Considering Climate Change in Latin American and Caribbean Urban Transportation: Concepts, Applications, and Cases

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Appendices on Cobenefits

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1. Appendix One: Mexico City’s Metrobús – A Case Study in Estimating CO2 Impacts

A. Introduction

Metrobús is a bus rapid transit line running 19.5 kilometers from Indios Verdes in the northern region of Mexico City to Avenida Doctor Gálvez in the south. It operates on Avenida Insurgentes, one of the most important main roads in Mexico City with three to four lanes in each direction. The system emerged from a World Bank/GEF/EMBARQ project examining “Climate Friendly Transportation” in the Mexico City region. Metrobús opened on July 19, 2005, after three years of intensive planning and design. The initial impact was to move more than 250,000 people/day – 1.25% of the total daily trips in the region - on large new, high-floor buses operating in exclusive lanes with attractive median stations offering level boarding.

In this case study, we evaluate the Metrobús project using the framework presented in Chapter two. We show how the carbon reductions from Metrobús can be calculated for the main components of change – vehicle changes related to the bus system itself, impacts on traffic (including vehicles not part of the bus system but traveling along or across Insurgentes), and modal shifts away from cars or other mass transit to Metrobús.

The framework presented in Chapter 2 set forth the key dimensions of a methodology for analyzing the production of greenhouse gas emissions from the transport sector. These dimensions guide the analysis of the Metrobús. We articulate the relationship between the framework and the analysis in the following questions:

(1) What were the objectives of the project undertaken, particularly its scope and scale?

a. Urban development: Was the project part of a major thrust of urban development? If not, could it have a long run impact on that development?

b. Transportation: How did Metrobús project fit in the context of a plan for improved transportation for Mexico City? and

c. Emissions: Were the project’s efforts focused directly on fuels or CO2 emissions from the project? How did the Metrobús project affect emissions of greenhouse gases from transport in Mexico City?

(2) What was the economic valuation of the various costs and benefits of the project including impacts on travel time, street congestion, security and safety on the buses as well as the streets, local emissions, etc.? How was the project justified? The CO2 saved is a co-benefit of good transport projects: Is the value of carbon co-benefit and fuel saved a significant share of the total project benefits? How does this co-benefit vary in value over a range of CO2 prices? What were the immediate impacts of the project on emissions that were used in this economic evaluation?

(3) What could the longer run effects of the project be compared to a business-as-usual or “without project” scenario? Was there a long-term land-use travel model that could be used

to predict what would happen to trip making and travel without Metrobús and gauge the effects? Were there side effects, particularly social impacts or other changes around the corridor that should be analyzed and understood alongside the benefits provided to the transport system?

(4) What arrangements were made (or are still being undertaken) to monitor the longer-term impacts of this project?

The Metrobús project was conceived of as a way to simultaneously reduce traffic congestion (caused by high volumes of colectivos and growing private auto use), improve bus speed, convenience, and reliability and therefore attract riders away from cars and colectivos, improve transport access for the poor, and reduce air pollution and CO2 emissions from both colectivos and automobiles.

In this section we evaluate the impacts of Metrobús following the Framework on Integration of CO2 Considerations in to urban planning developed in this paper.

i. Scope and Scale

Metrobús involved a number of changes to collective transportation along the Insurgentes corridor. Key among these included vehicle substitutions, changes in street design and operation, and changes in bus stop design and operation. Most of the colectivos previously operating on Insurgentes were completely scrapped (at no small social cost to former drivers), while the buses that belonged to the city company, RTP, were deployed elsewhere, replacing similar but older RTP buses.

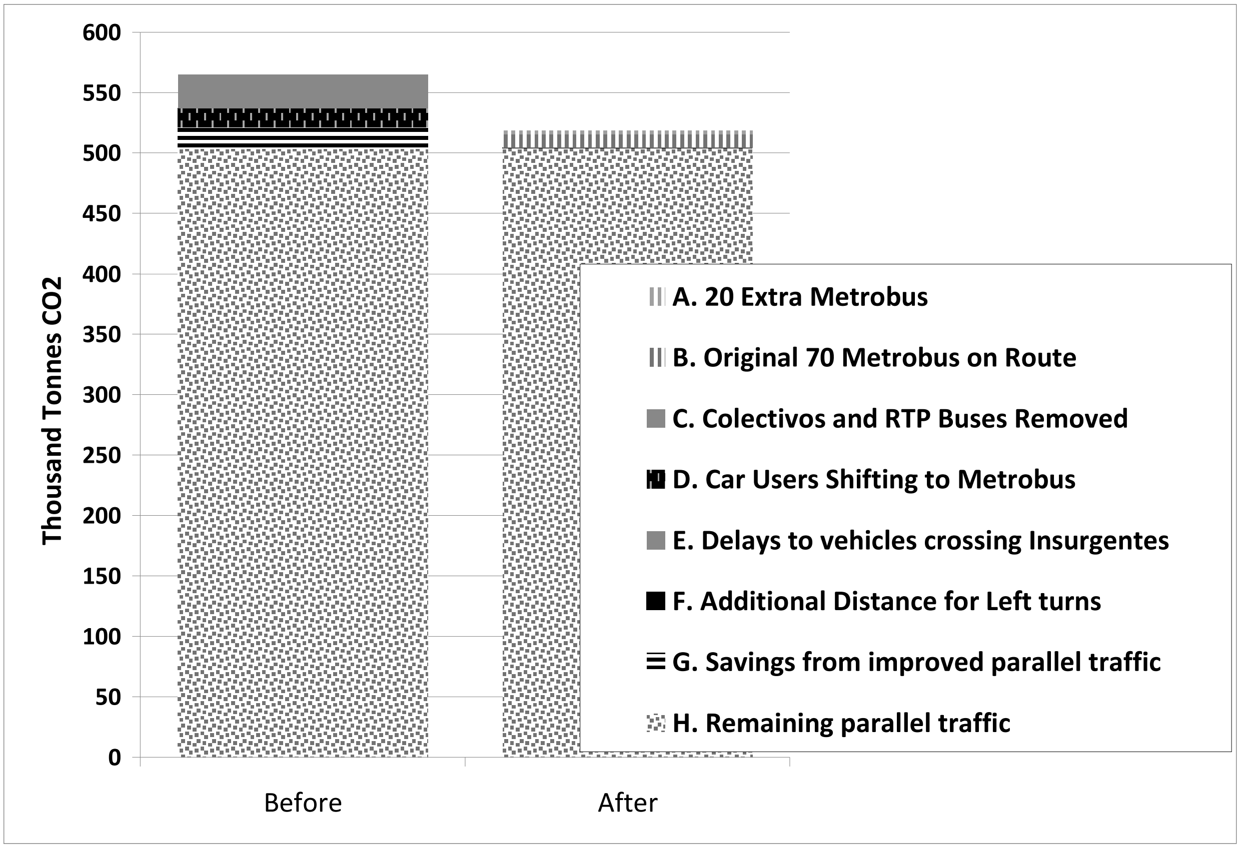
The initial conception of Metrobús was not part of a new urban development plan; it was conceived primarily for its transport benefits, which were large. Mexico City authorities had been considering options for dealing with nearly three dozen street corridors with very large (50 000/day) flows of people. The transport analyses behind these options (SETRAVI, 2002) addressed the existing flows, but not longer-term urban development questions. After almost 2 years of discussions of the possibility of a BRT corridor, the Insurgentes route (along with another option, Eje 8) were the subject of intense study in 2003, and Insurgentes was selected in 2004.

The Metrobús project undertook no specific measures to reduce CO2 related to vehicles or fuels other than the reduced fuel use from buses running in a protected BRT corridor. An option to acquire diesel hybrid buses for this project was evaluated. The hybrids would have saved only slightly more than 20% of the fuel than the buses chosen used. This would have amounted to about 6% additional fuel and CO2 than the entire Metrobús transport project saved. Because they would have been very expensive and untried on a large scale in Mexico City, they were not considered further. Still, major steps to reduce CO2 emissions were successfully embedded in a transport project.

ii. Immediate CO2 Impacts and Co-benefits- Summary

Immediate demand shifts resulting from the new service included large shifts from colectivos to Metrobús, as well as modest shifts from auto to Metrobús. Improved traffic along the Insurgentes corridor led to slight reductions in the fuel use of parallel traffic. The estimates of CO2 saved, given in a subsequent section, are approximately 50,000 metric tonnes of CO2, or about 0.25 % of total road transport sector emissions in the Mexico City Metropolitan region and 010% of the emissions associated with traffic observed along the Insurgentes corridor. The calculations were undertaken in Rogers (2006) and will be explained in detail in Section III. Figure A.1.1 and Table A.1.1 summarize the results.

