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MEASURING THE INVISIBLE

QUANTIFYING EMISSIONS REDUCTIONS FROM TRANSPORT SOLUTIONS

Querétaro Case Study

LEAD AUTHOR
MARIA CORDEIRO

CONTRIBUTING AUTHORS
LEE SCHIPPER
DIANA NORIEGA

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ROBYN LISKA
EDITOR

HYACINTH BILLINGS
PUBLICATIONS DIRECTOR

MAGGIE POWELL
LAYOUT

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EXECUTIVE SUMMARY

The state of Querétaro, located in the central region of Mexico, has seen a steady population increase in recent years as a result of favorable economic growth and proximity to Mexico City. The municipality of Querétaro, the principal urban center in the state where most of the economic activity, services and jobs are concentrated, is planning to implement a Bus Rapid Transit (BRT) corridor with the goal of reducing congestion and providing a more efficient public transportation service to the citizens of Querétaro.

The US Environmental Protection Agency contracted EMBARQ - The WRI Center for Sustainable Transport - to provide technical assistance to the government authorities of Querétaro. EMBARQ worked closely with local partners to estimate the impact of the BRT corridor on local and global emissions by evaluating the introduction of alternative fuels and emission control technologies in the BRT trunk route fleet; the reduction of the overall bus fleet by half its size; and the removal of the oldest buses and those operating on gasoline and liquid petroleum gas. This study provides an estimate of the emissions resulting from the current bus network and the expected emission reductions from six different BRT project scenarios.

The results of this study indicate that the introduction of the BRT corridor and improved efficiency of the bus network could yield extensive emissions reductions from Querétaro's bus fleet. Emissions of CO₂ are projected to fall by more than 85% from the current level - 165,220 tons per year - to an estimated 21,819 tons. Emissions of criteria pollutants are also projected to dramatically decrease between 80 and 95%. Clearly, the potential gains in economic and health terms are considerable. The projected reductions are made possible by carefully

mapping transport capacity to demand, thereby allowing for the removal of almost half of the buses from operation. The first buses to be retired would be the oldest and most polluting. Thus, not only would there be fewer buses in operation, but these buses would each cover on average 64% fewer kilometers per year than those of the existing fleet.

Conversely, while all the scenarios yield dramatic benefits, there is not much difference between them. While different fuel and engine choices do perform somewhat better than others on individual pollutants, these differences are typically on the order of 10% and no single choice performs better than the others across all pollutants. The reason for this small variation between the BRT scenarios is that the alternative fuels and emission control technologies, which were the distinguishing feature between the scenarios, were only applied to 18 buses operating on the trunk route. The 18 buses will run 4,444 km per year, the equivalent of 4% of the total distance to be traveled on city's bus system.

Given the costs of switching fuels and the relatively small benefits from doing so for a limited fleet, the project team recommends that the introduction of the BRT corridor be linked with a particular focus on improving the entire system's efficiency and the use of the available 350 ppm sulfur diesel throughout the fleet. Diesel with lower sulfur content (15 ppm) was to be made available in September 2007, and the use of this upgraded fuel should be kept under consideration. Further study would be needed to estimate the benefits to be gained by adopting alternative fuels and emission control technologies across the whole city's bus fleet, but that analysis is beyond the scope of this report.

INTRODUCTION, OBJECTIVES AND SCOPE

All over the world, transportation projects are changing the way people and goods move, with direct and indirect impacts on global and local air pollutant emissions. A growing body of evidence points to the serious adverse effects of motorized transportation on health and climate change. In 1992 the United States signed the U.N. Framework Convention on Climate Change (UNFCCC). This international treaty addresses the growing problem of anthropogenic greenhouse gas (GHG) emissions. In support of the U.S. government's participation in the UNFCCC, the US Environmental Protection Agency's "Integrated Environmental Strategies" (IES) program works with developing countries to promote the analysis and local implementation of greenhouse gas-reducing policy measures with multiple economic, environmental, and public health benefits. In many developing countries, including Mexico, transportation is one of the sectors in which properly designed policy measures can result in significant benefits in multiple areas of public interest.

The US Environmental Protection Agency (US EPA) is currently working with a number of partners on transportation-related measures in Mexico City and is interested in expanding this analysis to other cities in Mexico. In particular, the Mexican state of Querétaro is presently designing a Bus Rapid Transit (BRT) system for the eponymous city of Querétaro. The US EPA contracted EMBARQ - The WRI Center for Sustainable Transport - to provide technical assistance to the government authorities of Querétaro in order to estimate the impact on local and global emissions that will result from the introduction of the BRT corridor system.

This initiative had additional support from the U.S. Agency for International Development (USAID) through the project "Coupling GHG Emission Reductions with Transport and Local Emissions Management" that envisages the development of a reliable and cost-effective approach for estimating greenhouse gases and criteria pollutant emissions from transport interventions.

This study provides a snapshot of the emissions from the current bus network and compares this to potential emission reductions from six alternative BRT project scenarios. The criteria pollutants included in this analysis were nitrogen oxides (NO_x), Hydrocarbons (HC), Carbon Monoxide (CO), and Particulate Matter (PM); the greenhouse gas analyzed was carbon dioxide, the most significant criteria pollutant and greenhouse gas emitted by "on-road" mobile sources.

Estimating the direct impacts of projects involving fuel or technology switching is relatively straightforward conceptually but still has some major barriers related to data reliability. This study does not include emissions resulting from the indirect impacts of transport projects, such as induced demand, rebound effects, modal shift, or changes in origin-destination patterns.

This report is organized into five sections as follows:

- SECTION 1** – Introduction, objectives and scope. This section explains the background, objectives and scope of the project, and the organization of this report.
- SECTION 2** – The state and municipality of Querétaro. This section describes the current situation and trends of the demography, economy, transport and environment of the region, together with a brief overview of plans, regulations and institutions.
- SECTION 3** – Methodology. This section lists the equations, assumptions and data sources used in this study to estimate emissions.
- SECTION 4** – Project results. This section discusses and analyzes the results.
- SECTION 5** – Conclusions and recommendations. This section presents the conclusions and provides recommendations for the City of Querétaro.

THE STATE AND MUNICIPALITY OF QUERÉTARO

LOCATION, POPULATION AND ECONOMY

The state of Querétaro, located in the central region of Mexico has a population of 1,615,118¹ (Figure 1) that is rapidly increasing as a result of favorable economic growth and proximity to Mexico City. Adequate basic infrastructure, high educational levels and close proximity to Mexico City have favored economic growth in the state of Querétaro and enhanced its reputation as a good target for financial investment.

In 2003 the economic growth of the state of Querétaro was 3.5%, compared to the average growth rate of 1.3% for the rest of the country. The state of Querétaro is following a policy of employment creation and it is expected that the inauguration of the international airport will continue to support this trend.

The state of Querétaro consists of 18 municipalities, of which the municipality of Querétaro, with 745,189² inhabitants (Figure 1), is the principal urban center where most of the economic activity, services and jobs are concentrated. In 2005, the municipality generated 66.02% of the total GDP for the state – 34.8% from manufacturing activities, 37.6% from services and 27.7% from commerce³.

The regions with the highest population densities are located on the periphery of the metropolitan region, while

1. Projections of CONAPO for 2006 (<http://www.queretaro.gob.mx/sedesu/deseeco/esteco/perfeco/qroact/qroact.htm#territorio>)
2. Projections of CONAPO for 2005 (<http://www.queretaro.gob.mx/sedesu/deseeco/esteco/perfeco/municipios/queretaro.htm>)
3. Estimations from SIREM, do not include primary sector.

