.407	18.853	1.829	7.5	7.5 ARTERIAL
7.586	8.949	10.403	11.226	13.748	16.718	21.679	5.191	26.568	17.633	1.716	10	10.0 ARTERIAL
6.947	8.195	9.527	10.281	12.602	15.324	19.961	5.341	24.305	16.131	1.578	12.5	12.5 ARTERIAL
6.521	7.693	8.943	9.65	11.837	14.394	18.816	5.441	22.796	15.129	1.486	15	15.0 ARTERIAL
6.114	7.212	8.384	9.048	11.106	13.505	17.721	5.584	21.354	14.172	1.398	17.5	17.5 ARTERIAL
5.808	6.852	7.965	8.596	10.558	12.839	16.9	5.692	20.272	13.454	1.331	20	20.0 ARTERIAL
5.56	6.558	7.624	8.227	10.111	12.295	16.231	5.831	19.39	12.869	1.277	22.5	22.5 ARTERIAL
5.36	6.324	7.351	7.933	9.754	11.861	15.695	5.942	18.685	12.401	1.234	25	25 ARTERIAL
5.233	6.173	7.175	7.743	9.524	11.582	15.351	6.079	18.232	12.1	1.207	27.5	27.5 ARTERIAL
5.126	6.047	7.029	7.586	9.333	11.349	15.065	6.192	17.854	11.849	1.184	30	30 ARTERIAL
5.1	6.017	6.994	7.548	9.287	11.294	14.996	6.327	17.764	11.79	1.178	32.5	32.5 ARTERIAL
5.079	5.991	6.965	7.516	9.248	11.246	14.938	6.443	17.687	11.738	1.173	35	35 ARTERIAL
5.151	6.076	7.063	7.622	9.378	11.403	15.131	6.576	17.942	11.908	1.189	37.5	37.5 ARTERIAL
5.214	6.151	7.15	7.716	9.491	11.541	15.301	6.693	18.165	12.056	1.203	40	40 ARTERIAL
5.39	6.358	7.391	7.976	9.806	11.925	15.774	6.826	18.788	12.469	1.241	42.5	42.5 ARTERIAL
5.546	6.542	7.605	8.207	10.087	12.266	16.194	6.944	19.342	12.837	1.275	45	45 ARTERIAL
5.844	6.894	8.014	8.648	10.622	12.916	16.995	7.076	20.398	13.537	1.339	47.5	47.5 ARTERIAL
6.112	7.21	8.382	9.045	11.103	13.502	17.717	7.194	21.348	14.168	1.397	50	50 ARTERIAL
6.567	7.747	9.005	9.718	11.919	14.494	18.939	7.325	22.958	15.237	1.496	52.5	52.5 ARTERIAL
6.98	8.234	9.572	10.329	12.661	15.396	20.05	7.445	24.421	16.208	1.585	55	55 ARTERIAL
7.647	9.021	10.487	11.317	13.858	16.852	21.844	7.575	26.785	17.777	1.73	57.5	57.5 ARTERIAL
8.259	9.743	11.326	12.222	14.956	18.187	23.488	7.695	28.951	19.215	1.862	60	60 ARTERIAL
9.23	10.888	12.657	13.658	16.698	20.305	26.098	7.825	32.389	21.496	2.073	62.5	62.5 ARTERIAL
10.125	11.945	13.885	14.984	18.306	22.26	28.507	7.946	35.562	23.602	2.267	65	65 ARTERIAL

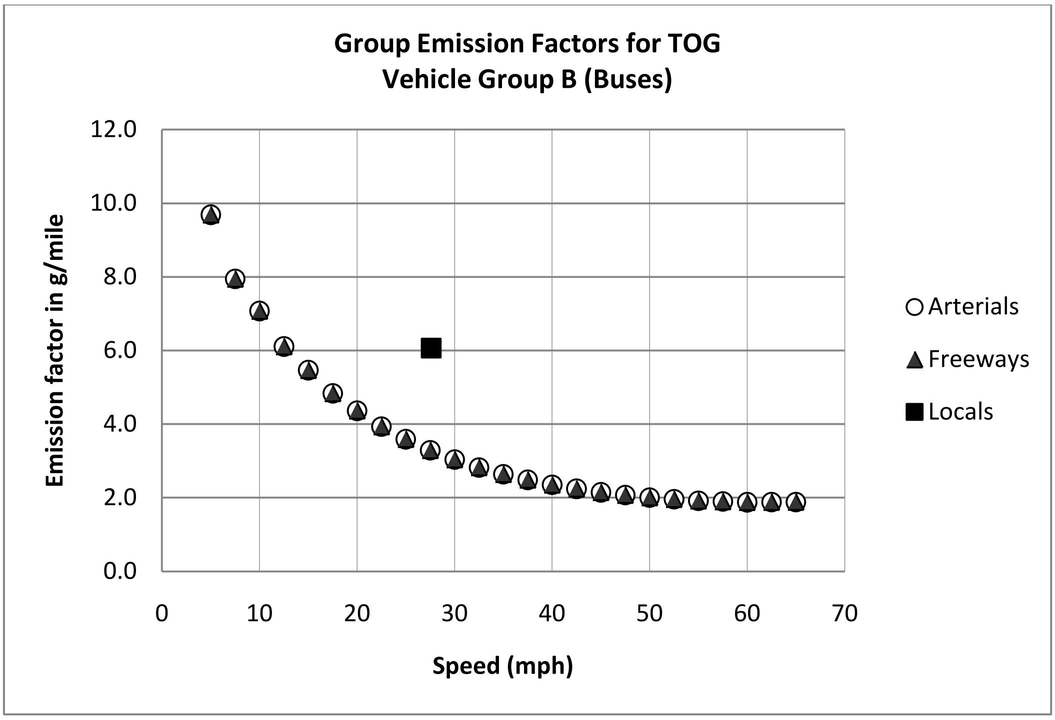
Poll	LDGV	LDGT1	LDGT2	LDGT3	LDGT4	HDGV2B	HDGV3	HDGV4	HDGV5	HDGV6	HDGV7	HDGV8A	LDDT12
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7
CO2	349.6	456.5	455.2	584.5	584.2	815.7	850.3	794.8	987.5	994.1	1051.7	1101.1	377.7

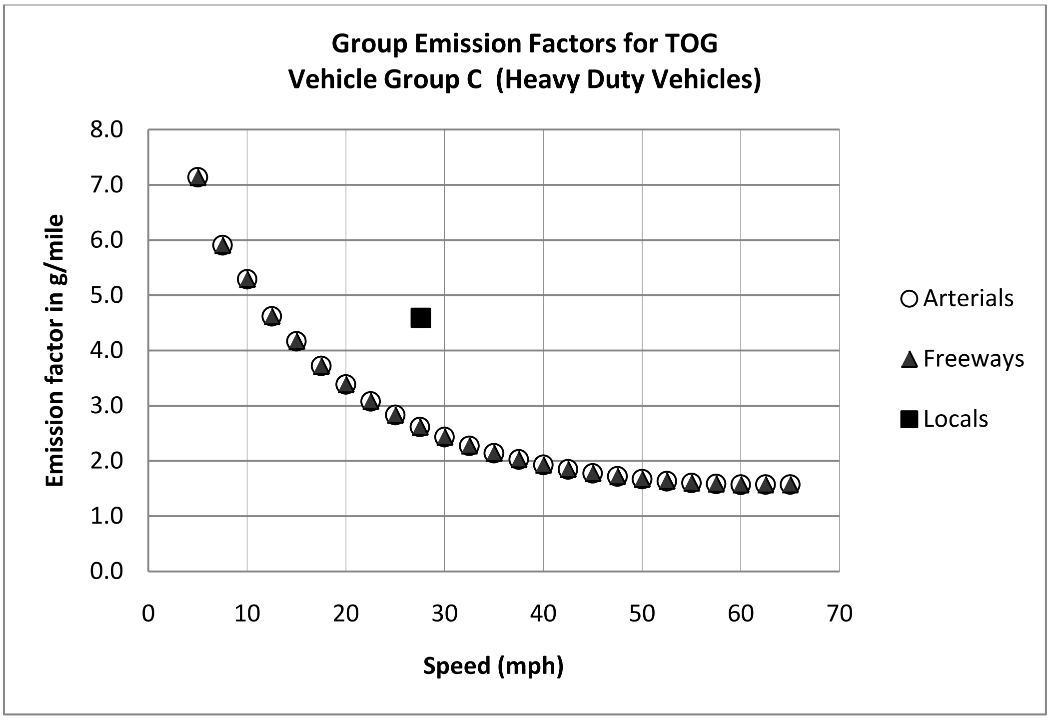
HDDV2E	HDDV3	HDDV4	HDDV5	HDDV6	HDDV7	HDDV8A	GAS BUS	URB BUS	COM BU	LDDT34	Avg Spd	Description
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	27.6	LOCAL
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	2.5	2.5 NON-RAMP
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	5	5 NON-RAMP
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	7.5	7.5 NON-RAMP
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	10	10.0 NON-RAMP
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	12.5	12.5 NON-RAMP
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	15	15.0 NON-RAMP
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	17.5	17.5 NON-RAMP
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	20	20.0 NON-RAMP
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	22.5	22.5 NON-RAMP
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	25	25 NON-RAMP
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	27.5	27.5 NON-RAMP
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	30	30 NON-RAMP
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	32.5	32.5 NON-RAMP
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	35	35 NON-RAMP
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	37.5	37.5 NON-RAMP
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	40	40 NON-RAMP
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	42.5	42.5 NON-RAMP
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	45	45 NON-RAMP
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	47.5	47.5 NON-RAMP
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	50	50 NON-RAMP
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	52.5	52.5 NON-RAMP
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	55	55 NON-RAMP
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	57.5	57.5 NON-RAMP
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	60	60 NON-RAMP
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	62.5	62.5 NON-RAMP
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	65	65 NON-RAMP
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	2.5	2.5 ARTERIAL
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	5	5 ARTERIAL
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	7.5	7.5 ARTERIAL
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	10	10.0 ARTERIAL
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	12.5	12.5 ARTERIAL
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	15	15.0 ARTERIAL
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	17.5	17.5 ARTERIAL
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	20	20.0 ARTERIAL
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	22.5	22.5 ARTERIAL
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	25	25 ARTERIAL
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	27.5	27.5 ARTERIAL
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	30	30 ARTERIAL
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	32.5	32.5 ARTERIAL
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	35	35 ARTERIAL
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	37.5	37.5 ARTERIAL
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	40	40 ARTERIAL
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	42.5	42.5 ARTERIAL
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	45	45 ARTERIAL
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	47.5	47.5 ARTERIAL
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	50	50 ARTERIAL
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	52.5	52.5 ARTERIAL
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	55	55 ARTERIAL
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	57.5	57.5 ARTERIAL
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	60	60 ARTERIAL
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	62.5	62.5 ARTERIAL
790.5	870.3	991	1022.5	1159.6	1333.8	1533.1	1045.4	2322.5	1619.5	589.9	65	65 ARTERIAL