Figure A1.1. Metrobús Emissions Before and After



Source: Rogers, 2006 and Rogers, 2009.

Notes: Legend explanations: A and B are the emission from Metrobús after; C is the emissions of the transit vehicles removed; D is the emissions imputed before drivers switched to Metrobús; E and F are the extra emissions from delays and circuity imposed by Metrobús. G, shown as emissions in the corridor before that were saved because traffic on Insurgentes is smoother after Metrobús is put in place. H gives the remaining emissions from all parallel traffic on Insurgentes. Details given in section III.

Table A1.1 Changes in CO2 Emissions from Metrobús Project

	Average Annual Reductions in Emissions
Operating condition improvements and/or the substitution of the number and technology of buses that operate on the main route or BRT corridor ***METHODS:*** *Measured fuel consumption of original vehicles, Metrobús; daily driving distance; carbon content of each fuel.*	**17,554**
Improving the operating conditions for other vehicles operating on the main route ***METHODS:*** *Number, type of vehicles operating on Insurgentes, average speed before and after Metrobús; model of fuel use vs. speed.*	**17,515**

Modal shift from cars on the route to buses ***METHODS:*** *Surveyed Metrobús riders who originally took cars; average distance of trip, average load factor of car; average fuel consumption of cars on Insurgentes based on counts of types and City database.*	**15,610**
Total Annual Emissions Reductions all Years, tonnes CO2	**50,679**

Source: Rogers, 2006 and Rogers, 2009.

Table A1.2 Increases in Emissions – Averaged Annual Increases and One Time Increases at Project Outset

Extra buses required due to Modal shift from cars, Metro or other more-fuel-efficient-transport to buses on the BRT corridor plus rebound and new trip creation on the buses ***METHODS:*** *Measured fuel consumption of bus times distance/year times carbon coefficient of fuel*	**2,996**
Elimination of left turns on the route or BRT corridor generates increased travel time and distance for those vehicles that now have to go-round-the-block ***METHODS:*** *Observed number of left turning cars times extra distance times average fuel use/km times carbon coefficient*	**693**
Longer distance required for vehicles to cross the corridor due to the elimination of crossing points in the with-project case	**0**
Longer time required for vehicles to cross the route or BRT corridor due to traffic signal timing altered giving priority to buses	**543**
Detours During Construction (one time) ***METHODS:*** *Changes in average speed times distance times number of vehicles; fuel consumption modeled as function of speed.*	**2,685**
Greenhouse gas emissions due to construction activities of the project and energy used to produce the construction materials. Fuel used to melt discarded colectivos. (one time) ***METHODS:*** *Use of input-output tables to convert construction expenditures of main construction components and activities (approx USD $31 million) into energy consumption by fuel and, with IPCC coefficients CO2 emissions.*	**67,774**

Source and details See Section III.

iii. Economic Impacts and Co-benefits of CO2 Reduction

Key benefits of the project were identified as savings in time, reductions in congestion and traffic, and reductions in air pollution. The main cost-benefit study (INE, 2006) found that when these other benefits were monetized they reach USD $6.5 million.[1] If the fuel saved to both bus operators and drivers is included in the value of the project, the total added up more than USD $18 million/year. CO2 savings as co-benefits valued at USD $5/tonne (the initial price offered to Mexico City for certified savings) are about USD $0.23 million, or trivial compared to the other benefits. If CO2 is valued at USD $85/tonne, the CO2 co-benefits add almost USD $4m to the total, and the CO2 is worth about 20% of the total project benefits. With this higher CO2 price, the CO2 value is substantial, but is it enough to make a transport project decisive? Over two-thirds of the benefits of fuel and CO2 saving accrue to other car drivers on Insurgentes or those leaving cars for Metrobús. City authorities might be justified in a project that brought these benefits to the region, but it is hard to believe that the CO2 benefit alone could justify a project.[2]

INE did not place any value on the reduction in accidents and deaths, or value of the creating of Metrobús itself as a faster form of transportation, something that could stimulate economic activity. Also omitted from this analysis is any economic impact to businesses or homes along the Insurgentes Corridor. Work by Muñoz-Raskin (2006) and Lefevre (2007) suggests that there are changes in land values and apartment rents on or near the Transmilenio Corridors. Also omitted was an analysis of the socio-economic changes that may have befallen former colectivo drivers whose routes disappeared. These impacts should be part of any longer-term understanding of the total value of the Metrobús project.

iv. Long-Term Impacts

Figure 2.1 in the text noted that a project or policy should be evaluated over time, not simply in comparison to “before” but in comparison to an estimate of what would have occurred had the project or policy not been implemented. It is probably too soon to measure these impacts, but it is important to speculate on what they could be and then observe whether they occur.

Longer term impacts could appear if Metrobús stimulated more travel, more trips of longer distance, or, conversely, more development on and close to the Insurgentes corridor that reduces trip lengths and stimulates more walking between homes, jobs, shopping and services.

Metrobús may have some impacts that raise CO2 by stimulating more travel or attracting development (and riders) from its extreme ends. However, a region-wide system integrating Metrobús with other buses and the Metro could result in much greater shifts away from autos than a single Metrobús line. As we shall see, it is possible that modal shifts to Metrobús result in a larger savings of CO2 than does the actual substitution of buses in the BRT system. Finally, the actual CO2 impacts depend on the longer term evolution of vehicles and fuels of all modes.

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[1] INE did not monetize either the fuel saving or the CO2 co-benefits.

[2] These figures are also summarized in Table 2.2.

B. Detailed Analysis of Major CO2 Impacts from Metrobús as a Transportation Project

Figure A.2.1 summarized the main components of CO2 emissions changes from the introduction of Metrobús. For comparison, urban traffic including trucks emitted just over 20 million tones of CO2 in 2006 (Páramo Figueroa, personal communication, 2006), the first full calendar year of Metrobús operations. The basic figures for fuel saved come from Rogers (2006), who used data from the region, including the MCMA 2006 Emissions Inventory and vehicle fuel efficiency tests performed by Mexico City officials, as well as data gathered specifically for the Metrobús project. (Rogers, 2006) INE 2006; Schipper et al., 2006; SMA, 2006; and Clarke et al., 2006).

Rogers' approach examined a number of components of changes in CO2 emissions related to project vehicles (buses removed, Metrobús added), cross and parallel traffic, and modal shift from cars or other modes to Metrobús. He included a term for additional buses added after the initial Metrobús project started (these buses were added because Metrobús loads were higher than anticipated). He also estimated the one-time increase in emissions from traffic delays caused by Metrobús station construction and route preparation, the emissions associated with making materials used and the construction process itself, as well as the emissions used in melting the colectivos replaced. These one-time emissions were small – around 125% of a single year's emissions savings – and are not considered in detail. However, for heavy construction projects involving tunneling, bridges or elevated structures the costs of the associated CO2 emissions can be substantial.