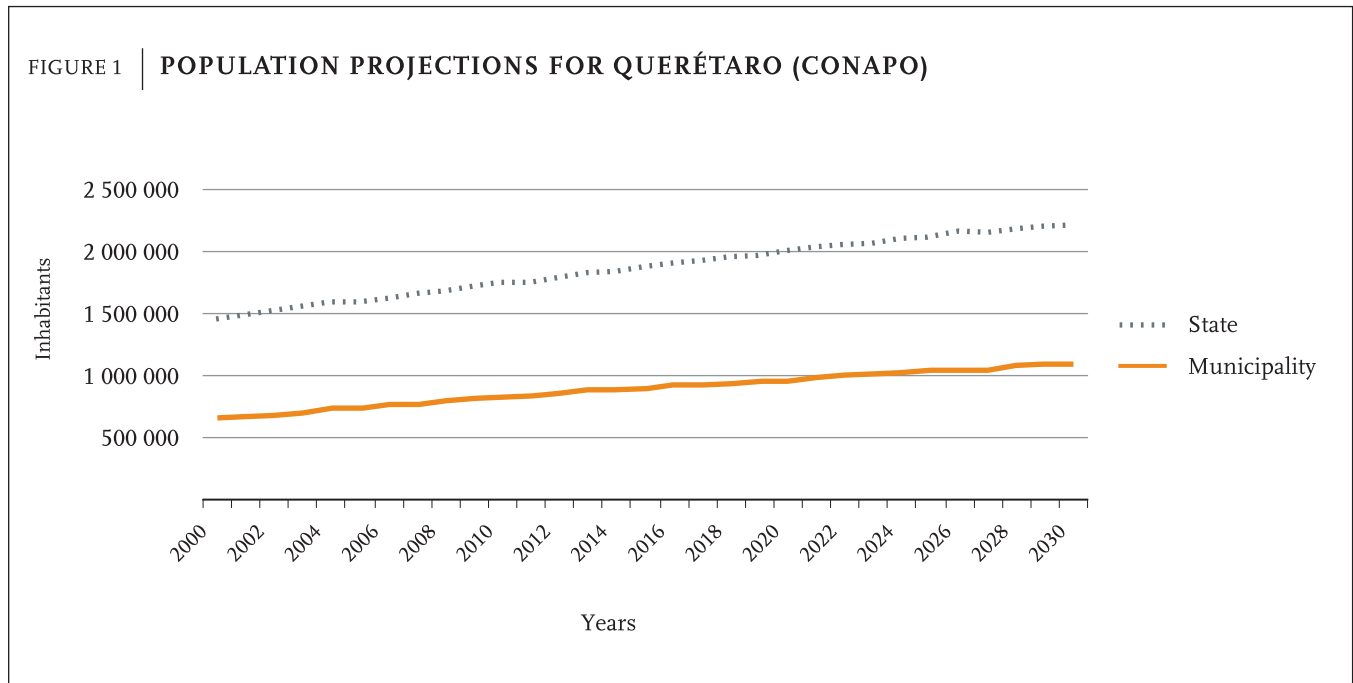
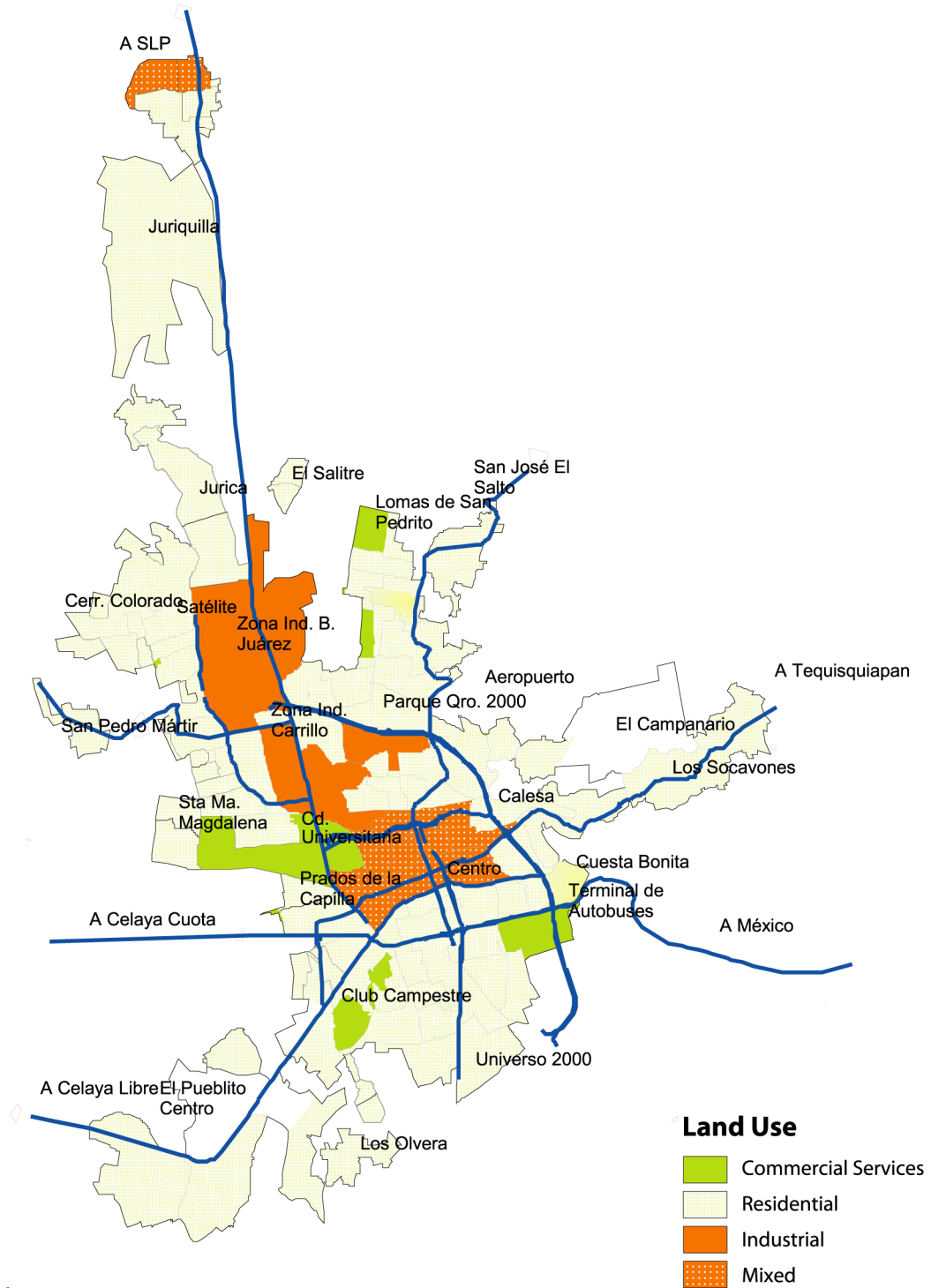


FIGURE 2 | LAND USE DISTRIBUTION IN THE MUNICIPALITY OF QUERÉTARO



Source: Transconsult, S.C. (5)

the regions with highest population growth are located in the north and northeast of this region.

Figure 2 shows that the residential areas are located at the periphery while commercial services and industrial activity are located in the historic center and north-west of the city.

AIR QUALITY AND GHG EMISSIONS

At the national level, the Ministry of Health is the government agency that establishes air quality standards, while the Ministry of the Environment and Natural Resources is the agency responsible for setting air quality control regulations such as emissions standards. At the state and local level, the Secretariat of Sustainable Development funds the air quality monitoring network.

Querétaro’s 2004 State Development Plan sets the framework for state executive activities and contains a chapter on Sustainable Development that covers the subject of Environmental Protection.

Since 2000, Querétaro has been operating a Mobile Air Monitoring Unit (UMMA) to provide constant, automatic and real-time monitoring of the concentration of ozone,

sulfur dioxide, nitrogen dioxide, carbon particles and carbon monoxide.

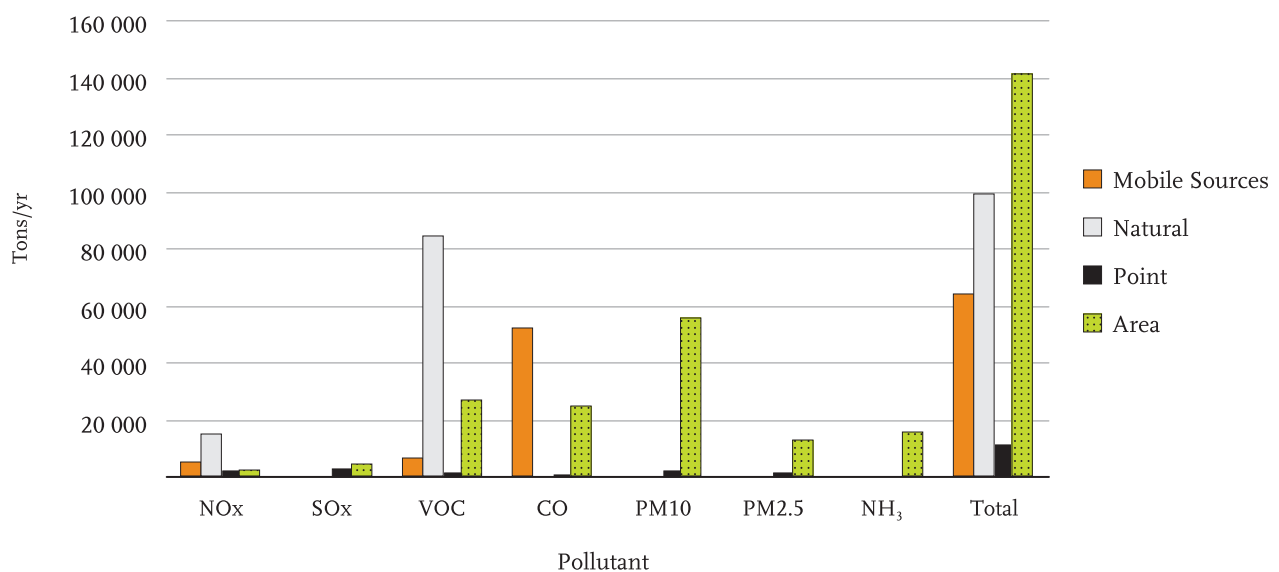
To complement UMMA information, five automatic stations monitor meteorological variables - four are fixed in the city of Querétaro and one is mobile. This system has been operating since 1987, when it started with four stations, making it possible to observe air quality parameter behavior over a span of almost twenty years.

In addition, Querétaro operates a manual air quality monitoring network that consists of seven stations located in different points around the city. These stations measure, on a weekly basis, concentrations of total suspended particles, sulfur dioxide, nitrates, sulfates and certain metals.