Annex F Plots, Speed Regression Equations and constant values for TOG, CO, NO_x and CO_2 Average Emission Factors for three vehicle groups

Total Organic Compounds

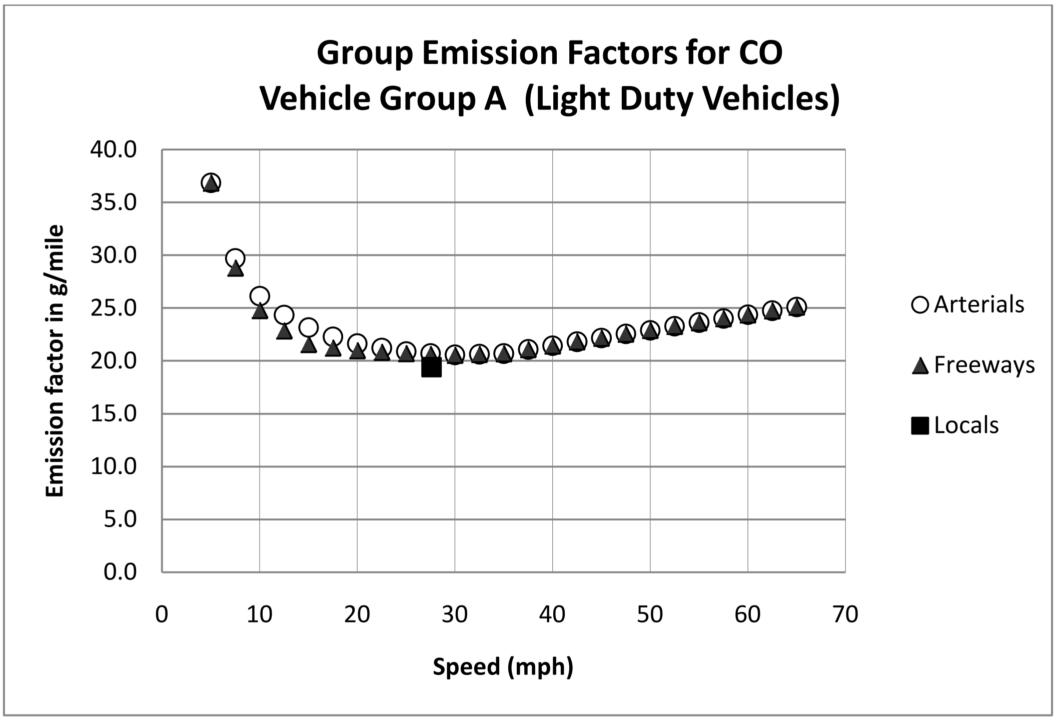


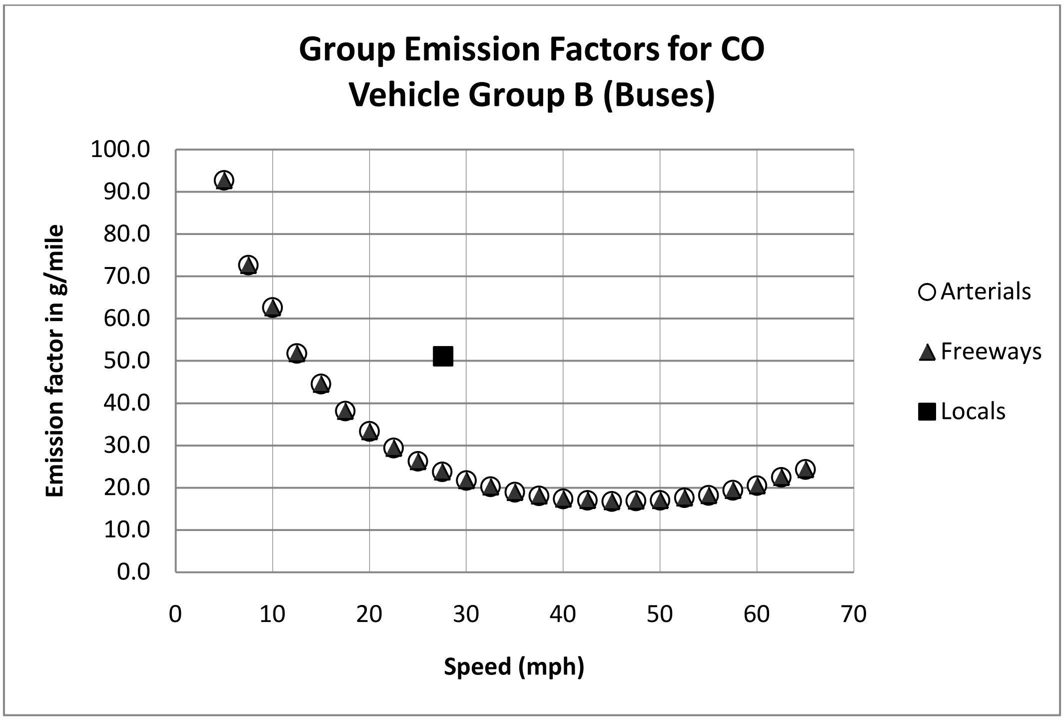


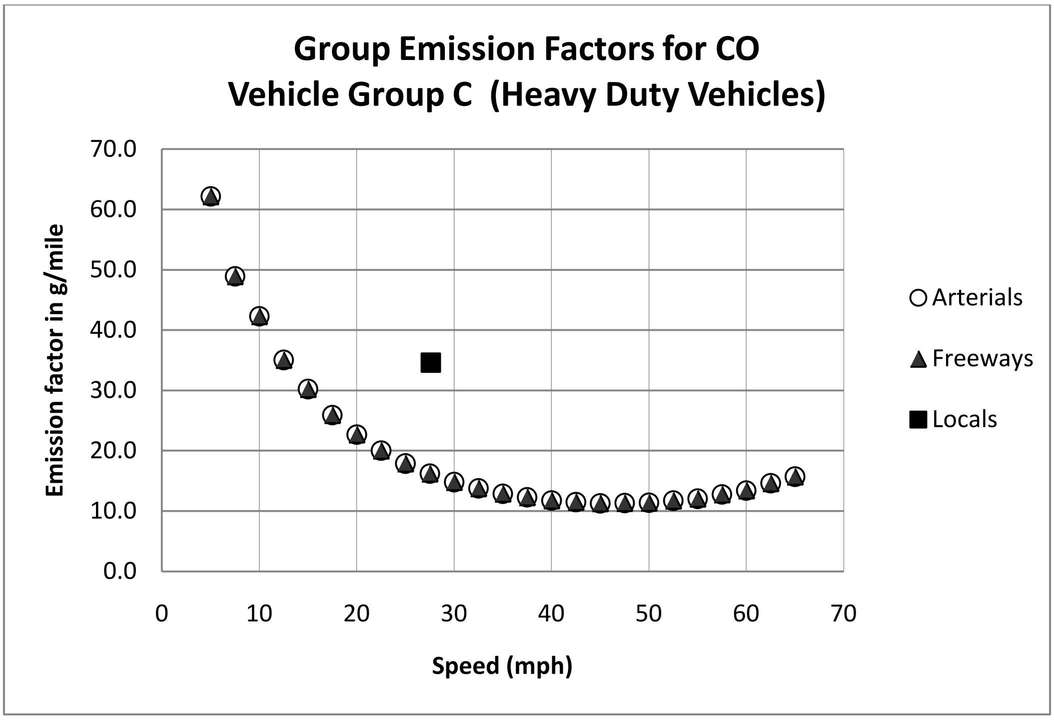


<table>
<tr><th colspan="5">TOG Speed Regression Equations and constant values for emission factors</th></tr>
<tr><th rowspan="2">Speed Range</th><th rowspan="2">Facility Type</th><th colspan="3">Vehicle Group</th></tr>
<tr><th>A</th><th>B</th><th>C</th></tr>
<tr><td><2.5mph</td><td></td><td>13.47</td><td>12.71</td><td>9.52</td></tr>
<tr><td rowspan="3">2.5 - 65 mph</td><td>LOCAL</td><td>3</td><td>6.06</td><td>4.58</td></tr>
<tr><td>ARTERIAL</td><td>y = 0.0000000039x6 - 0.0000009060x5 + 0.0000850405x4 - 0.0040738043x3 + 0.1053318005x2 - 1.4244985551x + 10.5816903254</td><td rowspan="2">y = 0.0000000019x6 - 0.0000004455x5 + 0.0000425195x4 - 0.0021368717x3 + 0.0628876805x2 - 1.1652340364x + 14.1075889068</td><td rowspan="2">y = 0.0000000014x6 - 0.0000003279x5 + 0.0000311576x4 - 0.0015539482x3 + 0.0451903199x2 - 0.8276455694x + 10.2680227588</td></tr>
<tr><td>FREEWAYS</td><td>y = 0.0000000041x6 - 0.0000009710x5 + 0.0000917331x4 - 0.0044185659x3 + 0.1144269857x2 - 1.5332881326x + 10.9422898210</td></tr>
<tr><td>>65 mph</td><td></td><td>1.98</td><td>1.88</td><td>1.57</td></tr>
</table>