The RTP buses previously running on Insurgentes were used to replace older RTP buses. No detailed assessment of the fuel use of the newer (vintage 2001) buses was made. These newer buses, which carry 10% more passengers than the older ones may have slightly higher fuel use/km despite electronic injection and other features not present on the older buses. No detailed study was made of their overall impacts, which are nevertheless likely to be small.[3]

Rogers' approach to estimating emission is based on distance. He estimated changes in number of buses, and, from passengers' trip information, the modal shift to Metrobús from cars and other modes. Emissions estimates for Metrobús and the colectivos Metrobús replaced were made by Metrobús itself, and these estimates used a large database on vehicles maintained by SMA. Changes in emissions factors that were caused by changes in traffic were estimated from filmed flow measurements of vehicles on Insurgentes. Counts of cross traffic and left-turning traffic were used to estimate extra waiting time to cross Insurgentes or extra distance traveled to make left turns. Since most of the savings in fuel and CO2 do not accrue to project vehicles (e.g., Metrobús) but instead to non–project vehicles, (i.e., cars on Insurgentes, cars crossing Insurgentes, and cars left at home in favor of Metrobús) collecting fuel consumption data directly is virtually impossible. While the total reduction in CO2 emissions from changes to these other vehicles is almost 40,000 tonnes of CO2, this figure by itself represents only 0.5% of the total fuel sold and consumed in the Mexico City region, a change far too small to be seen against fuel sales statistics. Thus the distance-based approach using a combination of observations,

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[3] In the diesel retrofit project carried out by the City, EMBARQ, and CTS (Schipper et al., 2006), the 2001 buses had an average fuel efficiency of 1.6 -1.8km/l while the next oldest vintage buses (1992) provide 2.3 km/l despite having a higher horsepower. The newer buses satisfied EPA 98 emissions standards as well. If this difference in fuel efficiency is applied to 80 buses running 140km/day 365 days/year the result is an increase in CO2 emissions of 1,465 tonnes.

Metrobús rider surveys, vehicle counts, camera and other measurements of vehicle flows and speeds, and fuel simulations gives the results for which details are shown below.

i. Large BRT Buses in Place of Conventional Buses and Colectivos

Rogers's (2006) estimation of emissions changes from Metrobús centers on a comparison of vehicles taken out of service with those put in service. Initially 70 articulated buses with capacity of 160 persons standing and sitting were substituted for approximately 80 smaller colectivos, 240 10-meter colectivos, and conventional 12 meter buses from the city's RTP company. He obtained data on average daily running distance and average fuel consumption/km for each vehicle type and fuel. In this case, 80 small colectivos (capacity 30 passengers) running 100 km/day on gasoline and LPG, and 240 larger diesel colectivos and diesel RTP buses running 140 km/day. Vehicles ran 365 days/year.

Using measured fuel consumption data, Rogers employed emission coefficients from the Intergovernmental Panel on Climate change (IPCC) for each fuel used to arrive at the CO2 emissions coefficients. The small colectivos emitted on average 1.4 kg CO2/km, and the larger diesel colectivos and RTP buses emitted on average 1.7 kg/km. Thus the original vehicles released approximately 28,500 tonnes of CO2 per year. Over a year the initial 70 Metrobús vehicles would release 10,487tonnes/CO2. The original flees was supplemented with 20 additional articulated buses when it was a clear that the demand for travel was higher than forecasted. With the 20 additional vehicles supplied later the total yearly emissions increased to almost 13,500 tonnes/year.[4]

The reduction in CO2 from this substitution is the difference of the "before" vehicles and "after" vehicles, or 14,558 tonnes of CO2.

There are some key questions to ask when using this methodology to estimate CO2 emissions changes:

1. *How reliable are the estimates of fuel use and distance traveled from vehicles that previously operated on Insurgentes. How many of these vehicles are out of traffic permanently?*
2. *What are the present fuel use figures for Metrobús? Have they varied over time as drivers have become better accustomed to vehicle performance?*
3. *What are the real passenger loads and trip distances on Metrobús?*
4. *How much has Metrobús traffic grown or fallen from the first year of operation?*
5. *How much extra energy does a vehicle require if one more passenger boards?*

ii. Effect of Modal Shifts from Cars to Metrobús

Rogers used two approaches to estimate modal shift. Initially he estimated that 1% of the riders in the 60,000 cars/day using the Insurgentes would switch to Metrobús. By assuming a 5 km car trip and using an average fuel use of 14.2 l/100 km (based on the City's own vehicle inspection data and simulations, a value corresponding to 318 gm/km), and assuming 1.5 passengers per

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[4] Rogers debits the additional CO2 for these 20 buses against the credit of CO2 from modal shift to Metrobús.

car, he estimated a savings of 1,300 tonnes/year of CO2.[5] This initial estimate of modal shift proved to be too low.

From more detailed rider surveys made available after Metrobús started, Rogers noted that closer to 7% of the more than 250,000 riders switched from cars.[6] From these surveys and traffic observations he estimated 7,000 fewer cars ran on Insurgentes to give the increase in ridership to Metrobús. He used a distance of 8.4 km base on separate on board surveys to determine the trip length on Metrobús of ex-car users. Observations on Insurgentes showed the average car had 1.5 occupants. His revised estimate for savings from modal shifts to cars is 15,610 tonnes/year of CO2.

Rogers estimated that 20 additional buses were necessary to take up the riders shifting from other modes to Insurgentes and provide service for extra passengers making new trips. These generated almost 3,000 tonnes/CO2 per day and are added to the Metrobús total.

Some travelers used to take the Metro, Trolleybus (STE) or light rail in Mexico City, which operate on electricity. The shift was not enough to trigger a reduction in Metro, STE or LR service, so no significant reduction in electricity use can be claimed. The difference is the CO2 equivalent energy to move a passenger on the Metro or STE Trolleys vs. marginal passenger energy on required by BRT. No accounting for possible emissions from their travel was made by Rogers.

iii. Impacts on Other Traffic – Increases and Decreases in CO2

A third set of CO2 impacts results improved traffic flow. Rogers (2006) noted that even small reductions in fuel use to the tens of thousands of vehicles running parallel to Metrobús on Insurgentes or across Insurgentes could add up to substantial CO2 savings. First, the removal of the smaller colectivos that previously plied Insurgentes and often blocked traffic let to an improvement in traffic. On the other hand, three or four lanes of traffic in each direction were compressed to two or three lanes in each direction. Left turns from Insurgentes were banned, requiring drivers to turn to the right and circle back. And cross traffic was slowed somewhat.

To estimate the effect of changes in traffic operations on emissions Rogers used traffic flow data collected for every segment of the Insurgentes route, as well as counts of cross traffic and left turn traffic. He estimated the extra delay time for cross traffic. By observing and averaging the number of cars and other vehicles delayed and using an average fuel use at idle of (3.16 liters/hour) and an average delay time of 30 seconds, applied to nearly 26,000 cars/day, he estimated the CO2 expenditure for delayed vehicles at 293 tonnes/year. Based on traffic observations, he estimated that no vehicles had to drive circuitous routes to cross Insurgentes because some crossings were closed. Much of Insurgentes already had a median that restricted crossings from smaller streets.

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[5] The emissions factor 307 gm/km is based on a large visual sample of cars using Insurgentes and then matched to the emission data base of the Secretaría de Media Ambiente based on twice-yearly emissions inspections.

6 The first year ridership of Metrobús exceeded 250,000 riders/year. A 2007 survey showed that nearly half of Metrobús riders did have cars at home. 6% of those riders took their cars before Metrobús was open, and 2% took taxi. Three quarters of riders used to take other modes on the same route before Metrobús was opened. An earlier survey (2006) conducted for the Center for Sustainable Transport indicated that about 16% of riders previously took cars or taxis, while the survey from the first six months, carried out in December 2005, reported only 6% switchers from cars or taxis. The 2008 level of switchers is 9%. Taking the 2007 figure as a conservative average of the four years implies 15,000 daily car trips not taken (out of the initial 250,000 trips/day on Metrobús).

For cars turning left Rogers estimated the extra distance traveled by left-turners (400 m/vehicle). Using observations to get average numbers of vehicles by type turning left and the emission per kilometer from the City data base, he calculated the extra driving for left turn vehicles led to 693 tonnes/year of CO2.

From traffic counts Rogers found approximately 60,000 vehicles/day using Insurgentes. He noted that the elimination of colectivos and buses stopping erratically and blocking traffic actually improved the flow of traffic. He relied on estimates of traffic flow, speed and acceleration, and delay on eight segments covering the entire route. To simplify his calculations he assumed that he could represent the difference in fuel consumption by the drop in travel time in free flow conditions and, separately, in congested conditions. This was used to derive average speeds on each segment by vehicle type. Using a simulation program of fuel consumption vs. speed he derived the savings per vehicle and kilometer from improved traffic. All together, he estimated 17,515 tonnes of CO2 saved this way. The same procedure permitted Rogers to estimate the baseline emissions from parallel traffic in the corridor before Metrobús as a function of number of vehicles by type and speed. He estimated approximately 510,000 tonnes of CO2 for all traffic in the corridor.