Despite industrial and demographic growth in the outlying areas of the city of Querétaro, the state’s air quality generally remains within the limits established by National legislation. Only in the case of particular matter is Querétaro over the legal limit with 62 µg/m³ annual average compared to the 50 µg/m³ stipulated in norm [11].

Mexico’s Environmental Report of 2004 states that the main cause for air quality degradation in Querétaro is

FIGURE 3 | QUERÉTARO ANNUAL EMISSIONS BY SOURCE TYPE AND POLLUTANT



Source: Based on Mexico National Emissions Inventory, 1999

transport, due to its dramatic increase in size from 2003 onwards. The Mexico National Emissions Inventory of 1999 [10] shows that transport is the main contributor of carbon monoxide while area sources are the main contributor of PM₁₀ and PM_{2.5}, and a significant contributor of CO and VOC (volatile organic compounds) Natural sources are the main contributors of VOC (Figure 3).

Mobile sources include exhaust emissions from motor-vehicles that travel on roadways, such as private automobiles, motorcycles, taxis, buses and heavy-duty diesel trucks, as well as non-road mobile sources such as exhaust emissions from agricultural and construction equipment.

Area sources are small industrial facilities that are not classified as point sources; dispersed activities such as dry cleaners and disposal of consumer solvents; and fugitive sources of particular matter such as agricultural tilling, vehicle travel on unpaved roads, and windblown dust.

Natural sources include vegetation and soils.

Querétaro does not have a city-specific emission inventory but the Mexico National Emissions Inventory of 1999 provided the estimation illustrated in Figure 4 and 5.

Figure 4 shows that light-duty gasoline vehicles (LDGV) are the main mobile motor source of carbon monoxide

and volatile organic compounds in Mexico, followed by light-duty gasoline trucks (LDGT) and then heavy-duty gasoline vehicles (HDGV). The main mobile motor source of nitrogen oxides are the heavy-duty diesel vehicles (HDDV), followed by LDGV and LDGT.

Figure 5 show that the main mobile source emitter of PM₁₀ and PM_{2.5} in Mexico are the heavy duty diesel vehicles (HDDV) followed by the light-duty gasoline vehicles (HDGV) and the heavy duty gasoline vehicles (HDGV). LDDTs are light-duty diesel trucks, LDDV are light-duty diesel vehicles, and MCs are motorcycles.

TRANSPORTATION

At the national level, the Secretariat of Social Development (SEDESOL) is the government agency responsible for public transportation and urban planning. At the state level, the Secretariat of Public Security is in charge of public transportation and traffic management and the Secretariat of Urban Development and Public Works oversees urban planning. At the local level the Secretariat of Public Works is responsible for traffic planning and design; the Secretariat of Sustainable Development is in charge for urban planning; and the Secretariat of Municipal Public Security oversees traffic management.

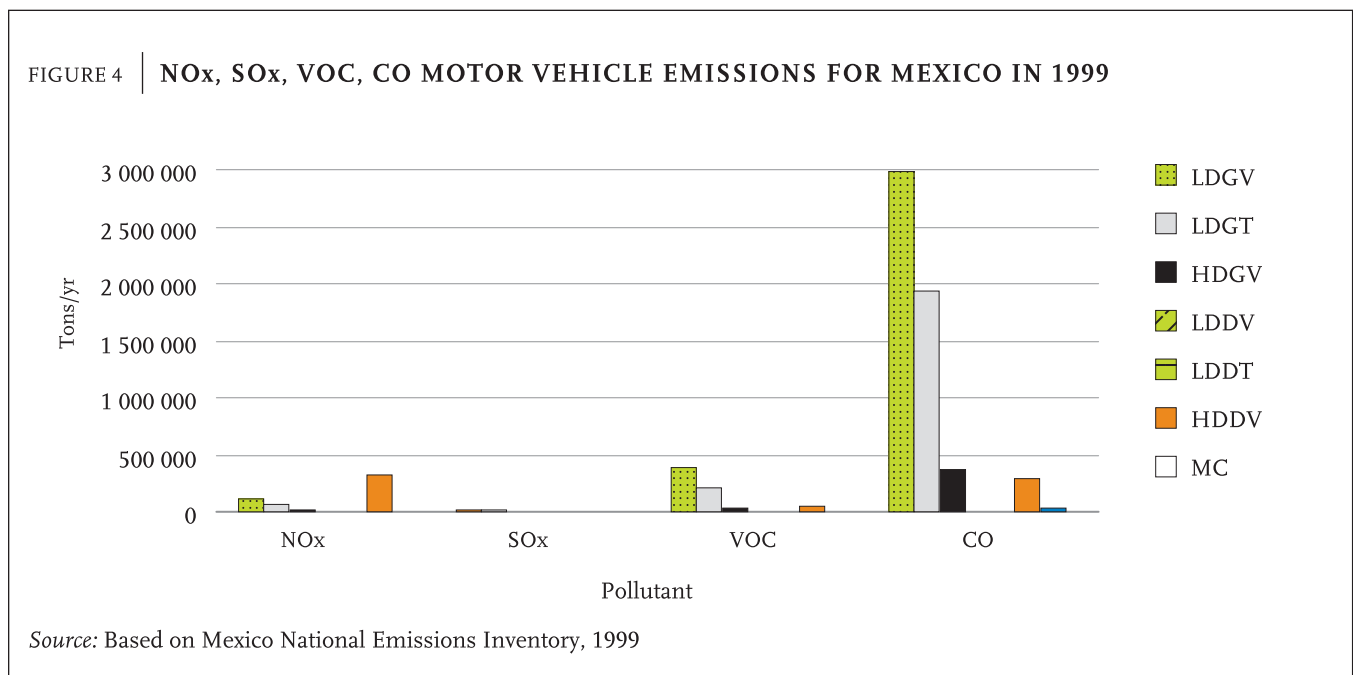
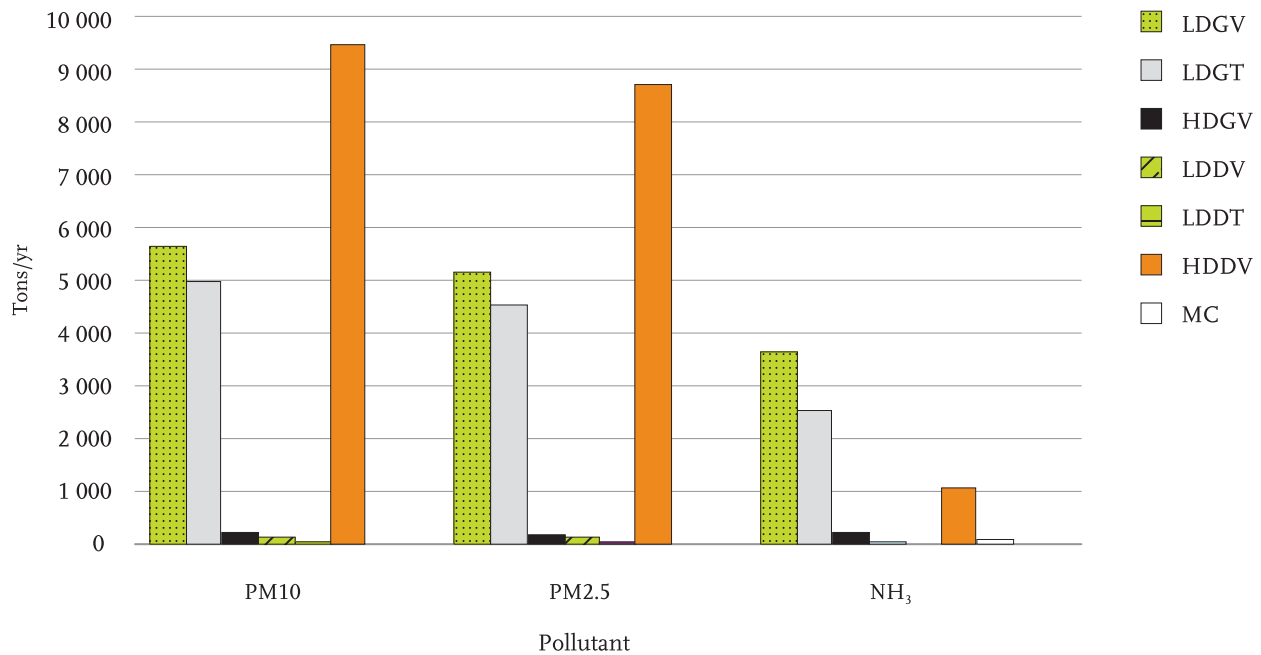


FIGURE 5 | PM AND NH₃ MOTOR VEHICLE EMISSIONS FOR MEXICO IN 1999



Source: Based on Mexico National Emissions Inventory, 1999

Historically, transportation services in the State of Querétaro have evolved in an unplanned manner, in response to the demand generated by new communities and cyclical political and social pressures. Table 1 gives an overview of the transport services currently available in the city of Querétaro.

It should be noted that different sources of information report different data. For example, the operators of the fleet report having a total of 1,763 units while the Government State Secretary reported 1,519 units in the concessions circulating in the Metropolitan Region of Querétaro.