Carbon Monoxide

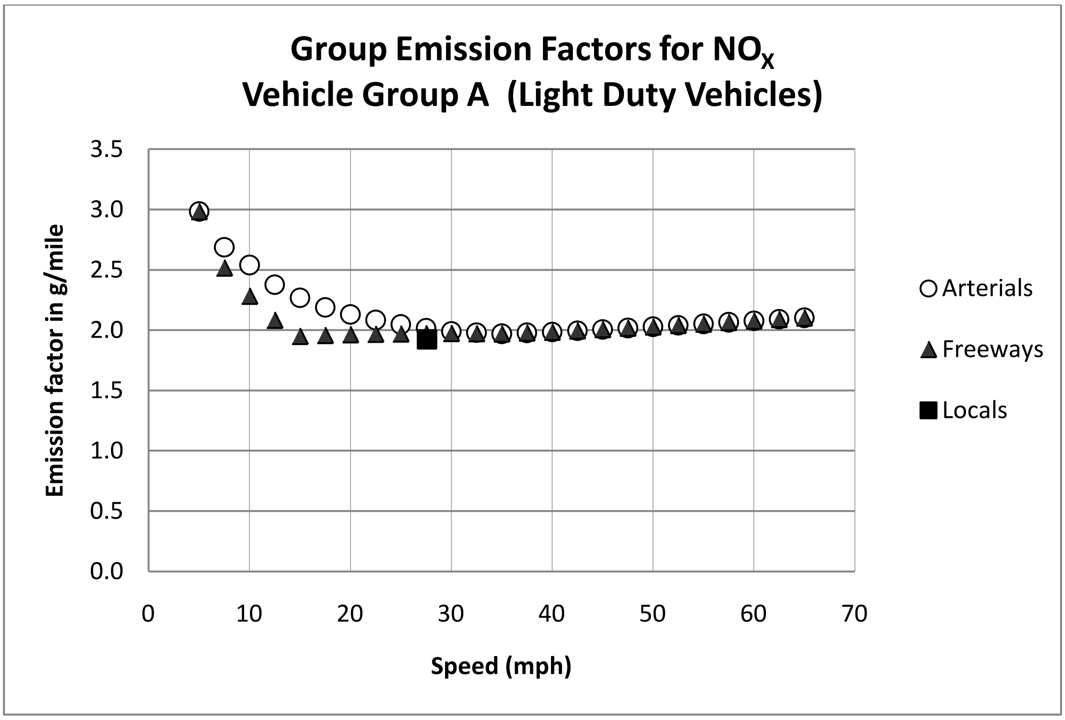


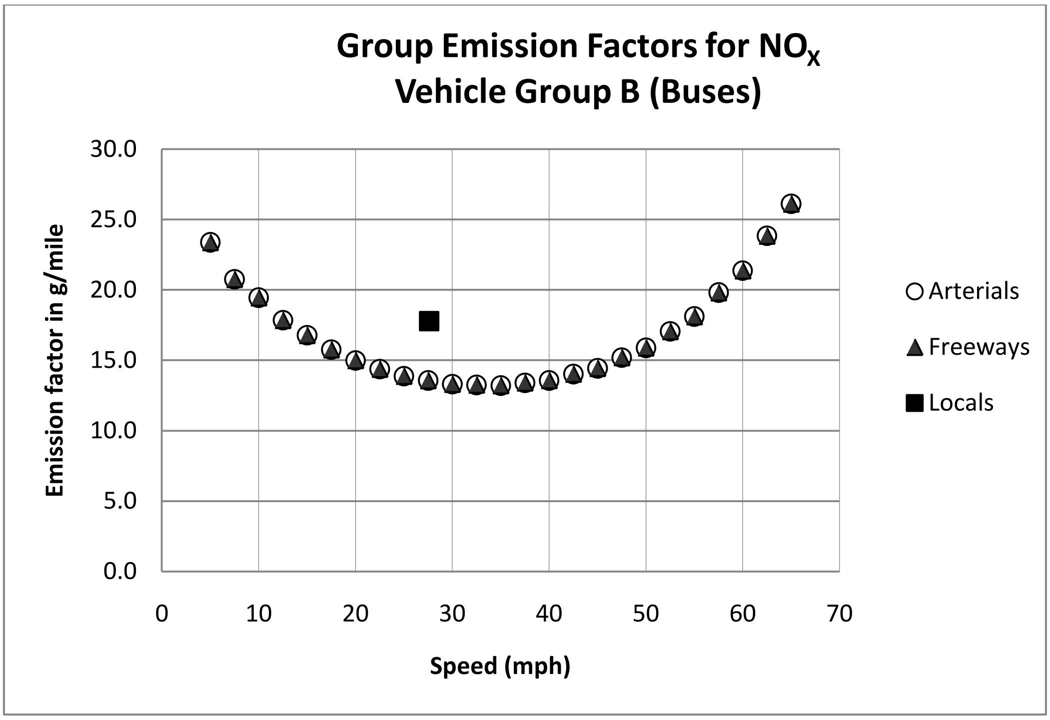


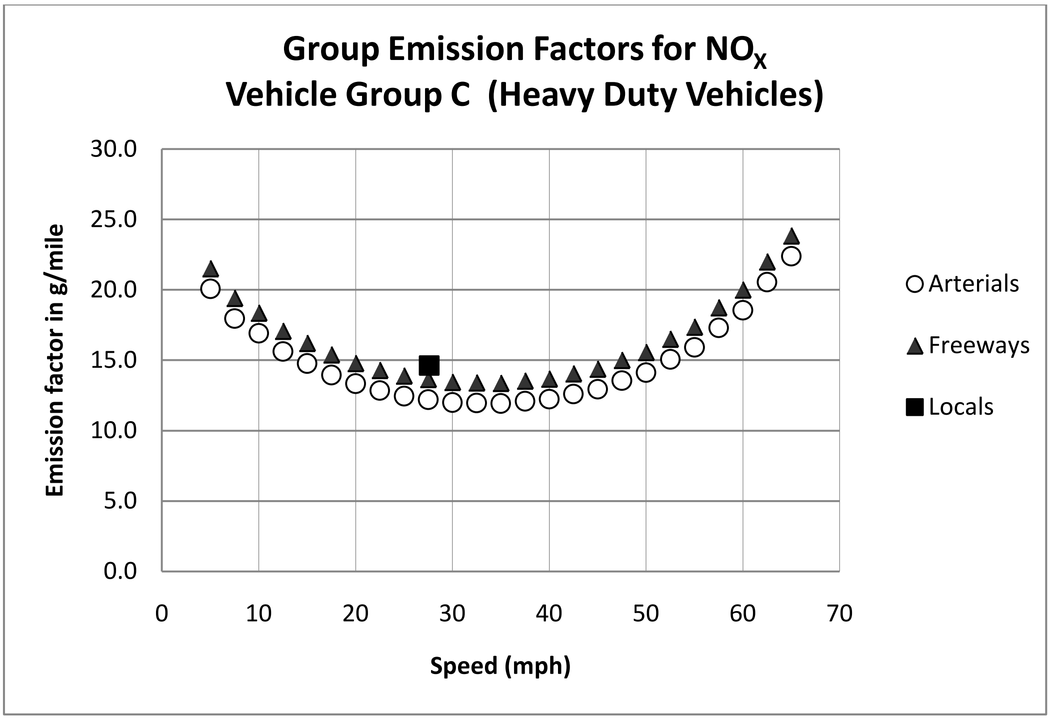


<table>
<tr><td colspan="5">CO Speed Regression Equations and constant values according to speed ranges</td></tr>
<tr><td rowspan="2">Speed Range</td><td rowspan="2">Facility Type</td><td colspan="3">Vehicle group</td></tr>
<tr><td>A</td><td>B</td><td>C</td></tr>
<tr><td><2.5mph</td><td></td><td>60.7</td><td>115.06</td><td>76.82</td></tr>
<tr><td rowspan="3">2.5 - 65 mph</td><td>LOCAL</td><td>19.4</td><td>51.09</td><td>34.59</td></tr>
<tr><td>ARTERIAL</td><td>y = 0.0000000212x6 - 0.0000048819x5 + 0.0004460586x4 - 0.0207415846x3 + 0.5243347626x2 - 7.0010945903x + 60.7359740692</td><td rowspan="2">y = 0.0000000191x6 - 0.0000045602x5 + 0.0004486414x4 - 0.0235343137x3 + 0.7271891582x2 - 13.6045951714x + 144.4626911587</td><td rowspan="2">y = 0.0000000124x6 - 0.0000029617x5 + 0.0002913257x4 - 0.0152882004x3 + 0.4735920709x2 - 8.9256292360x + 96.1715062875</td></tr>
<tr><td>FREEWAYS</td><td>y = 0.0000000254x6 - 0.0000059416x5 + 0.0005524238x4 - 0.0260864734x3 + 0.6620496240x2 - 8.6144832653x + 66.0330985010</td></tr>
<tr><td>>65 mph</td><td></td><td>25.11</td><td>24.33</td><td>15.7</td></tr>
</table>