Putting all the impacts Metrobús had on traffic together thus gives a **net savings of approximately 16,500 tonnes/year of CO2.**

Rogers estimated the total emissions of vehicles along the Insurgentes corridor from the observations along eight segments.

iv. CO2 from One-Time Construction Activities

Two main fixed costs from the project construction were included in a brief life cycle analysis. All 320 colectivos removed from the corridor were melted down. Rogers estimated the emissions from the oil required to carry out this melting as 176 tonnes of CO2, based on the thermal energy of 2.6 GJ required to melt each 3 tonne vehicle. Using factors from input-output analysis developed at Carnegie Mellon University (See Chester, 2008), Rogers estimated that 67,000 tonnes of CO2 equivalent was released in the construction of USD $32.9 million worth of guideways and stations. Almost 2,700 tonnes of CO2 were released because of traffic delays and detours during construction. With savings of nearly 50,000 tonnes/year of CO2, this investment of CO2 paid back in less than one year.

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In sum, Metrobús operations have “saved” almost 50,000 tonnes of CO2 every year.[7] More than two thirds came from modal switch and improved traffic. Even if the latter two estimates are off by 100%, they still represent significant savings compared with the direct savings from switching vehicles alone. This is an important finding for any assessment of CO2 savings from a project or policy. Changes can occur in vehicles besides those designed as part of a project. These non-project vehicles’ emissions changes might dominate the changes, so they must be studied carefully.

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[7] This must be adjusted downward for the slightly more than 70,000 tonnes of CO2 emissions associated with the preparation of Metrobús. If the Metrobús project is amortized over 12 years, this means the savings should be reduced by almost 6,000 tonnes/year.

v. Economic Impacts and the CO2 saving as a Co-Benefit

While it may not be trivial to monetize these changes and evaluate them in a common framework, they must have been considered in the planning process that led to the intervention. They can be evaluated after the fact with careful observation.

Economic evaluations were made for many of the impacts of Metrobús, including impacts on fuel consumption, time, pollution, accidents and CO2. Stevens, from the Instituto Nacional de Ecología (INE) conducted one such evaluation in 2006. (INE, 2006) Her work covered reduced travel time, reduced air pollutants (as benefits to health), reduction in operating costs (but not externalities) from fewer vehicles using the roads, savings of fuel in transit vehicles, and the overall economic benefits of Metrobús as BRT. Savings in CO2 and the increased reliability in travel time were quantified but not monetized. Reductions in noise, reduced accidents and death in traffic, greater access and equity of access, more reliable commercial deliveries, and improved working conditions and productivity stemming from improved trips to work were described, but not quantified. Rogers (2006) estimated the effects of improved traffic and reduced idling on both lower fuel use and CO2 emissions of non-Metrobús vehicles.

Travel time. A major goal of good transport is travel time savings. If travel time is reduced because vehicles operate in lower levels of congestion, then CO2 is saved. If dwell time is reduced, CO2 and local emissions are reduced. If buses are given dedicated lanes, then overall travel is smoother, also reducing CO2. Time savings were estimated from on-board surveys. INE (2006) valued the time savings from Metrobús at USD $1.3m, based on savings of 2.6 million rider-hours a year saved and a value of time of USD $0.575/hour.

Reduced congestion and vehicle damage to Insurgentes. Investments in good public transport can shift travelers from individual to collective vehicles, and allow authorities to manage all vehicles on the street more efficiently. The Mexico City government surveyed riders on board to determine that at least 5% of these passengers previously used cars to make the same trip. With assumptions about the cost of every km a bus or car drives in Mexico City, INE estimated 12 million fewer veh-km and 32 million fewer private car and taxi km/year as a results of Metrobús, which they valued at USD $2.2 million. If the greater 2007 figures for car use were substituted, then the results would be about 1/3 higher.

Fuel Savings. The fuel savings that give rise to the CO2 savings had substantial value. Rogers calculated the reduction in gasoline (and a small amount of LPG) used by older buses and colectivos, the reduced use of gasoline in parallel traffic (net of the small increases for left turns and crossing delays), and the imputed fuel not consumed by those leaving cars at home to switch to Metrobús. The savings were tabulated in liters of gasoline (with a small amount of LPG) or diesel. At the prevailing prices of 55 US cents/liter for gasoline and 48 cents/liter for gasoline, these savings were substantial, close to USD $3.5 million of diesel for the buses and $3.9 million for cars left at home by those drivers switching to Metrobús, and USD $4.1 million for the net fuel savings from the various impacts Metrobús had on traffic (Savings from smoother corridor traffic minus extra fuel for delays crossing and circuitous left turns).

Air quality improvements. The most obvious improvements came from shifts from smaller to larger vehicles. In general, the larger vehicles carry more people per vehicle (lower emissions/pass-km), the larger vehicles are more modern/cleaner (lower emissions per veh-km), and the larger vehicles are less stuck in traffic less often (less idling). Lower veh-km run also reduces pollution. This affects everyone in a region's air basin, and has broad benefits.

Using the SMA database, data from INE, and more recent measurements undertaken as part of the World Bank Metrobús project, INE estimated emissions/km of criteria pollutants such as particulate matter, NOx and CO. These emissions were multiplied by changes in distance covered by each type of vehicle per year to get total reductions in pollutants of each kind. Where traffic was improved slightly reductions in emissions/km were counted; from studies of the health costs of each kg of pollutant, INE produced an overall value of the annual health benefits of the BRT line itself at approximately USD $3 million. Note that if emissions/km of all vehicles continue to fall as a result stronger fuel and emissions standards, this benefit will be smaller, happily so.

INE did not address the likely fall in traffic accidents from both fewer vehicles (particularly colectivos) and smoother traffic.

vi. Overall Economic Valuation and the CO2 Co-Benefit

To capture all of these results, we have added the value of the saved CO2 estimated in the previous section. This saved CO2 is the “co-benefit” realized in pursuit of the direct benefits noted above. To monetize these CO2 savings we used two valuations of CO2. In the low valuation of CO2 (USD $5/tonne, the first offer made for the savings from Metrobús) with the fuel prices for diesel and gasoline in Mexico in 2005, the total value of these benefits is over USD $18.3 million, of which the CO2 represents slightly more than 1.25%. Note that in Figure A1.1 the benefits from CO2 are almost invisible, showing up as the thick darkened above the estimated fuel savings from modal shift.

Valuing CO2 with a higher value of USD $85/tonne (Stern, 2006) and taking again the 2005 prices for gasoline and diesel, the CO2 savings represent 18% of the overall project savings that now surpass USD $22 million. The CO2 savings are clearly much larger, but are they a key determinant? With the lower carbon price, the value of the saved fuel to Metrobús itself is over USD $3.5 million, while the CO2 savings are insignificant. At the higher carbon value, the CO2 is worth about 40% as much of the fuel.

What is significant is that of the CO2 and fuel savings, only 30% of the saved fuel accrues to Metrobús itself, the rest predominantly to those who left cars for Metrobús and to some extent the 60,000 cars per day that saw overall traffic improvements yielding a small net savings in fuel to each of them.

Interestingly, a carbon tax applied to all fuel in the Mexico City region could have had a very large impact. The USD $85/tonne suggested above works out to about a 33% increase in the 2005 price of gasoline for Mexico City. With a long-term price elasticity of fuel economy of about –0.7, a 33% increase in fuel price will lead to 25% less fuel use per kilometer and about 4% fewer kilometers compared with no price increases, or 28% less fuel consumed than otherwise.[8] Applied to the gasoline used for light duty vehicles (cf. Table 1.2), this reduces CO2 by some 350,000 tonnes/year, roughly seven times of what the Metrobús project alone achieved. While the use of carbon pricing in evaluating transport choices in a region is informative, the impact of such a price as applied to all or most vehicles in the same region should not be overlooked.