Some of the operators reported more units than the ones registered in the Directorate of Transportation (FTEQ reported 59% more units than the registered, while ACSA reported a difference of almost 85%). In total there is a difference of 244 units or 16% more than the registered.

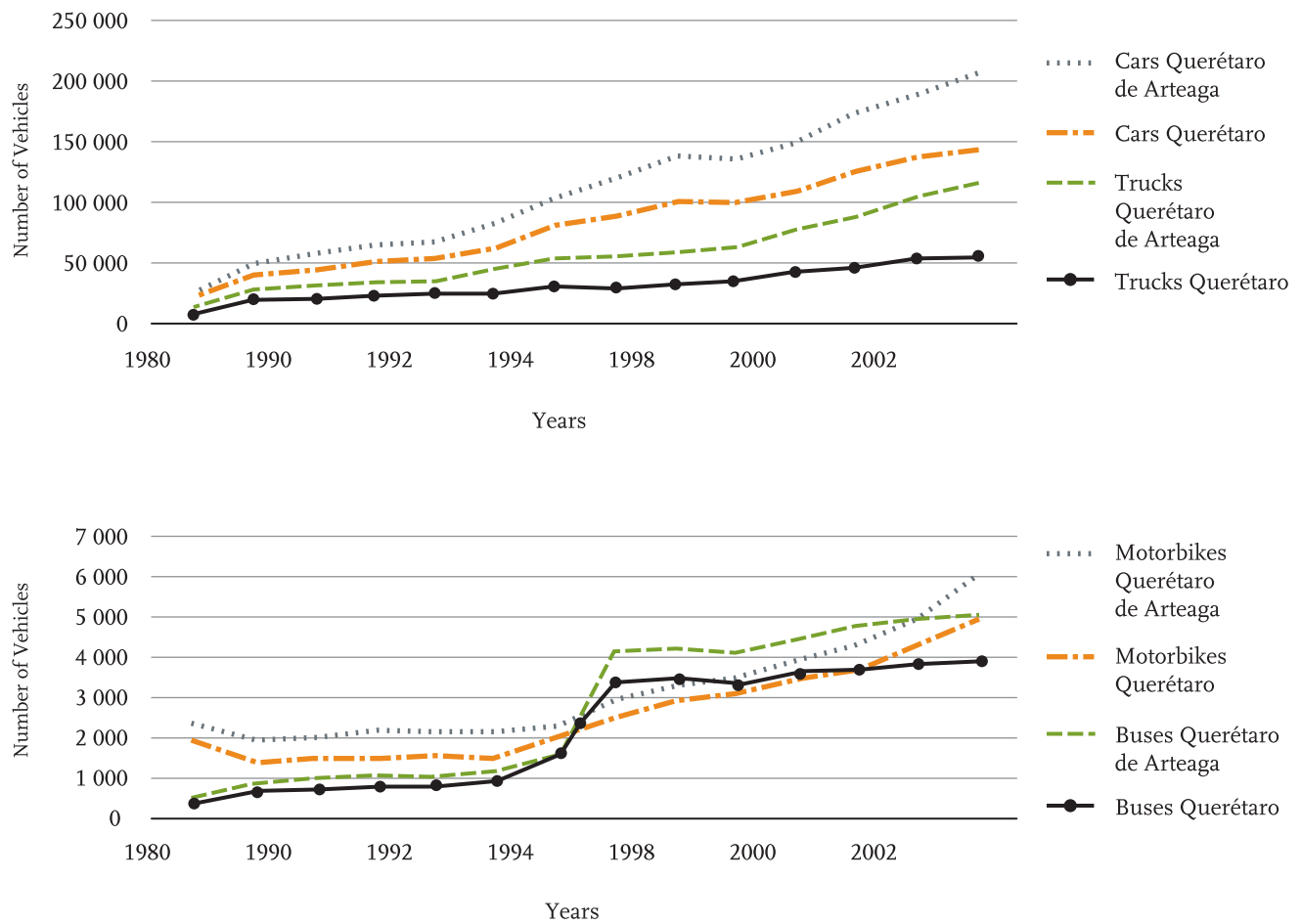
In this study we have chosen to use the official data provided by the Ministry of Urban Development and Public Works of the State of Querétaro.

TABLE 1 | VEHICLES AVAILABLE (or in circulation) IN QUERÉTARO

VEHICLE TYPE	NUMBER OF UNITS
Cars	147,466
Buses	1,519 buses; 1,290 of which in service in 108 routes. Length of all routes is 3,700 km and the distance travel in peak time (7:30-8:30am) is 24,763 km. [5]
Trucks	61,189
Motorcycles	4,406
Taxis	3,895

Source: Secretariat of Urban Development and Public Works of State of Querétaro; 2006.

FIGURE 6 | VEHICLES REGISTERED IN QUERÉTARO



Source: National Institute for Geographic Statistics and Informatics (INEGI)

Data shows that 64% of all trips are done by buses. There are currently no metro or suburban railways. Though the city center has pedestrian avenues, there is currently no non-motorized transportation system. There are no parking policies in place nor vehicle restrictions to the city center. Trucks are prohibited from driving in certain districts and on some of the city's main arteries. Figure 6 shows the upward trend in vehicles registered in the state and municipality of Querétaro.

Presently there is a series of excessively long and winding bus routes that overlap and congest the main roads leading into the downtown area. There is a low bus utilization rate (2.1 passengers carried per bus kilometer), the bus fleet has very old vehicles and the fuels used are diesel 350 ppm sulfur, gasoline and liquid petroleum gas (LPG).

Modeling of the current transportation system⁽⁵⁾ showed that, for the period of peak demand between 7:30-8:30 AM.:

- The average travel time is 23 minutes;
- The average time taken by a bus to complete a route is 77 minutes (average length is 17km);
- An estimated 4,500 or 16% of the users transfer during the period of highest demand.

Given this state of affairs, the Transportation Plan for the Metropolitan Region of Querétaro developed by the State Government in 2004 includes operational, functional, physical, financial and organizational measures with the aim of guaranteeing a high capacity and quality transportation service capable of achieving the following main objectives:

- Improve public transportation service quality
- Guarantee service profitability
- Have a centralized fare collection system
- Protect the environment
- Improve the urban landscape

- Promote the use of alternative forms of transportation and the replacement of the automobile with public transportation

The Transportation Plan for the Metropolitan Region of Querétaro is congruent with the transportation policy outlined in the 2004-2009 State Development Plan and revolves around the basic idea of an integrated transportation system in terms of operation and fares, structured around a set of transportation corridors (Bus Rapid Transit - BRT) using preferential or exclusive lanes and a set of auxiliary and complementary feeder routes.

The leadership of the project is in hands of the Director of Transport of the State Government. The governor of the state has allocated an initial capital of USD 16 million for infrastructure costs. The business model for the BRT system anticipates that the private sector will be responsible for purchasing the required new buses as well as for the operations and maintenance costs of providing transit services under the new system. Querétaro's legislature is contemplating the reform of the transportation law in order to include regulations to favor the implementation of the new system.



METHODOLOGY

CALCULATING THE BASELINE AND POST-PROJECT EMISSIONS

The baseline and project emissions scenarios of criteria pollutants - carbon monoxide, nitrogen oxides, particulate matter with aerodynamic diameter less than 10 and 2.5 microns – and carbon dioxide from the trunk route of the BRT corridor were calculated using Equation 1.

Equation 1

$$E_p = \frac{\sum_{vf} N_{vf} \times VKT_{vf} \times EF_{vf}}{1,000,000}$$

E_p = Vehicle emissions of pollutant p [ton/yr]

N_{vf} = Number of vehicles by vehicle model and fuel type [#]

VKT_{vf} = Annual⁴ average km traveled by vehicle model and fuel type [km/yr]

EF_{vf} = Emission factor for contaminant by vehicle model and fuel type [g/km]

The carbon dioxide emissions from the baseline scenario and from the feeding, auxiliary and remaining routes of project scenarios were calculated using Equation 2.

Equation 2

$$E_{CO_2} = \frac{\sum_{vf} N_{vf} \times VKT_{vf} \times EF_{vf}}{\eta_{vf} \times 1,000,000}$$

E_{CO_2} = Vehicle emissions of CO₂ [ton/yr]

N_{vf} = Number of vehicles by model and fuel type [#]

VKT_{vf} = Annual average km traveled by vehicle model and fuel type [km/yr]

η_{vf} = Fuel efficiency by vehicle model and fuel type [km/l]

EF_{vf} = Emission factor for CO₂ by vehicle model and fuel type [g/l]

These two equations were used because the emission factors available for the existing and new vehicle technology were given in different units – g/km and g/l.

BASELINE DATA SOURCES AND ASSUMPTIONS

EMBARQ and CTS-Mexico liaised with the Secretariat for Urban Development and Public Works of State of Querétaro to obtain and discuss data pertaining to the size and characteristics of the present bus fleet and network. EMBARQ and CTS-Mexico used the emission factors and fleet fuel efficiency data from Mexico City, as discussed in more detail below.

Table 2 summarizes the data needs and sources for the calculation of emissions from the baseline scenario.