Nitrogen Oxides

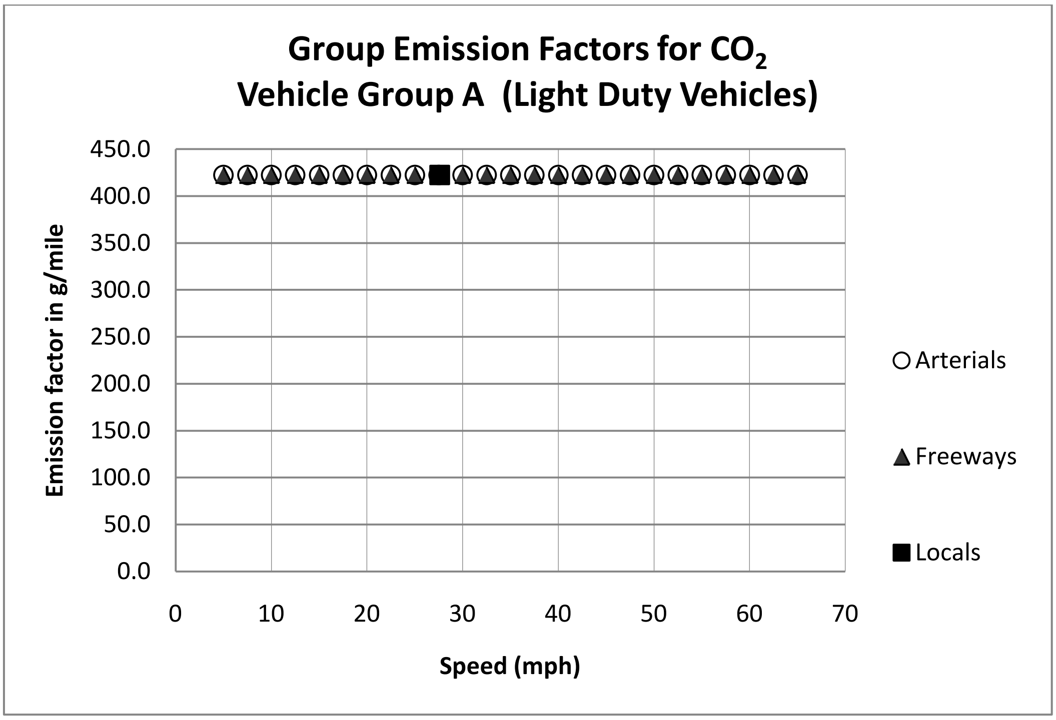


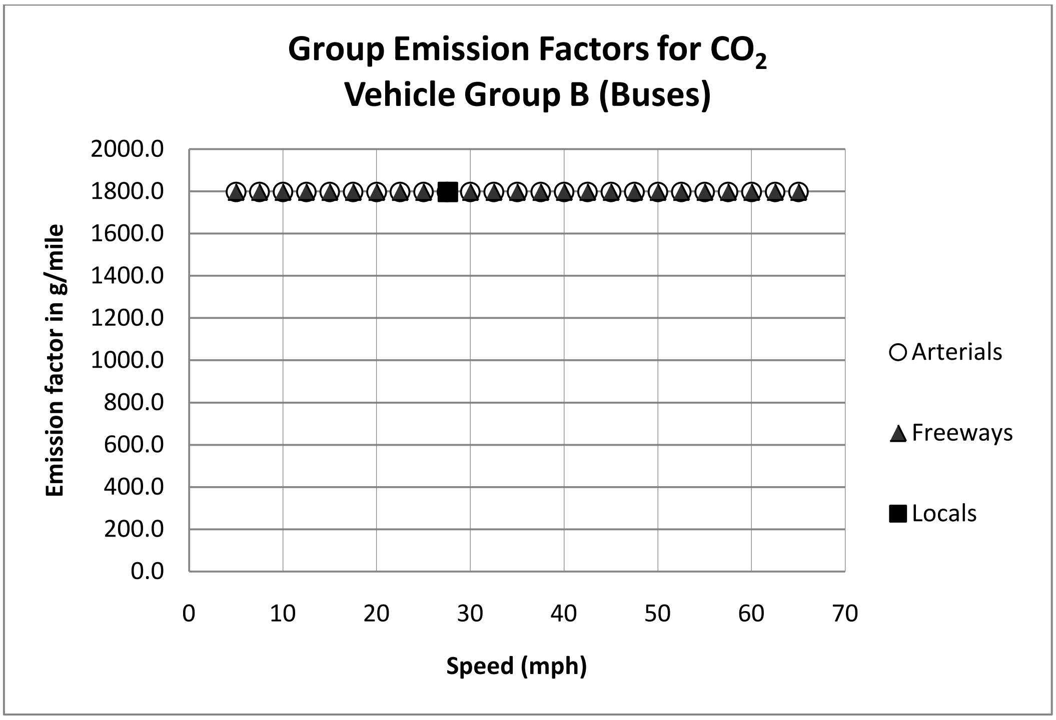


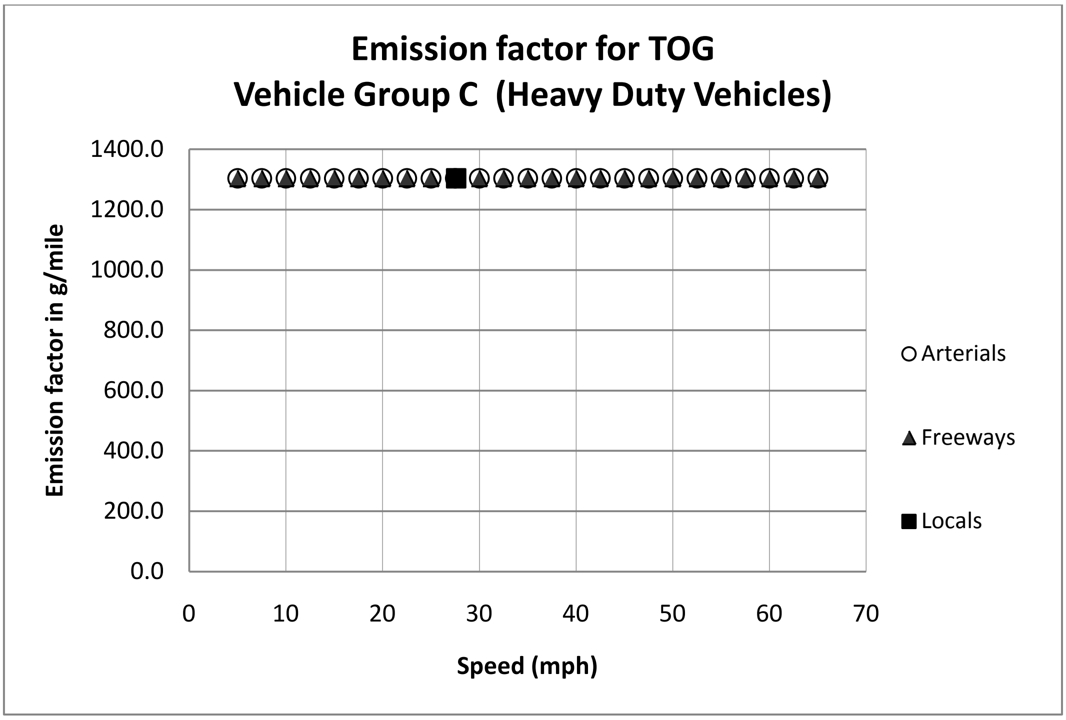


<table>
<tr><th colspan="5">NOX Speed Regression Equations and constant values according to speed ranges</th></tr>
<tr><th rowspan="2">Speed Range</th><th rowspan="2">Facility Type</th><th colspan="3">Vehicle group</th></tr>
<tr><th>A</th><th>B</th><th>C</th></tr>
<tr><td><2.5mph</td><td></td><td>3.35</td><td>25.98</td><td>23.61</td></tr>
<tr><td rowspan="3">2.5 - 65 mph</td><td>LOCAL</td><td>1.92</td><td>17.77</td><td>14.62</td></tr>
<tr><td>ARTERIAL</td><td>0.0000000004x6 - 0.0000001000x5 + 0.0000092880x4 - 0.0004534770x3 + 0.0129691267x2 - 0.2217538809x + 3.8107543055</td><td rowspan="2">0.0000000017x6 - 0.0000003679x5 + 0.0000360034x4 - 0.0019166897x3 + 0.0663122185x2 - 1.5139120920x + 29.3922899654</td><td>0.0000000013x6 - 0.0000002950x5 + 0.0000288867x4 - 0.0015392057x3 + 0.0533196196x2 - 1.2166588578x + 24.9016128593</td></tr>
<tr><td>FREEWAYS</td><td>0.0000000009x6 - 0.0000002281x5 + 0.0000232052x4 - 0.0012095029x3 + 0.0339729893x2 - 0.4850977690x + 4.6983530188</td><td>0.0000000013x6 - 0.0000002961x5 + 0.0000289754x4 - 0.0015426427x3 + 0.0533856614x2 - 1.2172446854x + 26.3536415269</td></tr>
<tr><td>>65 mph</td><td></td><td>2.1</td><td>26.13</td><td>23.85</td></tr>
</table>