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[8] Studies of consumer responses suggest that most of the response to higher fuel prices will appear as more fuel efficient vehicles rather than less vehicle use. based on elasticities estimated by Basso and Oum (2007) or Johansson and Schipper (1997). Averaged over all the cars in the Mexico City Region (cf. Chapter 1), this would reduce CO2 emissions from the region’s transport system by about 20% compared with no price increase.

vii. Impacts Over Time

Impacts of Metrobús evolve over time. While a full study is yet to be carried out, the yearly surveys undertaken for Mexico City show that the number of riders who declare "I was taking X before Metrobús when I traveled on Insurgentes" started at 4% car and 2% taxi by December 2005, rising to 10% car and 6% taxi in May of the following year, falling back to 6%/2% by May 2007 and then rising slightly to 6%/3% in May 2008. To the extent that this response is a stable indicator, it suggests that the switch to Metrobús shot up during the first full year, then fell back, but 9% may be a fair average. On the other hand, the 2008 survey was undertaken near the peak of gasoline prices, which may have influenced modal shift. The following year ushered in a recession. Clearly, these figures should be monitored closely to understand the impact many factors over time on ridership of Metrobús.

Analysis should take account of other changes that could occur over time. One is the possibility of addressing CO2 directly in the Metrobús vehicles or in vehicles riders used to get to/from. The latter option is important because in the 2008 survey, 54% of travelers surveyed took a colectivo of one type or another to transfer to Metrobús, and about a third of travelers planned to transfer to a colectivo after alighting from Metrobús. To measure longer-run impacts, the distances these linked trips covered should be surveyed or estimated. One possible long-run impact is that Metrobús actually pulls in travelers from origins and to destinations increasingly more dista0nt from the corridor itself. Finding these trends could either point the way to feeder routes or new BRT lines themselves.

C. Technological and Policy Options for the Long Run

i. Hybrid Buses

Although the World Bank project considered a number of fuels/propulsion combinations, conventional diesel was chosen to power Metrobús's articulated buses. Conventional diesel, ultra low sulfur diesel, parallel and series diesel hybrids, and CNG buses were tested. According to tests carried out by the City (SMA, 2006), conventional diesel articulated buses had the lowest fuel use and emissions per seat-km of all the different buses tested, except for 1 smaller 12 m diesel bus (of ten 12-meter buses tested). However, the volume of traffic on the Insurgentes corridor demanded large, articulated buses, which were ultimately those chosen.

Hybrid buses were tested by the Secretary of Environment as part of the World Bank project. One parallel hybrid showed very low criteria pollutants (particulate matter, CO and NOx) but emitted 6% more CO2/seat-km than the average of conventional diesel articulated buses chosen and had smaller capacity (113 places). However, diesel articulated hybrid buses similar in capacity to those used by Metrobús are run by King Country Transit in the Seattle region and use 20-25% less fuel/km than similar articulated diesel buses with conventional drive trains running similar King Country Transit (KCT) Routes. Since Metrobús itself emits approximately 13,000 tonnes of CO2/year, switching to hybrids would reduce emissions by 2,600 tonnes/year for the first 70 Metrobús vehicles, taking the lower figure for carbon and fuel savings. The extra cost of these hybrids, in excess of USD $150,000/bus (Boone, personal communication, 2007) are difficult to justify on the basis of fuel savings and lower pollutant emissions alone, even if a 25% savings was realized (Schipper et al., 2007).[9] However, Volvo Bus announced a lower-cost

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[9] At USD $85/tonne of CO2, the savings in CO2 at this value and fuel at the 2005 prices from exchanging the articulated diesel Metrobús for parallel hybrid versions currently used in Seattle Washington could be justified. While each hybrid would cost approximately USD $150,000 more than a conventional bus (Schipper et al., 2007), each bus

parallel hybrid for 2009 (Volvo Bus, 2007) claimed to pay back with fuel savings in four years. If this appears on the market with a much smaller marginal cost over conventional diesel it would be cost effective.

ii. Compressed Natural Gas (CNG)

Another option tested but not taken was to use buses running on compressed natural gas (CNG). CNG buses tend to cost more than diesel buses, in part because of their heavy fuel tanks. They have slightly higher maintenance costs. Moreover, a facility is required for compressing natural gas from the network to the high pressure required by the bus fuel tanks. Combustion of natural gas releases 25% less carbon dioxide per unit of energy than diesel (IPCC). However, CNG engines use more energy per vehicle kilometer and more fuel is lost in idling than diesel buses. This was borne out by the emission tests of CNG and diesel buses of similar size carried out for the World Bank GEF project in Mexico City (SMA, 2006; Clark et al., 2006). Only one of the CNG buses, with 140 places, emitted less CO2/km than the conventional diesel articulated buses tested. However, understanding emissions from different fuels requires a full fuel cycle analysis that compares not only of the energy of combustion (and resulting CO2 emissions) but emissions associated with other parts of the fuel cycle, such as the natural gas burned in compressing the CNG, typically 7% of the energy put in the tank, or the refining of diesel and the transportation of both fuels to where they are used.[10]

iii. Operational Improvements

Metrobús does not have automated priority at traffic signals, which has been shown to save fuel for transit operations by reducing idle time and permitting smoother operations. (Skea, personal communication, 2003) This is one additional benefit that could be harvested at a later date.

iv. Hybridization of Colectivos and Taxis

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would save approximately 30 tonnes/CO2, worth almost USD $2,800at the higher price of CO2, in addition to about USD $5,500 worth of fuel. The straight line rate of return is slightly over 5%, well below the interest rate Mexico City paid for its buses (Schipper et al., 2007). The investment in hybrids might be a justified investment for Mexico City or a third party, however. But the savings from this step, 3000 tones/year over all buses, is still a small fraction of the savings from the transport related changes – fewer larger buses, improved traffic, and modal shift.

[10] Combustion of gas to CO2 is not the only source of greenhouse gas emissions. Leaks of natural gas in transmission, storage, and compression could add significantly to the life-cycle greenhouse burden of natural gas as a fuel because its chemical, methane, is a far more potent greenhouse gas than CO2 on a molar, weight, or energy content basis. For the U.S., the upstream losses add 12-16% more GHG than the combustion of methane alone, excluding leakage in filling (Jaramillo, 2007). Similar fuel cycle burdens for diesel are closer to 8% of the losses in combustion. Thus overall full fuel cycle analysis suggest there is little or no real greenhouse-gas savings from using CNG buses of similar capacity and performance to diesel buses. Unfortunately, the Mexico City tests did not measure leakage in storage or natural gas used for compression at filling, nor were there estimates of actually pipeline leakage of methane in the Mexico City. In the end the extra cost of both natural gas buses (over conventional diesel) as well as the significant cost of a CNG refilling infrastructure deterred Mexico City from exercising this option. Since other LAC countries, notably Argentina but more recently Brazil and Peru embraced CNG for use by public transport, investigation of CNG options is an important step in CO2 analysis. As noted here, this must be done with full fuel cycle analysis.

Improving the performance of smaller collective transport vehicles is also worth considering, as there are still over 25,000 in Mexico City according to the SMA inventory. Several hundred colectivos were forced off the corridor in this project. While most vehicles were bought up and destroyed, many drivers lost their immediate jobs.

A more equitable and humane option might have been to explore a longer range role for these smaller vehicles as feeders, say with the use of hybrid engines for gasoline or diesel colectivos. For example, the older gasoline colectivos with 24-30 seats each and weighing 3 tonnes might be fitted with an inexpensive version of the powerful hybrid engine that powers the General Motors Tahoe of similar weight. Since the performance of gasoline engines is affected by bad congestion and idling more than that of diesels, this hybridization could offer significant savings to the gasoline colectivo fleet. Or the most recent diesel colectivos on Insurgentes, 10 meter Mercedes "Boxers" holding 36 places, could be adapted to diesel hybrid drive trains. The gasoline colectivos released 1.45 kg/km of CO2 while the diesels released 1.77 kg/km, slightly more than a Metrobús itself. Using hybrids on these routes could cut emissions by roughly 20-30%. They could be used to provide long-awaited feeder services to the larger BRT trunk line. This could guarantee the colectivo drivers better and more regular routes and incomes. If the drivers/owners could be enticed (through financing) to collectively purchase literally thousands of hybrid vans the price could fall. Indeed, Mercedes of Mexico financed the acquisition of hundreds of the Boxers after 2001 by accepting small regular payments from the drivers (Vieira Lima, personal communication, 2002). Scale purchases and financing could make this option affordable.