4. Note that we assumed that the transportation system would be operational 312 days per year (6 days per week, 52 weeks per year).

TABLE 2 | SUMMARY OF EMISSIONS BASELINE DATA NEEDS AND DATA SOURCES

DATA NEEDS	DATA SOURCE
Number of vehicles by vehicle model and fuel type	Querétaro [2]
Annual average km traveled by vehicle model and fuel type [km/yr]	Querétaro [1]
Fuel efficiency by vehicle model and fuel type [km/l]	SENES [6]
Emission factor for CO ₂ by vehicle model and fuel type [g/l]	INE [4]
Emission factor for criteria pollutant by vehicle model and fuel type [g/km]	MC Emissions Inventory [3]

The municipality of Querétaro prepared two databases [1 & 2] based on surveys of the operators which provided information on the current (baseline) situation:

- Database 1 provided the length of routes and number of cycles per operating company which enabled the calculation of an average of 250.21 kilometers traveled per day per vehicle for the whole fleet. It was not

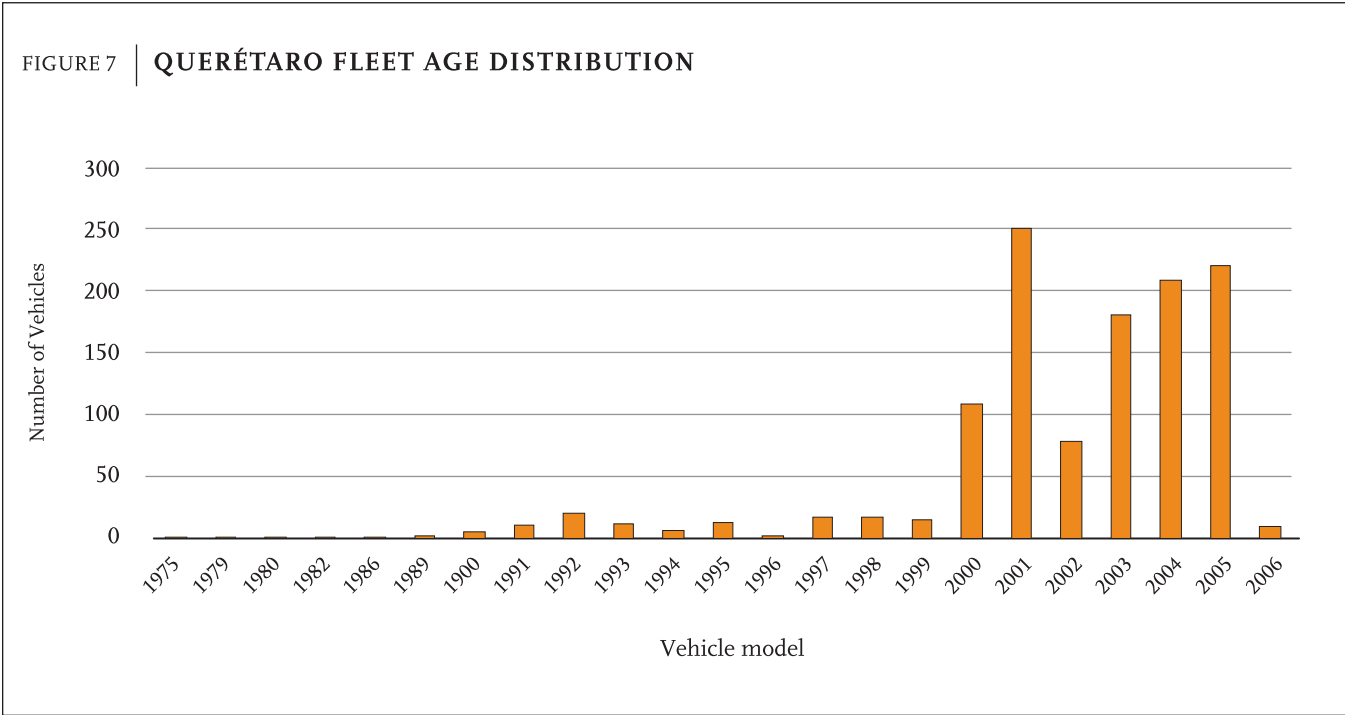
possible to obtain the number of kilometers traveled by fuel type and vehicle model year.

- Database 2 provided an itemization of the vehicles per operating company with information about each vehicle’s model, fuel type and number of seats. This database enabled the calculation of the number of vehicles per vehicle model year (Figure 7), fuel type and the categorization of vehicles in autobuses (> 36 seats) and minibuses (< 35 seats), which was important since the emissions factors varied according to the vehicle model year, fuel used and vehicle size.

The calculation of emissions for the baseline scenario used emissions factors from the Emissions Inventory for the Metropolitan region of Mexico City of 2004 [3].

The emission factors for hydrocarbons (HC), carbon monoxide (CO) and nitrogen oxides (NOx) were developed based on Mobile 5 - Mexico and on the Greenhouse Gas Inventory Reference Manual Volume 3 of the Intergovernmental Panel on Climate Change (IPCC).

The Mobile 5 - Mexico is a model developed by the US EPA and modified for the conditions in the various Mexican regions. This model gives emissions factors for diesel and gasoline vehicles. The IPCC manual gives emissions factors for vehicles using liquid petroleum gas and com-



pressed natural gas. The emission factors for particulate matter (PM₁₀ and PM_{2.5}) were developed based on Mobile 6 – Mexico and from the Heavy Duty Diesel Vehicle Testing for the Northern Front Range Air Quality Study.

Mobile 5 – Mexico and Mobile 6 – Mexico emission factors are suitable for cities with altitude equal and superior to 1,577 meters (5,500ft) [3]. Querétaro is at an altitude of 1,813 meters (5,948 ft). The project team organized Querétaro’s bus fleet by the number of seats and used the emission factors for minibuses and autobuses provided in the Emissions Inventory for the Metropolitan region of Mexico City of 2004 [3].

BRT SCENARIOS DATA SOURCES AND ASSUMPTIONS

EMBARQ and CTS-Mexico liaised with the Secretariat for Urban Development and Public Works of State of Querétaro to define the BRT project scenarios. The emission factors used for the fuel and technology used in the trunk route of the BRT corridor were compiled from fuel and vehicle and emissions-control technology testing campaigns done in Mexico City. The emission factors used to estimate the emissions from the other routes – feeding, auxiliary and remaining – were compiled from the Emissions Inventory for the Metropolitan region of Mexico City of 2004 [3]. Table 3 summarizes the data sources for the calculation of emissions for the BRT scenarios.

The municipality of Querétaro provided access to the Integrated Plan of Public Transport in the Metropolitan Region of Querétaro, which was developed by Transconsult, S.C. for the State of Querétaro government authorities. This plan used a diagnostic of the public transportation system for the metropolitan region of Querétaro which

was in turn undertaken based on the information compiled by the Science and Technology Council for the State of Querétaro (Consejo de Ciencia y Tecnología del Estado de Querétaro – CONCYTEQ).

The evaluation of alternative routes for the BRT system was done using the model for transport planning EMME/2. This software enables the use of bins for the analysis of public transport and road supply alternatives, combined with the respective current and forecast demand. The Integrated Plan of Public Transport in the Metropolitan Region of Querétaro does not look at the impact of the BRT on private vehicles so this feature of the model was not used.

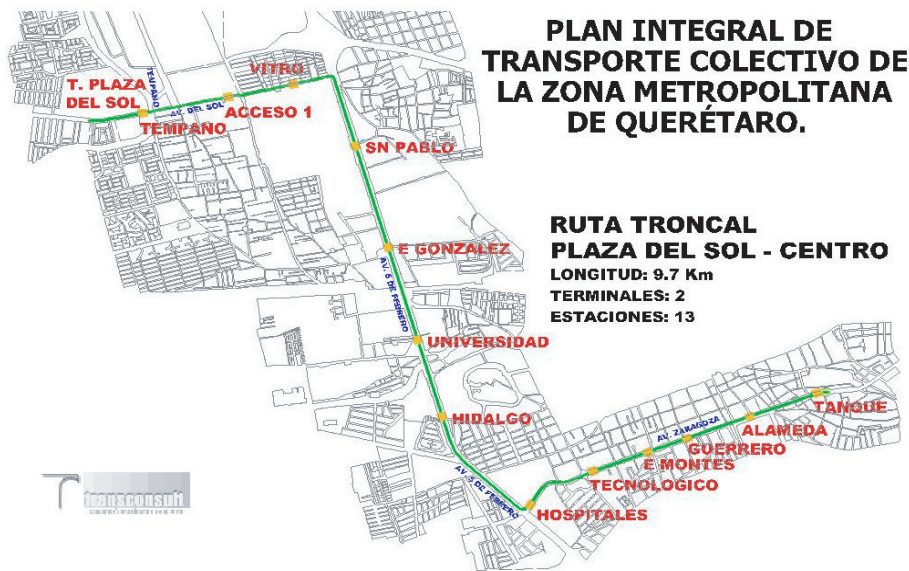
The model of demand was calibrated based on current conditions and had a good confidence level. The modeling or simulation process of the current situation (baseline scenario for 2004) was done only for the demand peak hour (7:30-8:30 am). This was the period of the day when CONCYTEQ carried out the origin-destination survey.