Carbon Dioxide

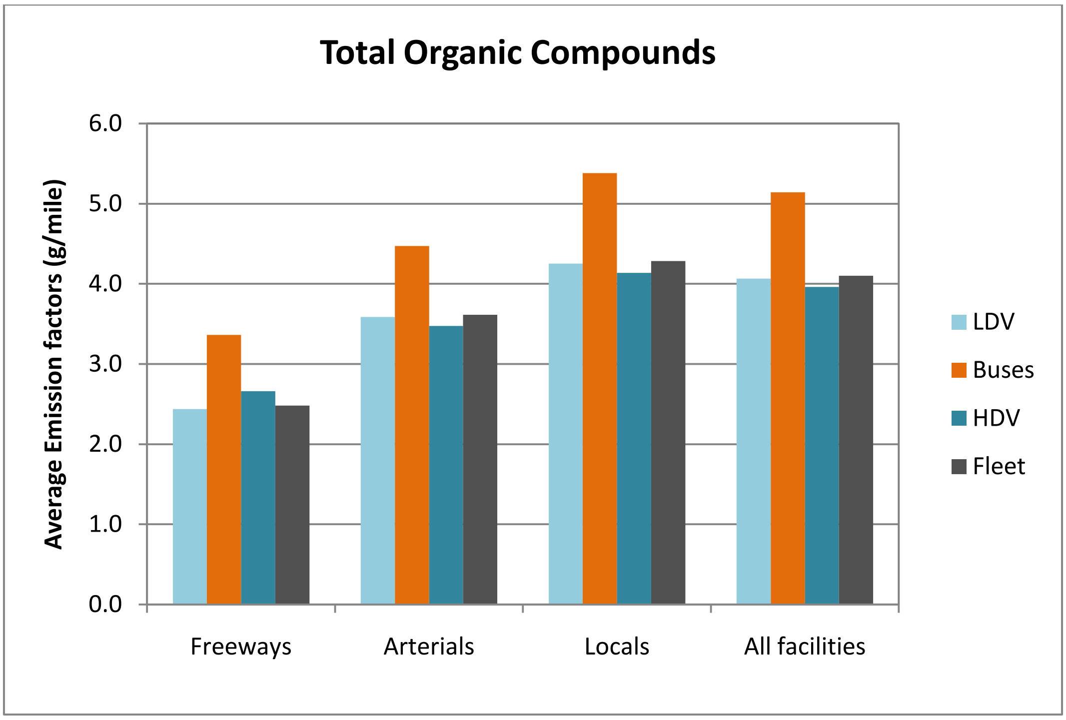


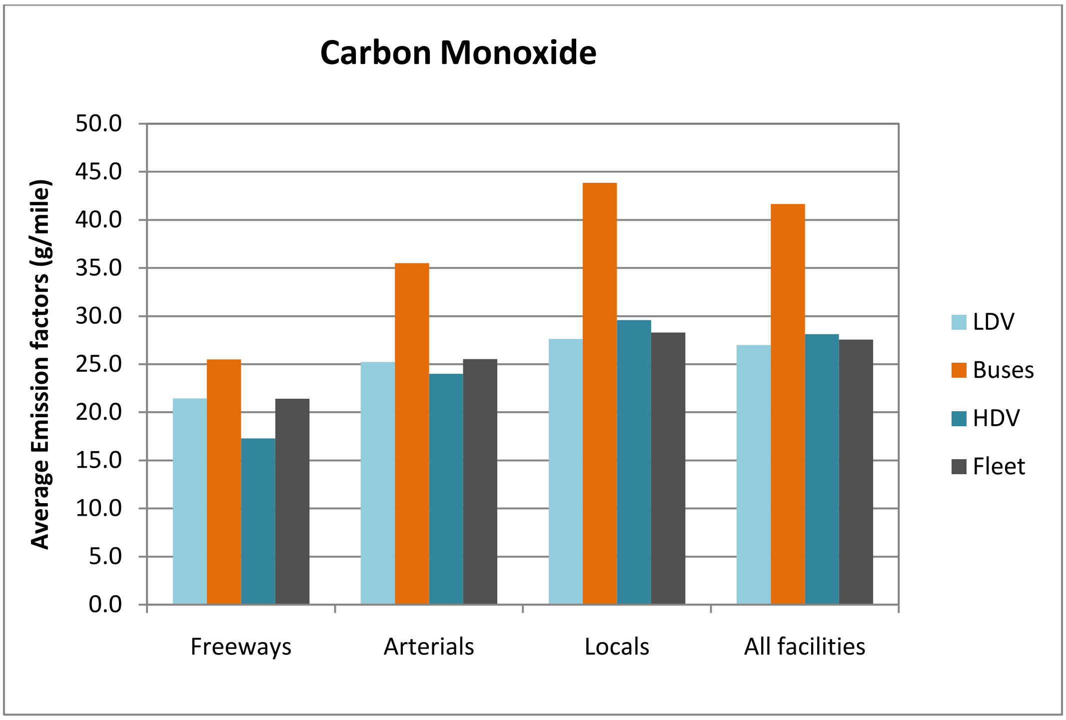


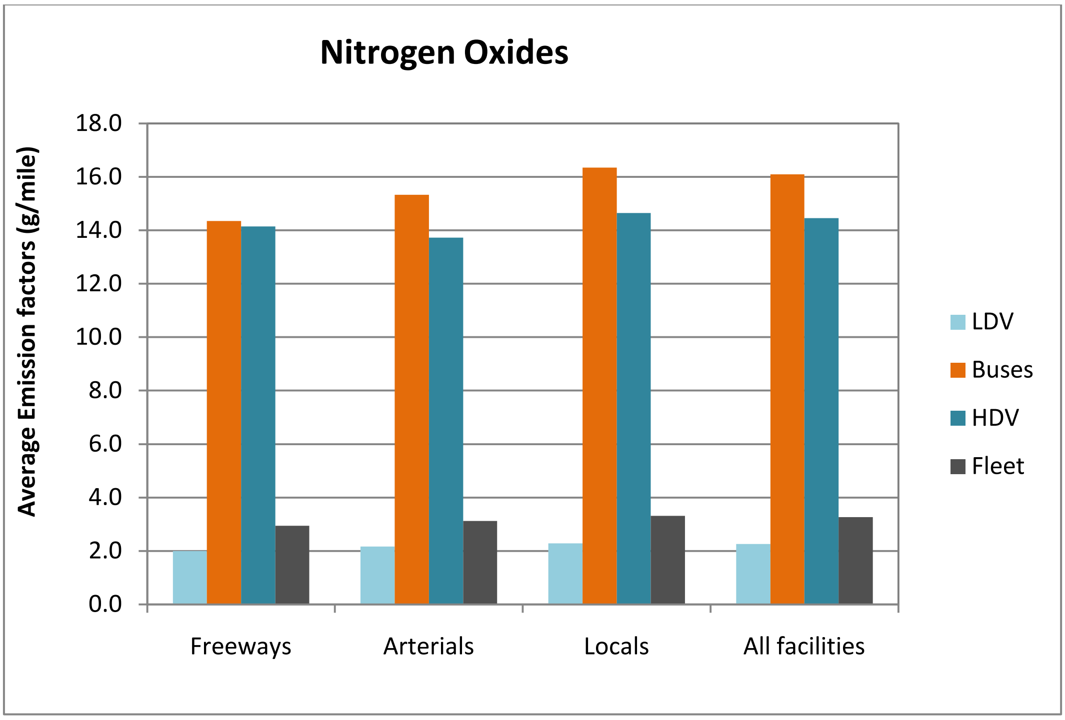


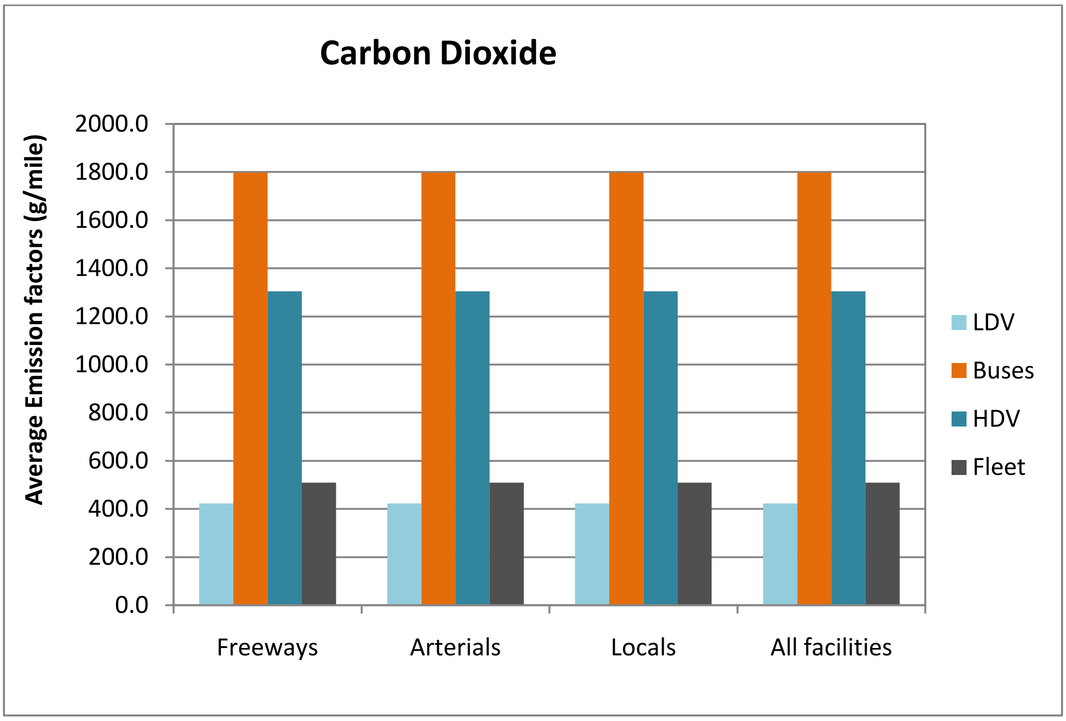
CO2				
Speed Range	Facility Type	Vehicle group		
		A	B	C
ALL	ALL	422.4717713	1797.237288	1303.922476

Annex G Average Emission Factors by facility type and vehicle groups.



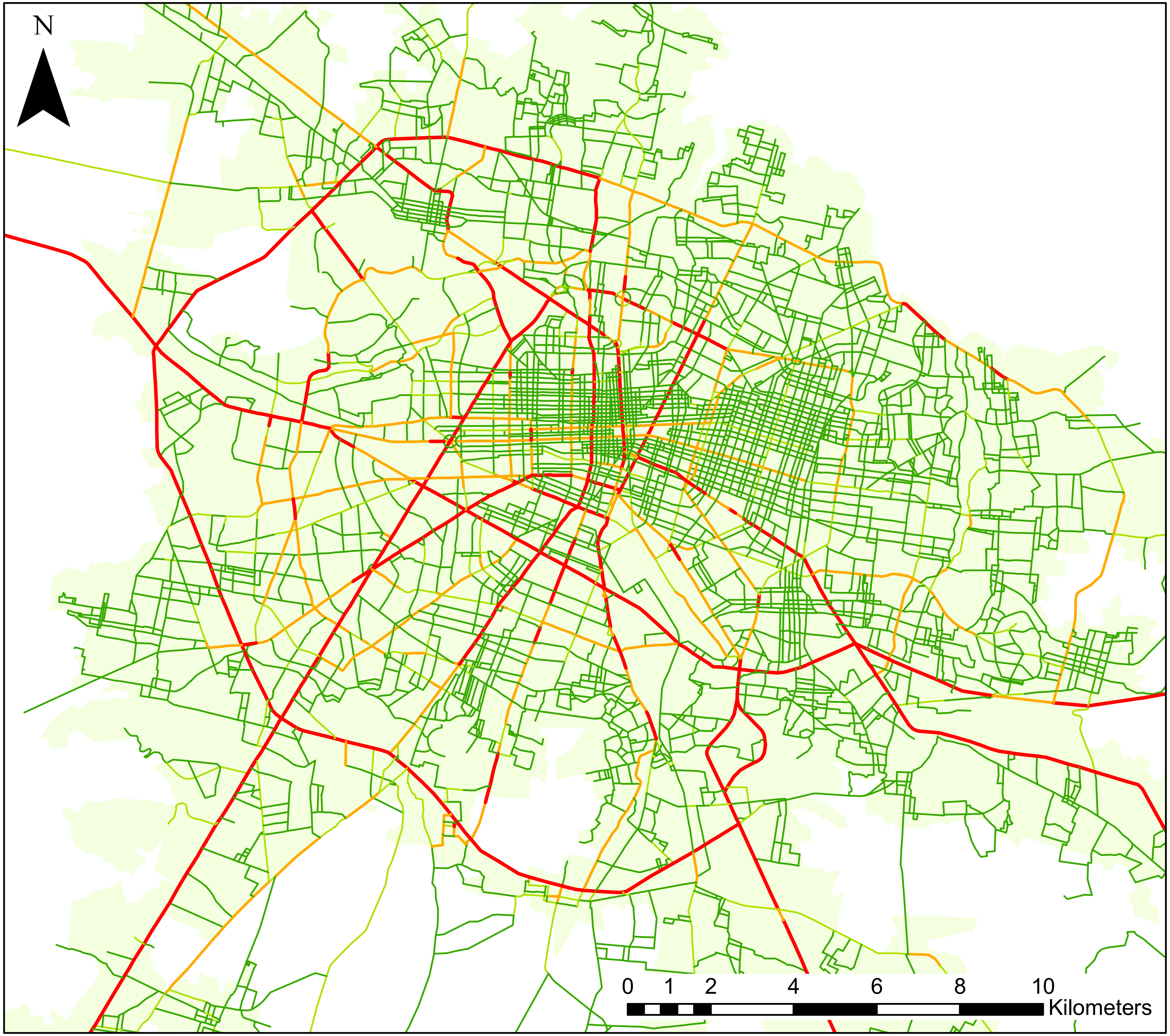



Nitrogen Oxides
Average Emission factors (g/mile)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Freeways
Arterials
Locals
All facilities
LDV
Buses
HDV
Fleet