The same hybridization may spread to private vehicles in Mexico City. Like colectivos, taxis, which run mostly on gasoline with a few using CNG, see the worst driving conditions, those where hybridization has its largest impact. Taxis are becoming increasingly gasoline hybrid in US cities as well as in Italy. Since Mexico City procures as many as 20,000 taxis at a time, the next opportunity for such a large scale purchase offers an opportunity for the city to explore hybrid gasoline vehicles or even CNG. Compared to gasoline, CNG offers GHG and local air pollution benefits even on a full fuel cycle basis. (ANL, 2007)

v. Biofuels

There are still expectations that at least modest amounts of lower CO2 fuels from biomass may be developed. Stockholm for example is running diesel engine buses on ethanol from Brazil, which for the time being represent the lowest CO2-emitting combustion buses in service. BEST, the coalition organized by the city of Stockholm, is testing such buses in Brazil. Mexico did experiment with four Scania buses using gasoline-type engines to run on Mexican produced ethanol. The project was scrapped because of poor results. (Hedberg, personal communication, 2003) The latest results with ethanol buses in Stockholm suggest this option has opened again. (Paedam, 2009)

vi. Summary of Long Term Technological Possibilities

This list of lower emission vehicles is not exhaustive, but indicates there are many possibilities for both collective transport and private vehicles. These advances in lower-carbon vehicles have one important consequence for projecting CO2 impacts of projects. If automobiles, taxis, or colectivos have lower vehicle or modal carbon intensities, then the CO2 gains from modal shifts away from these modes to large capacity buses have to be adjusted accordingly. In Brazil, for example, about ¼ of the automobile fuel is renewable ethanol from sugar cane with almost no net CO2 emissions compared with the gasoline replaced. Moving traffic from cars running on pure ethanol to fossil-fueled buses, while possibly desirable from a transport perspective, may have little or no CO2 savings and even represent an increase in CO2 emissions.

In considering technological options to reduce emissions from individual vehicles, it is important to remember that the region and its operators have limited funds. While advanced engines and fuels might save CO2, it is worth asking what alternative investments for the same funds (such as traffic signal synchronization or other applications of ITS, improved access to existing stations, or other improvements to transit service might provide more and improved travel for the same fuel use, rather than only permit the same level of travel and service on less fuel. Given the importance of transit remaining competitive with car use, planners should evaluation the CO2 consequences of a broad range of investments, not simply those that save carbon through advanced technology.

In summary, when considering long-term technological options, the following questions must be asked:

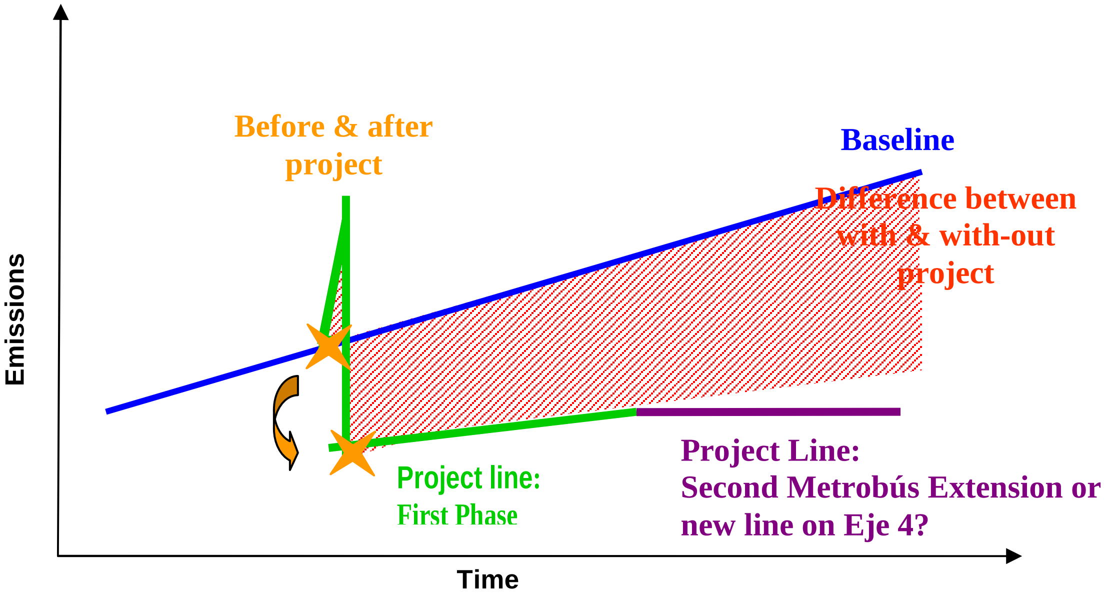
1. *What are the costs of options for vehicles and fuels*
2. *What are the expected fuel utilization rates relative to the marginal costs of the vehicles or fuels involved?*
3. *What are the net carbon savings from combustion, and what are the full fuel cycle impacts of each fuel?*
4. *What are the expected differences in operating costs among the alternatives?*
5. *What are the range of expected energy prices and carbon values to be used.*
6. *What are the overall carbon savings?*
7. *What is the value of the carbon savings relative to other savings or costs in fuel, and how do the total savings compare with the incremental costs of the equipment or fuels.*
8. *What special training for the vehicles or fuels is required?*
9. *What measures are in place to monitor the actual performance of the option (s) chosen relative to a base line?*

D. Longer Term Impacts

A number of longer-term impacts of Metrobús must be considered that may not yet have occurred or been measured. Some could increase CO2 emissions by stimulating change in land use. Yet with Metrobús it is likely that the overall effects maximize access or mobility opportunities for a given amount of CO2 released because Metrobús is so much less carbon intensive than car travel, which is what was growing the fastest at the margin.

Figure A2 below, taken from Figure 2.2 in Chapter Two of the Framework, illustrates one way of counting the various short-and long-term impacts of Metrobús. The upper blue line represents a project-path that emissions from traffic in the Insurgentes corridor and surrounding region might have taken with no Metrobús. Drawing this line presumes that the region has a good travel and emissions modeling capability. The green line represents emissions after the project was completed, with the exaggerated spike upwards illustrating traffic delays during some of the most intrusive phases of construction. The green line then represents the path of emissions after Metrobús started. The distance between the blue (hypothetical) and actual has been exaggerated for illustration.

Figure A2.2 Impacts of A Project Over Time, Compared to a Business As Usual Baseline



Two features of these curves illustrate the subtleties of measuring the impacts of projects. First, the green line was purposely drawn to have a smaller slope than the blue line. In other words, it is assumed that over time, that Metrobús yields not simply a one-time reduction in emissions from a rising baseline, but that its savings, illustrated by the red hatched area, increase over time.

The purple line represents a 2nd phase of Metrobús or, more broadly, a new the possibility of a new project that might build on Metrobús success (the extension of the first Metrobús line or the recent opening of a 2nd line, Eje 4). Adding feeder lines, as noted above, could be an attractive “2nd phase”.

In 2007 Metrobús was extended another 9 km to the Universidad Nacional Autónoma de México (UNAM), adding about 80 000 more daily riders. (Centro de Transporte Sustentable de México, personal communication, 2009) In December 2008 a 2nd Metrobús line was added on Eje 4, carrying 90 000 passengers a day along 20 km that did not cross the first line. More lines are expected that will yield a network much like the existing Metro, with more interchanges with the Metro. It will become important to monitor transfer traffic, as well as see whether increased access around the region leads to greater travel.

Not all the long term impacts of Metrobús (or any good transport intervention) reduce CO2 emissions from the base line as the drawing implies. The relative speed advantage of Metrobús over other modes can increase travel in the long term, which could turn the baseline upwards somewhat. Developers could build housing, office, shopping and other services at distant points along the Metrobús route, increasing the number and lengths of trips taken compared to the present distribution of origins and destinations. Workers from low-income parts of Estrada de Mexico who transfer to the northern terminus of Metrobús at Indios Verdes can reach more jobs for a given travel time. Conversely, developers may see the advantages of large developments along Metrobús that leave even more origins and destinations close to the Metrobús corridor. This could decrease travel distance for many, not simply for work trips but also for other trips, whose share of total travel tends to grow with growing incomes according to US and European travel surveys. A policy of intensifying development along the Metrobús Corridors to increase access to the bus could also stimulate both higher ridership and more walking along the corridor, if accompanied by improved side-walks (or bike ways) as was done in Bogotá and earlier in Curitiba.