As a result of this modeling exercise Transconsult, S.C. proposed the two-phased development of a BRT system in the “Integrated Plan for Public Transport” (Plan Integral de Transporte Colectivo). The first phase addresses the routes of highest demand by designing a principal trunk route - “Ruta Troncal Paza del Sol – Centro”. The second phase envisions the creation of 3-4 additional trunk routes by 2015.

The 10 kilometer Plaza del Sol-Centro transportation corridor is a major step towards the modernization and integration of the public transportation system in the Querétaro Metropolitan Zone (Figure 8).

TABLE 3 SUMMARY OF BRT PROJECT EMISSIONS DATA NEEDS AND DATA SOURCES	
DATA NEEDS	DATA SOURCE
Number of vehicles by vehicle model and fuel type	Transconsult for trunk route [5]; Querétaro for other routes [2]
Annual average km traveled by vehicle model and fuel type [km/yr]	Transconsult for trunk route [5]; Querétaro for other routes [1]
Fuel efficiency by vehicle model and fuel type [km/l]	SENES report [6]
Emission factor for CO ₂ by vehicle model and fuel type [g/l]	MC Retrofit and Component 3 tests for trunk route [7, 8]; INE for other routes [4]
Emission factor for criteria pollutant by vehicle model and fuel type [g/km]	MC Retrofit and Component 3 tests for trunk route [7, 8]; INE for other routes [3]

FIGURE 8 | BRT TRUNK ROUTE PLAZA DEL SOL-CENTRO



Source: Transconsult, S.C.

The North-South section of the corridor runs along an avenue that once was the main thoroughfare for freight going to and from the light and heavy industry located in that area. Now the freight vehicles are routed around the city and many of the industrial parks are abandoned or for sale. Housing developments are springing up to outside of this corridor, with a low-income sprawl pattern. It is necessary to estimate the avoided costs to the state if the next wave of housing could be developed along the corridor, thus avoiding further sprawl to the North and West of the city.

The corridor area already has water, natural gas and sewage infrastructure, while the sprawl area does not. From this basic estimate of infrastructure cost savings, we could go to the next step of developing a basic urban redevelopment plan for the corridor based on mixed-use land development along the main part of the corridor.

Querétaro’s BRT will be a feeder-trunk system. The trunk will be used exclusively by buses while the feeder routes (feeding, auxiliary and complementary/remaining routes) will not be used exclusively by buses. The first phase of the “Integrated Plan for Public Transport” (Plan Integral de Transporte Colectivo) that will be implemented in the first semester of 2007 will have the following route structure:

TABLE 4 | BRT CORRIDOR DATA AND ASSUMPTIONS

INDICATOR	
Length	10 km
Terminals	2
Stations	14
Bridge for vehicles	1
Passengers/day	60,000
Passengers/peak hour	5,000
Trunk articulated buses in operation	18
Diesel performance	18.60 gallon/100km

Source: Secretariat of Urban Development and Public Works of State of Querétaro; 2006.

1 trunk route that will go from El Tanque, in the city center, to Plaza del Sol in the extreme north west of the city (Av. Zaragoza, Av. 5 de Febrero and Av. Del Sol until approximately 800 meters after the intersection with Av. Témpano. An integration terminal is being proposed for construction in Plaza del Sol. A transfer station is being



proposed for construction in Vitro to enable the modal shift from feeder routes from the north of the city and the suburban routes from San Luis Potosi highway. The trunk route will operate articulated or accordion buses with a nominal capacity of 150 passengers (53 seats) or buses with capacity for 90 passengers (36 seats).

4 auxiliary routes to provide support service to the trunk route in order to serve areas of high demand. Both the demand and physical conditions of the city do not justify the construction of additional trunk routes. A condition is that the auxiliary routes are part of the integrated system (including tariffs). The auxiliary routes will operate buses with capacity for 75 passengers (38 seats).

- Plaza del Sol to bus terminal via Av. Bernardo Quintana. Goes through the industrial zone of Benito Juarez.
- Plaza del Sol to Plaza del Parque via Av. Bernardo Quintana until the bridge of Av. Corregidora, where they return back.
- Plaza del Sol to Corregidora, via Av. De la Revolucion, Av. 5 de Febrero and Av. Universidad, hasta Av. Corregidora, where they return back.
- Plaza del Sol to Pasteur Sur, via Av. De la Revolucion, Av. 5 de Febrero and Mexico- Querétaro highway and Av. Pasteur Sur until the ISSSTE clinic in the Aztec colony.

15 feeding routes that enable the transfer of users onto a terminal or onto an integration station in order for them to take the trunk route. The feeding routes will operate minibuses (30 passengers) or buses (50 passengers) depending on the demand for each of the routes.

- A-3, Plaza del Sol - Monte Atlas
- A-4, Plaza del Sol – Tzetzales
- A-9, Plaza del Sol – Cactus
- A-10, VITRO – Jiriquilla
- A-11, VITRO – Jurica
- A-12, VITRO – Santa Rosa
- A-13, VITRO – Fray Juan de Zumárraga
- A-14, Plaza del Sol – Cerro Minteche
- A-15, Plaza del Sol - Tarahumaras
- A-16, Plaza del Sol – Blvd. de la Luz
- A-17, Plaza del Sol – Matlazincas
- A-20, Plaza del Sol – Av. Colima
- A-22, Plaza del Sol – Miguel Hidalgo
- A-23, Plaza del Sol – Zona Industrial
- A-24, Plaza del Sol – Revolución



47 remaining or complementary routes provide service in the city but are not integrated with the tariff structure of the BRT system (although they may be physically integrated at some points in order to facilitate the transfer of passengers). The remaining or complementary routes will operate minibuses (30 passengers) or buses (50 passengers) depending on the demand for each of the routes.

The choice of articulated or non-articulated buses was made using a reference demand of 1,800 passengers per hour on the busiest route and direction. For this volume it is possible to guarantee intervals of 5 minutes between vehicles. Note that the operational design was developed based on lower than maximum bus capacities due to users being accustomed to excess demand. Table 5 shows the bus capacity used in the operational design [5].

In total, the implementation of the Plaza del Sol-Centro transportation corridor requires the use of only 681 units - one half of the units that are being used today in

the metropolitan region of Querétaro. In addition, the government authorities of Querétaro are planning to remove from the fleet the oldest buses and those currently operating on liquid petroleum gas or gasoline. This study will discuss the resultant implications for capital and operational costs and the indirect social and environment impacts gained by these changes (less fuel consumed, fewer emissions). Table 6 shows the bus technology and fuel type used in the BRT scenarios.

The fuel types selected for the BRT corridor were defined following the specification of the Secretary of Urban Development and Public Works of State of Querétaro. The bus technology mentioned in Table 6 for the fleet operating on the trunk route was the one used in testing campaigns in Mexico City to derive emission factors for the various fuel and emission control technologies. The bus technology used in the feeding, auxiliary and remaining routes is a selection of the youngest diesel buses running on the current bus fleet.

TABLE 5 FLEET DIMENSION AND TRIP FREQUENCY IN PEAK HOURS AND DISTANCE TRAVELED DAILY				
ROUTE TYPE	# VEHICLES	PASSENGER PER UNIT	TRIPS/HOUR	KM/DAY
Trunk	18 articulated buses	120	20.45	4,444.16
Auxiliary	39 autobuses	60	32.47	7,145.07
Feeder	115 Mini bus	40	107.78	21,482.48
Remaining	509 Mini bus	40	208.1	81,995.73

TABLE 6 BUS TECHNOLOGY AND FUEL TYPE USED IN BRT SCENARIOS			
SCENARIO	BUS TECHNOLOGY USED IN TRUNK ROUTE	FUEL AND EMISSION CONTROL TECHNOLOGY USED	
		TRUNK ROUTE	FEEDING, AUXILIARY, REMAINING ROUTES
1	Scania (MB), 18m articulated, EURO III	Diesel, 350 ppm sulfur	Diesel, 350 ppm sulfur
2	Scania, 18m articulated, EURO III	Diesel, 50 ppm sulfur	Diesel, 350 ppm sulfur
3	RTP 3 (MB Torino), 12m, EPA98	Diesel, 50 ppm sulfur, DPF	Diesel, 350 ppm sulfur
4	MB 11, 11.4m, EPA98	Diesel, 15 ppm sulfur	Diesel, 350 ppm sulfur
5	FAW, 16m, EPA2004	Compressed Natural Gas (CNG)	Diesel, 350 ppm sulfur
6	Electrabus, 12m, EUROII	Hybrid series, Diesel 15 ppm	Diesel, 350 ppm sulfur
7	Allison, 12m, EPA2004	Hybrid parallel, Diesel 15 ppm, DPF	Diesel, 350 ppm sulfur

PROJECT RESULTS AND ANALYSIS

The data analysis show that for the baseline scenario, the diesel vehicles had the highest per unit contribution of particulate matter and nitrous oxides, while gasoline vehicles had the highest per unit contribution of hydrocarbons and carbon monoxide. The vehicles with higher emissions of carbon dioxide were the ones operating on liquid petroleum gas, followed closely by the diesel vehicles and finally by the gasoline vehicles. (Figure 9)

The contribution of the vehicles operating on gasoline and liquid petroleum gas is overshadowed by the much higher numbers of diesel vehicles, as illustrated by Figure 10.