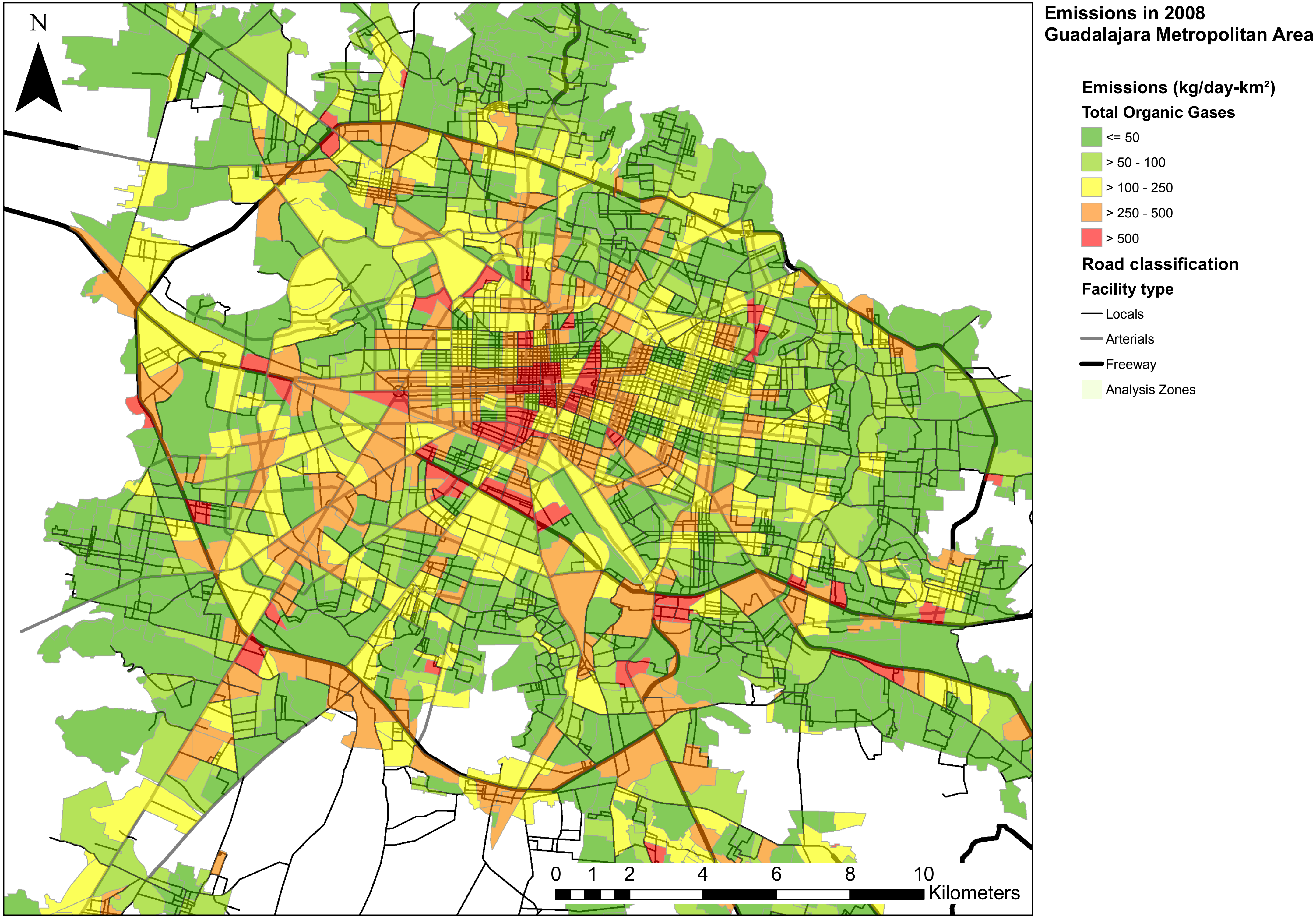

Carbon Dioxide
Average Emission factors (g/mile)
2000.0
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
Freeways
Arterials
Locals
All facilities
LDV
Buses
HDV
Fleet

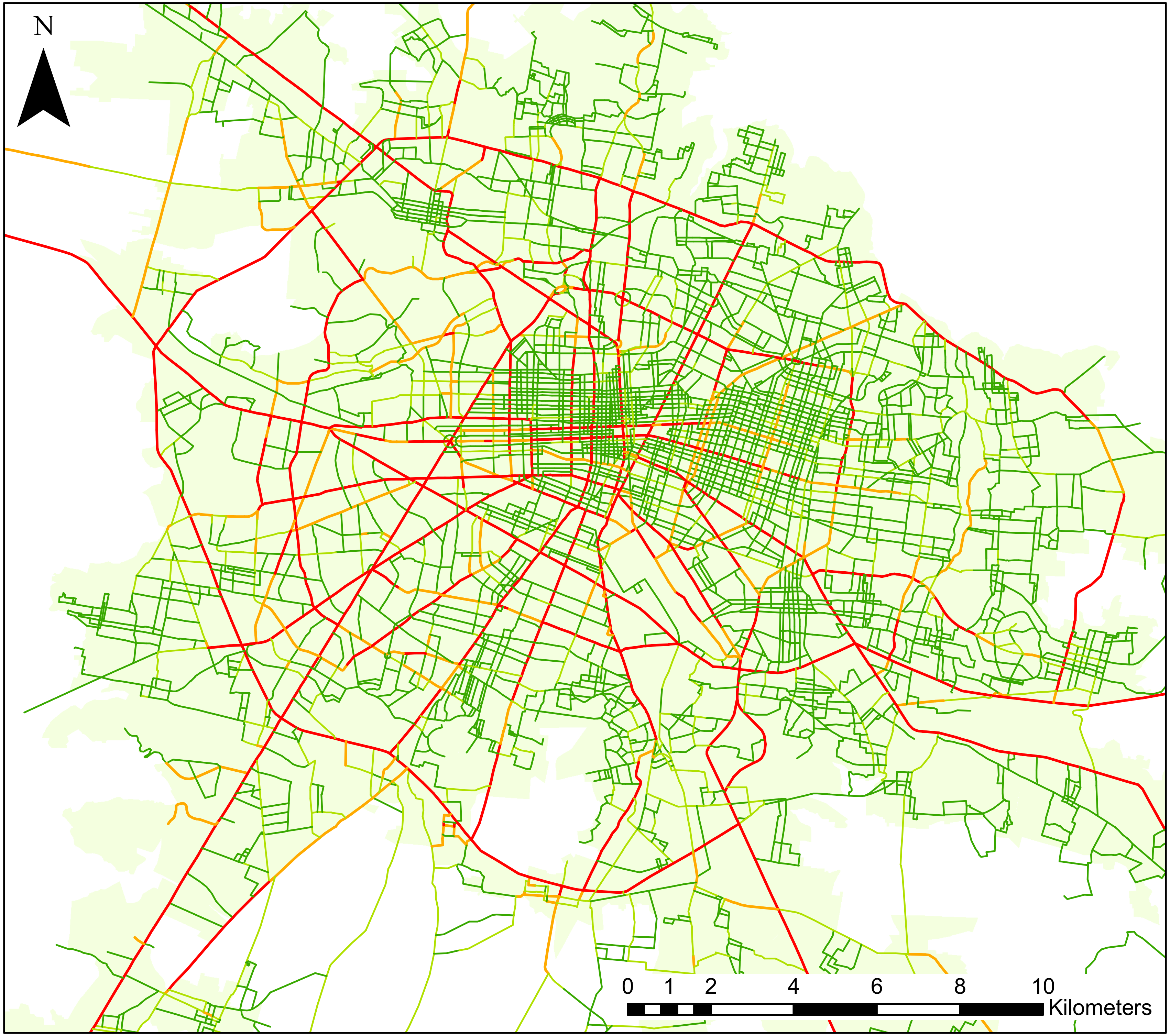
Annex H

In the next pages, maps of the transportation network showing emission levels per street and analysis area are presented. Those maps correspond to total organic gases, carbon monoxide, nitrogen oxides and carbon dioxide in that order.