Other policies could intensify Metrobús use. Special off peak tariffs, for example for families on evening or weekend leisure and shopping outings, could reduce the variable cost of using Metrobús to below that of a car (fuel plus parking). If the Metrobús network grows and its fares integrated with those of other modes, a much larger portion of Mexico City would be connected to truly fast mass transit, restraining the car share significantly. Because present car use is 5-10x more carbon intensive than use of Metrobús or Metro, a significant increase in per capita travel by these modes could accompany a decrease in actual and projected CO2 emissions from much lower car use.

Travel models can simulate some of these possible results from an improved transit network. Good travel and traffic surveys and up-to date modeling techniques should be employed regularly to spot these trends and use them to adjust the models the region employs.

Questions to ask about the long-term evolution of a metropolitan area and its transport system include these:

1. *Is the region's transport model detailed enough to portray individual projects and their impacts on travel, traffic, etc.?*
2. *Is there a simulation model to estimate emissions from traffic in the region, particularly traffic affected by a project?*
3. *Can the impact of changes in land use close to the zone influenced by a project be modeled?*
4. *Conversely, can the model simulate changes in land use resulting from improved transport service, speed, or accessibility?*
5. *Did success of a project or policy lead to strengthening of the policy or implementation of more projects? In the case of Metrobús, the initial line was extended several kilometers, and a 2nd line was opened in December 2008, with more planned.*

E. Institutions for Better Monitoring

Since Metrobús was primarily a transport project it is important that its transport consequences be measured. Three institutions have been involved in data gathering and analysis of transportation and emissions. Metrobús itself has the yearly on-board surveys carried out by a private firm. Mexico City supports an origin-destination survey published by INEGI, with previous ones carried out in 1986 and 1994 and the most recent survey 2006. The data published by the Transport Secretary SETRAVI in the various regional transport plans (PITV) gave total trips and modal split but not distances traveled or trip purposes. The picture of how Mexico City residents travel has been incomplete because this lack.

The city's environmental ministry, or Secretaría de Medio Ambiente (SMA), assembles a detailed emissions inventory. Emissions of criteria pollutants and fuel use are based both on the twice-yearly inspections of light duty vehicles as well as estimates for heavier diesel vehicles. A "Mexicanized" version of Mobile 5 is used to simulate fuel use. Because the twice-yearly inspection gathers odometer data, the utilization of light duty vehicles in the Mexico City region is well understood. From these data, the use of gasoline can be tabulated bottom up by numbers of vehicles, distance/vehicle, and fuel use/distance and compared with sales. This inventory is one of the most complete of any city in the world.

Table 1.3 summarizes the main information contained in the Mexico City mobile source emissions inventory (SMA, 2006). This inventory was commenced in 1994 and evaluated every other year to monitor progress towards reduced emissions of air pollutants from all vehicles in the Mexico City Municipal Area, which includes parts of the States of Mexico and small parts of other states that share the same air basin. The summary figures are built from readings of odometer readings of all light duty vehicles, which are inspected twice a year and tested for emissions. From the inspections, the yearly distance traveled and numbers of vehicles in use by each major vehicle/vehicle technology/fuel combination available over the last 30 years are known. Various tests and use of the Mexican version of Mobile 6 permit authorities to construct estimates of emission factors (in grams/km) of each major pollutant, as well as fuel use (and CO2 emissions) for each of these classes of vehicles. Such detail permitted Rogers to base his estimates for Metrobús savings not on average vehicle emissions but on average emissions of vehicles observed regularly in the Insurgentes corridor.

A more detailed picture of the use of Metrobús may be available when the 2006 Origin-Destination survey for Mexico City is released. The 1994 study was too out of date to provide reliable information on travel patterns in Mexico City just before Metrobús was inaugurated. While estimates based on traffic and bus counts were made in the planning stages of Metrobús, there was no real OD survey carried out. Hence Rogers' approach was to use available data and new traffic counts and measurements to establish distances vehicles moved and changes in vehicle speeds.

What Mexico City has lacked, however, is a good measure of trip distance by mode and purpose. The 1994 O-D Survey yielded only number of trips by mode. With information on distance and trip purpose, a better picture of present travel patterns in the region and their variation over the region by income and location of home and work can yield a better picture of future travel. Combined with the vehicle activity and emission from the SMA emissions inventory, Mexico City could develop a much better picture of how home location (and indirectly land uses), travel, vehicle use, and emissions are related, as has been done for many US cities and more recently the Paris Region. (Hivert, 2007) Such information provide invaluable background for building a business-as-usual case and then link changes in travel and vehicle use to changes in fuel consumption and CO2 emissions.

Most of the analysis of the CO2 impacts of Metrobús was carried out by Rogers in preparing the Metrobús case for funding from the Clean Development Mechanism. (Rogers, 2006) Mexico City authorities probably have the capability to do this work now after Rogers' approach (or other approaches). However, as this discussion implies, the various data sources are spread around the government, with no single authority empowered to reconcile the data. SMA collects only vehicle-based data but nothing on passenger travel. The figures used by SETRAVI in previous transport plans are quoted in trips, not in travel by mode. Thus there has not been a measure of mobility of Mexico City region residents. Since Metrobús is a project that changes peoples' travel patterns, it is difficult to imagine a thorough evaluation of the impact of Metrobús on CO2 emissions without a clear connection to both vehicles and people’s travel in kilometers, which is critical for understanding not only for estimating the impacts of modal shift as well as the CO2 associated with modes taken before passengers get on Metrobús or after they alight.

2. Appendix Two: CO2 Emissions Reductions from a Bikeway Project in Santiago de Chile

The framework presented in Chapter 2 set forth a methodology for analyzing the production of greenhouse gas emissions from the transportation sector. In this section, the framework guides an analysis of the case of bicycle improvements in Santiago de Chile.

We articulate the relationship between the framework and the analysis with the following questions:

(1) How does the intervention affect urban development, transportation and greenhouse gas emissions in Santiago?

Urban development: How does the bikeways project fit in the context of urban development of Santiago?

Transportation: How does the bikeways project fit in the context of good transportation for Santiago? and

Emissions: How does the bikeway project affect emissions of greenhouse gases from transport in Santiago?

Following the framework, we also want to know:

(2) The costs and benefits of the project. What are the values of carbon saved and other project benefits? Is the value of carbon saved a significant share of the total project benefits or not?

(3) The effects of the project in the short run and the long run compared to the “without project” scenario. And,

(4) The first and second order effects of the bikeways on emissions, as well as on other factors such as safety, accessibility, and livability.

We use a range of data sources to carry out this analysis, including local plans and reports, archived data for Santiago, academic articles, World Bank project documents, and project evaluations made by a third party, Steer Davies Gleave. The Steer Davies Gleave project evaluation presented calculations of carbon savings and other project benefits, and in the following sections we discuss their methodology in the context of this framework. (See Box 1)

Our description of the project and analysis of the case follow.

Box A2.1. Steer Davies Gleave Method to Calculate the Expected Greenhouse Gas Emissions Savings from the Bikeways Project

Data:	• 2001 Origin-Destination survey for Santiago • Intercept survey of bikeway bicyclists: what is their mode shift from auto and other modes to bicycle? It is 5%. • Intercept survey: trip length • Bicycle flow counts: what is the actual change in bicycle flows? • Fleet characteristics: catalytic converters
Demand for bicycle trips:	• Base year: Actual bicycle trips within and between the three neighborhoods in the project area in 2001. • Construct three scenarios for growth in bicycle trips for 2001-2006 (slow, medium, and high) using actual measures of the growth in bicycle flows.
VKT reduction:	• For the final year of the constructed scenarios, 2006, 5% of the trips would have been made by auto. • Assuming that the average bicycle trip length equals the average auto trip length, calculate the VKT saved.
Emissions savings:	• Use default values and fleet data to account for emissions differences between vehicles with and without catalytic converters in the project area. • Use default values to account for the effects of effect of cold starts on emissions. • Apply the GHG emissions production formula from the COPERT III model to the estimated VKT savings in 2006 to calculate greenhouse gas emissions saved for each of the three scenarios.