Table 7 summarizes the results for overall emissions from the baseline and with-BRT corridor scenarios.

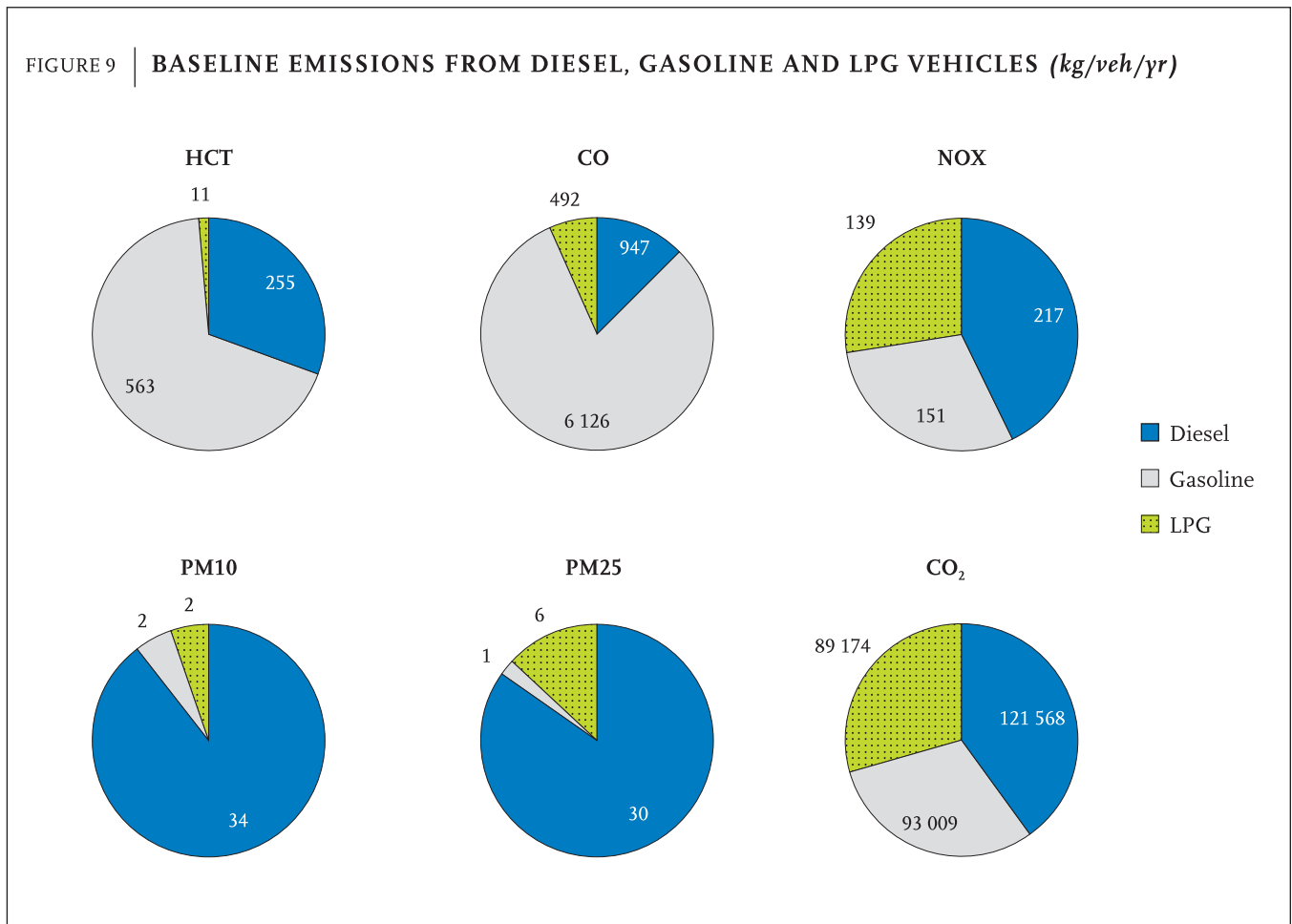
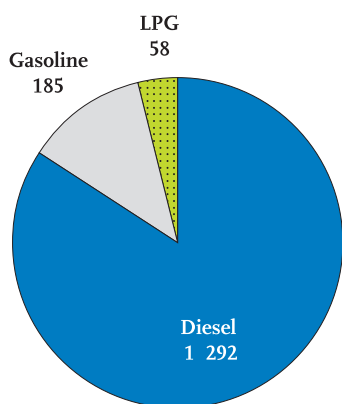


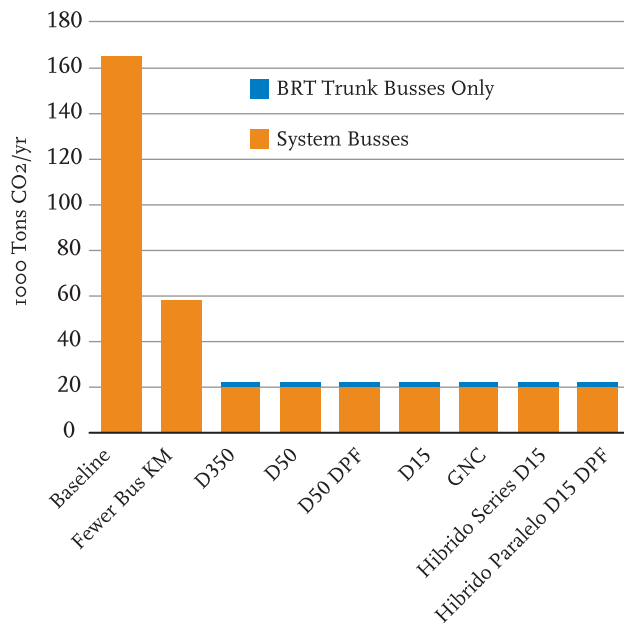
FIGURE 10 | **BASELINE SCENARIO BUS FLEET FUEL SHARE (number of vehicles)**



Note that there was no emission factor for total hydrocarbons (HCT) and PM 2.5 for the articulated buses operating on the trunk route. Therefore the results for the BRT scenarios for these pollutants pertain only to the emissions from the feeding, auxiliary, and remaining routes. This explains the fact that for the BRT scenarios the emissions for HCT and PM_{2.5} are the same as illustrated in Table 7.

As illustrated in Figure 11 the introduction of the BRT project and resultant optimization of the bus fleet in the municipality of Querétaro will result in a dramatic reduction in CO₂ emissions. The calculations show the potential for a decrease from 165,220 tons of CO₂ per year to an

FIGURE 11 | **CO₂ EMISSIONS FROM BASELINE AND WITH BRT SCENARIOS**



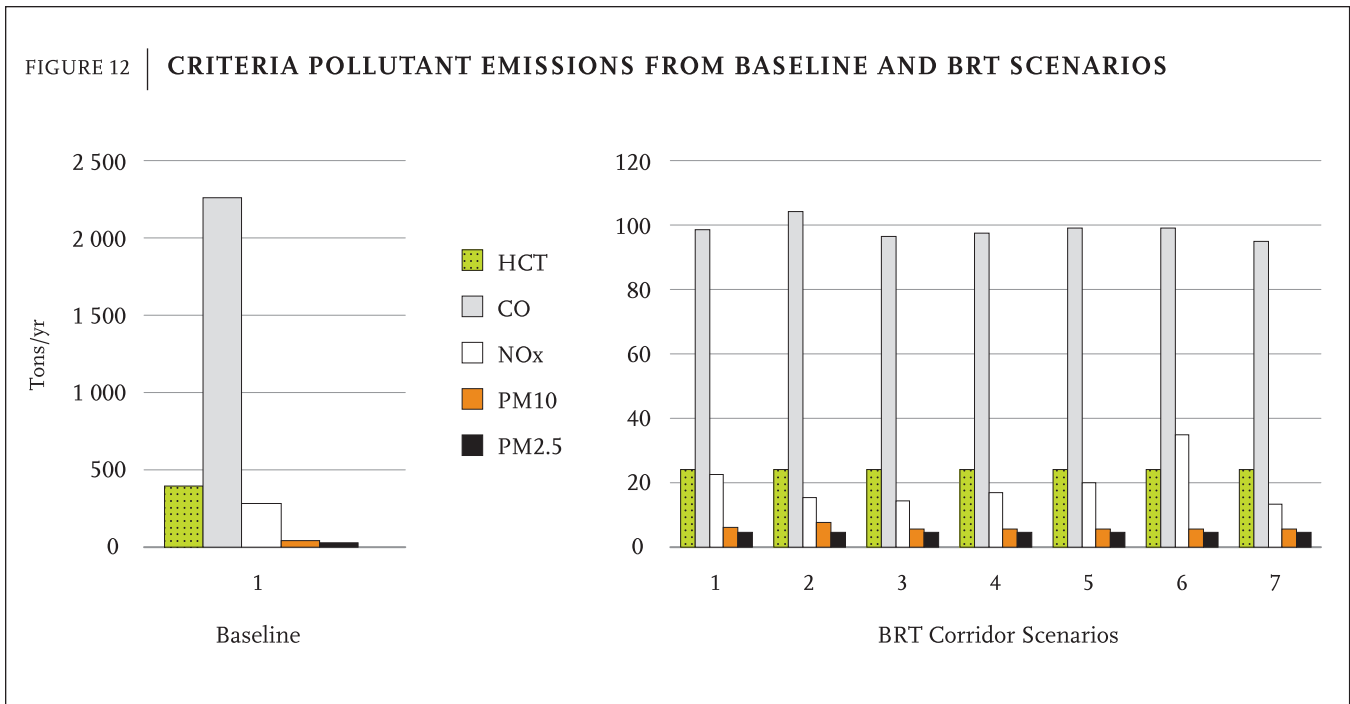
average of 21,819 tons of CO₂ per year. On the other hand, the differences between the six BRT project scenarios are not significant.