Emissions in 2008
Guadalajara Metropolitan Area


N
Emissions in 2008
Guadalajara Metropolitan Area
Emissions (kg/day-km²)
Total Organic Gases
<= 50
> 50 - 100
> 100 - 250
> 250 - 500
> 500
Road classification
Facility type
Locals
Arterials
Freeway
Analysis Zones
0 1 2 4 6 8 10
Kilometers

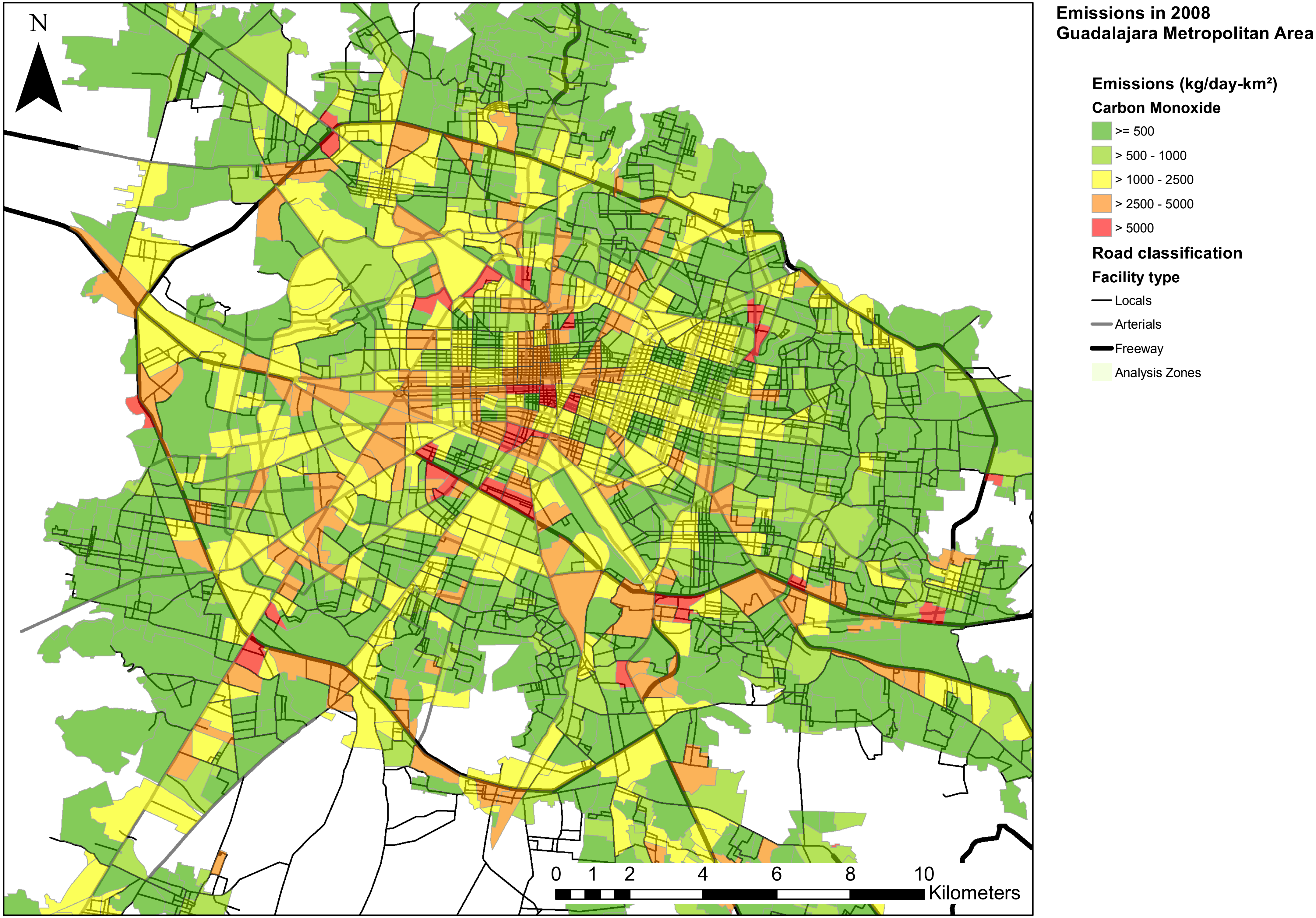


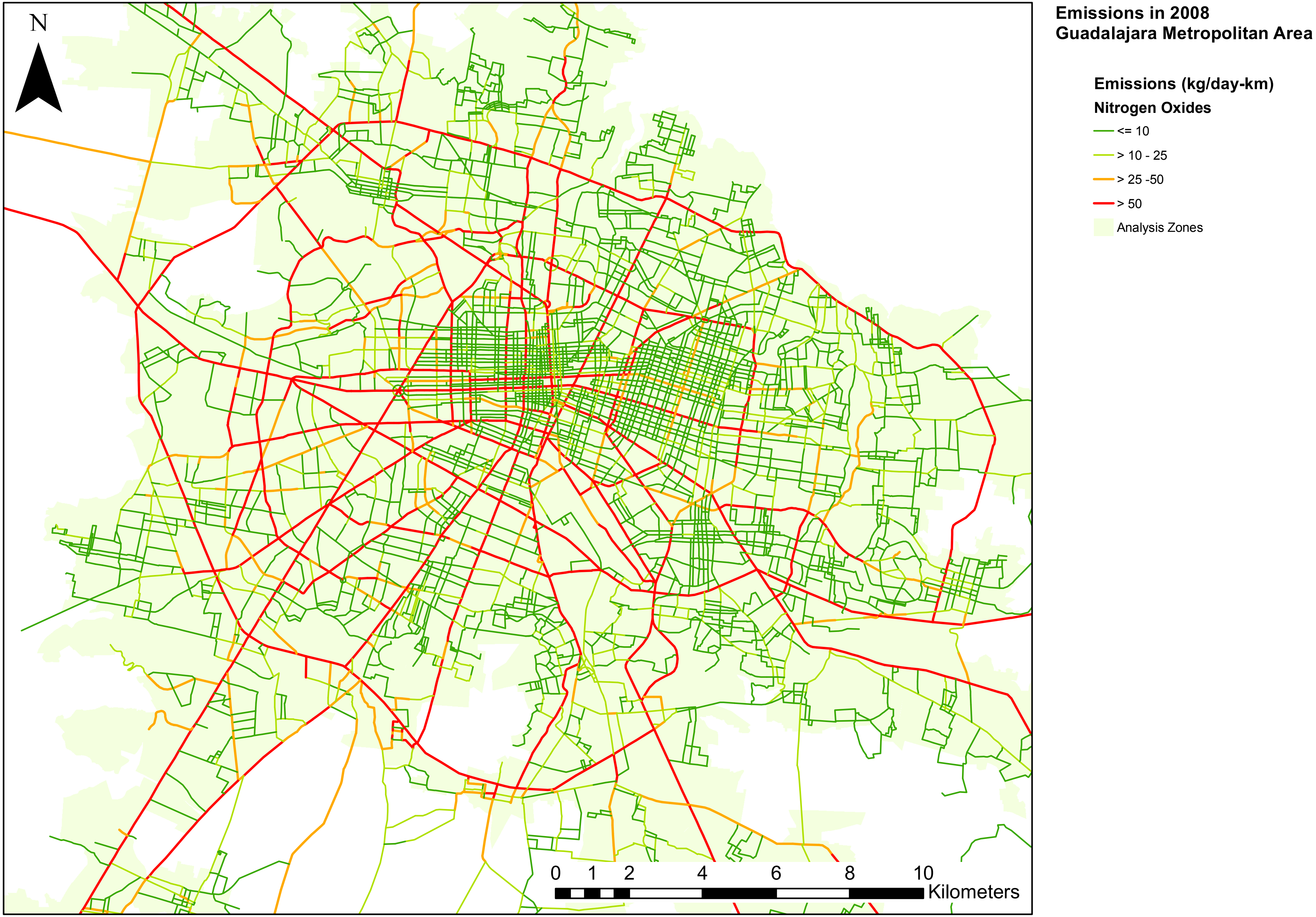
Emissions in 2008
Guadalajara Metropolitan Area

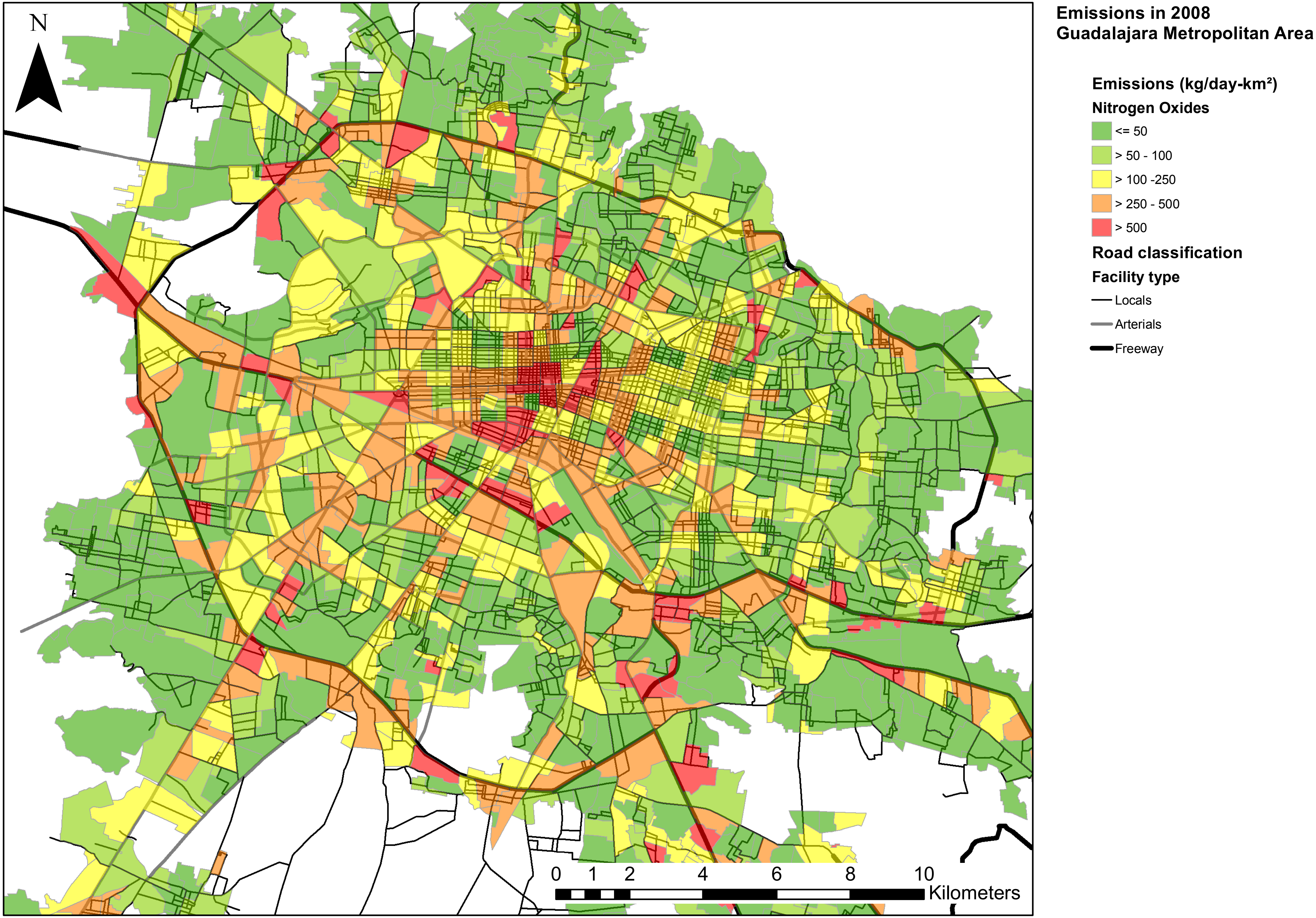
Emissions (kg/day-km)

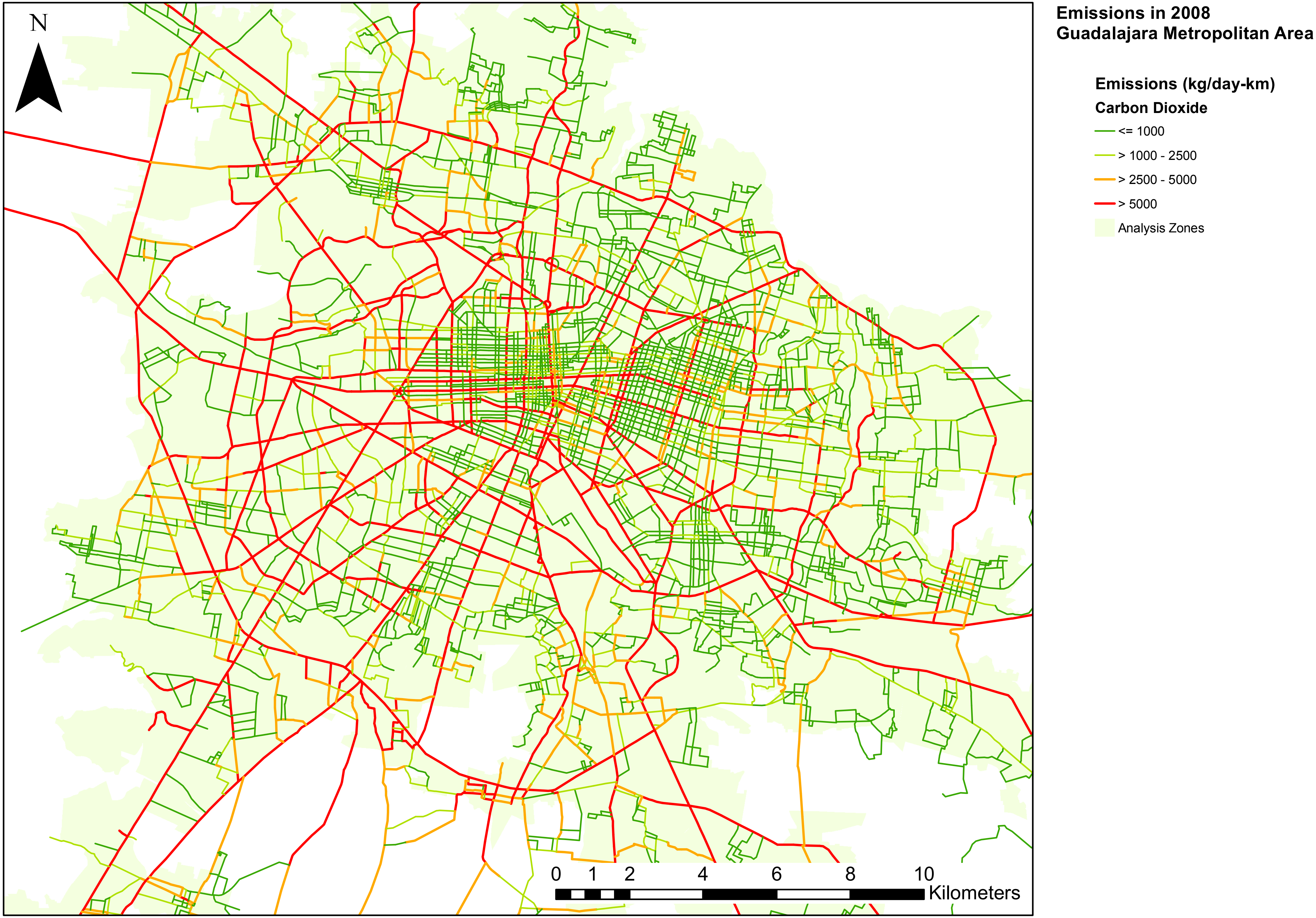
Carbon Monoxide

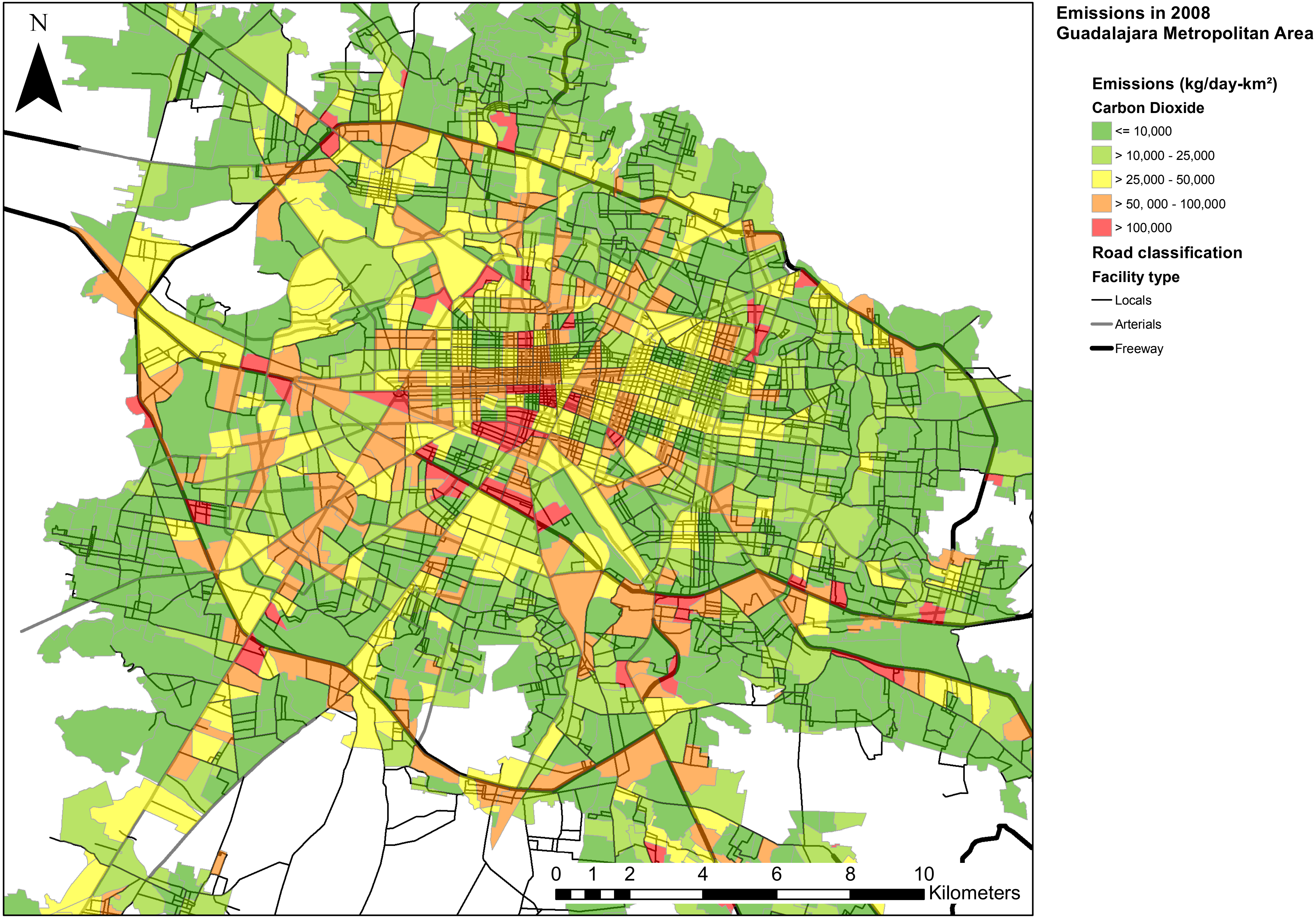
- <= 100
- > 100 - 250
- > 250 - 500
- > 500
- Analysis Zones


N
Emissions in 2008
Guadalajara Metropolitan Area
Emissions (kg/day-km²)
Carbon Monoxide
>= 500
> 500 - 1000
> 1000 - 2500
> 2500 - 5000
> 5000
Road classification
Facility type
Locals
Arterials
Freeway
Analysis Zones
0 1 2 4 6 8 10
Kilometers


N
0 1 2 4 6 8 10
Kilometers
Emissions in 2008
Guadalajara Metropolitan Area
Emissions (kg/day-km)
Nitrogen Oxides
<= 10
> 10 - 25
> 25 -50
> 50
Analysis Zones


N
0 1 2 4 6 8 10
Kilometers
Emissions in 2008
Guadalajara Metropolitan Area
Emissions (kg/day-km²)
Nitrogen Oxides
<= 50
> 50 - 100
> 100 -250
> 250 - 500
> 500
Road classification
Facility type
Locals
Arterials
Freeway


N
Emissions in 2008
Guadalajara Metropolitan Area
Emissions (kg/day-km)
Carbon Dioxide
<= 1000
> 1000 - 2500
> 2500 - 5000
> 5000
Analysis Zones
0 1 2 4 6 8 10
Kilometers



N
Emissions in 2008
Guadalajara Metropolitan Area
Emissions (kg/day-km²)
Carbon Dioxide
<= 10,000
> 10,000 - 25,000
> 25,000 - 50,000
> 50, 000 - 100,000
> 100,000
Road classification
Facility type
Locals
Arterials
Freeway
0 1 2 4 6 8 10
Kilometers