Figure 12 shows that the introduction of the BRT corridor and associated optimization of bus network efficiency will lead to similar dramatic reductions in criteria pollutant emissions, while the variation of emissions between the BRT projects scenarios will not be so significant.

TABLE 7 | **EMISSIONS FROM BASELINE AND WITH BRT SCENARIOS (tons/yr)**

SCENARIO	DESCRIPTION	HCT	CO	NO _x	PM10	PM2.5	CO ₂
0	Baseline	404.48	2,274.90	663.07	40.47	35.36	165,220
1	Diesel 35ppm S	24.10	97.91	54.61	6.08	4.74	22,394
2	Diesel 50ppm S	24.10	103.46	47.40	7.61	4.74	22,548
3	Diesel 50ppm with DPF	24.10	95.79	46.52	5.53	4.74	21,312
4	Diesel 15ppm	24.10	97.15	49.34	5.58	4.74	21,258
5	CNG	24.10	98.40	52.02	5.49	4.74	21,814
6	Hybrid series, D15ppm S	24.10	98.61	67.22	5.53	4.74	21,523
7	Hybrid parallel, D 15ppm S, with DPF	24.10	94.45	45.73	5.50	4.74	21,880

FIGURE 12 | CRITERIA POLLUTANT EMISSIONS FROM BASELINE AND BRT SCENARIOS



The dramatic decrease in emissions is achieved by adjusting the bus supply to the existing demand and creating a BRT trunk-feeder system. Due to these changes, the fleet size is reduced from 1290 vehicles to 681 vehicles and the daily kilometers traveled are reduced from 322,771 km to 115,067 km (yielding a total saving of 207,703 km/day). This step represents 64% of the emission reductions (Figure 11). Another important factor is the removal of the oldest, most polluting vehicles from the fleet, which improves the emission factors by an order of magnitude. It is important to note that the fate of the old buses has not yet been decided. If they are deployed in another city the emissions will have been simply displaced rather than eliminated.

The limited variation on emissions between the BRT corridor scenarios is a result of the application of the fuel improvement and emission control technologies to the 18 buses operating on the trunk route and running 4,444 km/day or 4% of the total distance traveled in the BRT corridor scenarios.

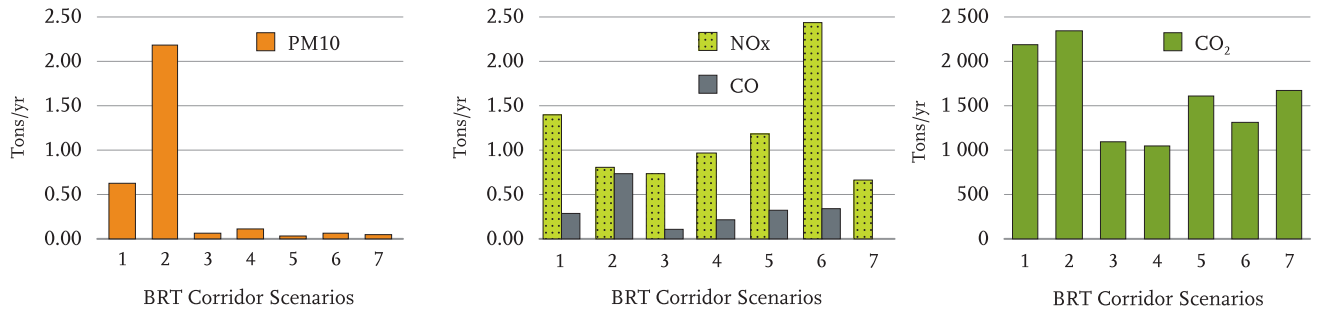
When comparing the emissions from the trunk route alone we can appreciate more distinctively the potential impact of applying alternative fuels and emission control technologies (Figure 13).

Figure 13 shows that the buses operating on the trunk route with 50 ppm sulfur diesel and retrofitted with DPF (Scenario 3) have lower emissions than the buses operating with 350 ppm sulfur diesel (Scenario 1). The buses operating with 50 ppm sulfur diesel without DPFs (Scenario 2) have higher PM and CO₂ emissions than the buses operating with 350 ppm sulfur diesel. This is a result of higher emission factors and the source of these indicates that there was a contamination of the fuel that could have led to this anomaly. [7]

As illustrated by Scenario 5, CNG shows a considerable improvement on PM but a less impressive improvement on NOx, CO and CO₂.

It should also be pointed out that the hybrid bus operating with EURO II showed the highest NOx emission levels (Scenario 6), while the hybrid bus operating with EPA 2004 and retrofitted with DPF showed the lowest NOx emissions levels. The Center for Sustainable Transport of Mexico, coordinator of the tests that produced the emission factors used, indicated that the EURO II hybrid experienced high temperatures in the engine that could have caused the significant increase in NOx.

FIGURE 13 | EMISSIONS FROM BRT TRUNK ROUTE SCENARIOS



CONCLUSIONS AND RECOMMENDATIONS

The impacts of a transport project can vary greatly depending on an array of parameters – distances traveled, route design, technology and fuel options, etc. A careful impact assessment of these projects, including the environmental and health dimensions, is clearly important to providing decision makers with a complete view of the implications of their investments. The resulting changes in local and global emissions can play an important role in evaluating the desirability of different transport solutions.

This study shows that improvements to the efficiency of the bus network, and to some extent the introduction of a Bus Rapid Transit corridor could yield extensive reductions in the emissions from Querétaro’s bus fleet. Emissions of CO₂ would fall by more than 85%, from 165,220 tons of CO₂ per year to an average of 21,819 tons. Emissions of criteria pollutants also show dramatic reductions of between 80 and 95% in every case. Clearly the potential gains in economic and health terms are considerable.

These reductions derive mostly from an optimization of the bus fleet operation. By more carefully mapping transport capacity to demand, a reduction by almost half the number of buses currently in operation is made possible. Since the first buses to be retired will be the oldest and most polluting, this results in a large reduction in emissions. Not only are there fewer buses in operation, but those buses each cover on average 64% fewer kilometers per year than those in today’s fleet. Finally, the fuel mix is improved by the elimination of gasoline and liquid petroleum gas. It is important to note that the fate of the old buses has not yet been decided. If they are deployed in another city the emissions will have been simply displaced rather than eliminated.

Conversely, while all the BRT scenarios yield benefits, there is not much difference between them. While different fuel and engine choices do perform better than others



on individual pollutants, these differences are typically on the order of 10% and no one choice performs better than the others across all pollutants.

The reason for this small variation among the scenarios is that the alternative fuels and emission control technologies, which were the distinguishing feature between the scenarios, were only applied to the 13–18 buses to be operating on the BRT corridor trunk route. The 13–18 buses will run 4,444 km per day or 4% of the total distance to be traveled on the BRT system.

Given the costs involved in switching fuels and the relatively small benefits of doing so for a limited fleet, the project team would recommend the restructuring of the bus fleet and services above all, even if still using diesel with 350ppm sulfur content in the fleet.

When diesel with lower content of sulfur (15 ppm) is made available, the use of the upgraded fuel and of the emission control technologies should be considered for the whole fleet. Further study would be needed to estimate the benefits granted by adopting alternative fuels and emission control technologies across the whole city’s bus fleet, but that is outside the scope of this report.

The follow-up projects that could be envisaged are:

1. The estimation of emissions for the use of alternative fuels and emissions control technologies in the whole fleet.
2. The estimation of the BRT project impact on the surrounding traffic emissions. The BRT corridor will require the removal of one lane and the suppression of left turns that will induce changes in congestion and traffic patterns of the surrounding traffic. These effects can lead to behavior changes such as modal shift, induced demand, change in travel patterns and schedules. The effect of relatively small changes in a large number of vehicles can result in significant impacts on emissions that can offset the reductions achieved with the reduction in vehicle fleets, the removal of older vehicles, changes in fuel and vehicle technology.
3. The forecast of the project impacts on emissions in five and ten years' time.
4. Development of a clean-fuel, clean-vehicle, emission control technologies decision model to develop cost-benefit analysis of options.
5. Monitoring of passengers and drivers personal exposure to hazardous emissions before and after the implementation of the BRT corridor to assess the impact on their health.

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