A. Description of the Bikeways Project

In 2003, the World Bank, in coordination with the Global Environmental Facility (GEF) and local counterparts, financed the bikeways project, among others, to promote the use of the bicycle as a mode of transport in Santiago, Chile. The financing was a grant from the GEF, which included USD $2.59 million for the bicycle component. The project included creating bikeway infrastructure and promotion activities in three neighborhoods in central Santiago: Santiago, Providencia, and Ñuñoa.

The objective of the project that included the bikeways was to “To help reduce greenhouse gases (GHG) from ground transport in Santiago through the promotion of a long-term modal shift to more efficient and less polluting forms of transport…” and this objective related directly to supporting the implementation of comprehensive, regional transportation plans for Santiago. (World Bank Group, 2003) Increasing the mode share of bicycles and reducing bicycle accidents were among the World Bank's performance measures for the project. (World Bank Group, 2003)

The project used GEF funding to construct about 10 km of new bikeways and the illumination of about 10 km of locally financed bikeways in Santiago, Ñuñoa, and Providencia, three municipal districts (*comunas*) in central Santiago that form the project area. These new bikeways complemented about 20 km of additional bikeways funded by Santiago, Ñuñoa, and Providencia, and the existing 11.6 km of bikeways in these same district municipalities.

The bikeway infrastructure included a range of designs including bikeways located in central medians separated from traffic by landscaping, bikeways separated from motorized traffic with physical barriers, and bikeways indicated with striping. The project also supported safety education programs.

B. Analysis of the Bikeways Project

i. Urban Development

The bikeways project was only a modest pilot project, but it fit into a much larger framework for urban development that Santiago had been planning. This planning framework included the broader local and national efforts to restructure the urban transportation sector in Santiago. Thus, the bikeways project benefited from the extensive planning, design, and institutional work that was underway in Santiago at the time. Linking the project to regional planning should create opportunities to coordinate across sectors (e.g., to facilitate education programs, land development planning), across transportation modes (e.g., to facilitate transit policies and infrastructure that support bicycle-transit trips), and with planning processes (e.g., community participation, design workshops).

Because the project was initiated by the district municipalities, and was co-financed and planned by these municipalities, there should also have been opportunities to plan and design the bikeways in the context of a neighborhood vision for development and transportation. This local planning could address other things such as local transit corridors, parking, local access to schools and shopping, security, and other neighborhood issues that should be considered in a planning process that integrates transportation and land use.

Short Run and Long Run Effects

In the short run, residents in the district municipalities with the new bikeways perceived them as neighborhood assets. Residents responded in surveys that they favored having the bikeways built "in front of their houses" (89%) even though many of those surveyed do not bicycle. In the long run, neighborhoods with better non-motorized access to local amenities and with calmer vehicular traffic may attract residents who prefer to make some of their trips by bicycle or walking, and may even induce some substitution to cleaner modes and more recreational travel by bicycle or walking. Indeed, in the short run the bikeways attracted existing riders, new riders, and new trips, including recreational trips.

Stakeholder Involvement

In this section on urban development, we should also discuss stakeholder involvement. Chile has a growing bicycle culture (possibly a counterculture) with bicycle advocacy groups such as the Movimiento Furioso Ciclistas (see www.furiosos.cl), organized critical mass rides, bicycle culture festivals, and Sunday rides on streets closed to motorists. This bicycle culture also has a web presence including weblogs, and extensive commentary on regional air quality and transportation planning websites by bicycle advocates (see www.publimetro.cl, on October 8, 2008, for example). A *San Francisco Chronicle* article from 2004 cites the bicycle movement as a factor in the increase in the use of the bicycle in Santiago, and figures from this article (from the Ministry of Transport) indicate that the bicycle mode share in Santiago could be as high as 5%. (Ross, 2004)

Engaging the bicycle advocates was a key element in the development of the bikeway project, and this is an example of how engaging social, environmental, and business stakeholders may make significant long-run contributions to sustainable metropolitan development in Santiago.

ii. Transportation

The bikeway network is part of a larger network of bicycle facilities for the Santiago region. Internet sites, press releases, and government documents reference a "Plan Maestro Regional de Ciclorutas" calling for 690 km of new bikeways in the metropolitan area by 2012. The bike planning effort is connected to regional air quality and transportation planning. In addition to bikeways, the region has increased bicycle parking at metro stations, and neighborhoods in the project study area have initiated a bike-share program. This signals popular and political support for non-motorized transportation improvements.

The cross-sector and intermodal planning is key for the bike planning, and the different transport modes should be considered together to achieve better policies and designs. For example, in addition to infrastructure, the bicycle planning consider bicycle parking policies and local zoning and business codes to ensure that bicycles have safe parking at trip destinations. Coordination with transit agencies should result in operating polices that regulate how bicycles can be accommodated on buses and trains, and how and where safe parking will be included at stations. Indeed, some of this coordination for infrastructure and policy was carried out in this project, and limited progress has been achieved so far (e.g. Metro has started to install safe bike parking facilities at some of their stations, a law to promote cycling that approaches the issues from a safety perspective is in the making). Nevertheless, coordinating policy and infrastructure is needed to fully promote bicycle use.

Short Run and Long Run Effects

It is also important to recognize that the bikeway project has a long history, and developing good metropolitan transportation is a long-term endeavor. Bicycle planning for Santiago was underway as early as 1985, with bikeway pilot projects implemented and evaluated in the late 1980s. (Latina, Ltd., 1994) During the 1990s, bicycle planning has been a component in the regional transportation plans for Santiago. In the late 1990s, transportation economists in Chile estimated the demand for bicycle travel in the city. (Ortúzar et al., 2000)

This prior work resulted in information that can be used for current bicycle planning. Through household surveys of a sample of Santiago residents and forecasting Ortúzar and his colleagues found:

- About 78% of women and about 66% of men never use a bicycle to make current trips.
- About 38% of women and 50% of men who use a bicycle make bicycle trips once a week or more.
- About 23% of women and 26% of men would be willing to use a bicycle for some trips.
- Half of the potential bicycle users are between 17 and 30 years old.
- In a future scenario with “a dense and properly designed cycle-way network, and Metro and suburban rail network significantly larger than at present, and much more congestion” the researchers estimated that for about 87% of the current person-trips bicycles would not be considered an option.
- Given the same future scenario, the researchers estimated the number of bicycle trips would increase from about 1.6% of all trips (from the 1991 O-D survey) to 5.81% on average, with more than 10% mode share in some neighborhoods.
- The forecasted bicycle mode shares for Santiago, Providencia, and Ñuñoa, were between about 4 and 5%, and these neighborhoods have medium to high levels of income, a factor associated with lower bicycle use. (Ortúzar et al., 2000)

Through focus groups with Santiago residents they found that bicycling is associated with a social stigma, particularly to people with higher incomes. (Although this may be the case, the bikeway project was implemented in upper class neighborhoods in Santiago, signaling a more complex relationship between class and active transportation modes than is commonly assumed.)

The short-run results from the bikeways project are generally consistent with Ortúzar’s findings on travel behavior. Most people in the neighborhoods do not use a bicycle, more men than women ride a bicycle (although during the project period there has been an increase of women riding a bike during weekdays from 8% to 20%), and most cyclists are younger. These results are presented in the next section. Long-run changes in travel behavior due to bicycle improvements are not yet known, and strategies to learn the long-run effects should be included in good transportation planning.

First and Higher Order Effects

In addition to knowing the effects of the bikeways on travel behavior, we need to know the effects of the bikeways on other aspects of the transportation system such as motor vehicle circulation, public transit service, and pedestrian travel.

For example, some, but not all, of the bikeways in this project’s network took a vehicle travel lane to create space for bicycles. The extent to which this decrease in the vehicle capacity of the network affected traffic flows is not known. Consultants conducted bicycle flow counts in the project area, but they did not conduct vehicle flow counts. This information should be included in the design and planning of the facilities, as well as the estimation of emissions discussed in the next section.

Similarly, if the project facilitated intermodal connections with buses or trains, and if bicycles were allowed on these vehicles, how did these new policies affect transit service in the long run and short run? Prior work by Ortúzar and findings from the evaluations of the bikeways suggest that bicycle-transit trips are rare, and not very appealing. Bike-to-transit transfers were considered part of this project in relation to efforts to increase bike parking at metro stations and in the study area. However, bicycle-transit trips are still rare.

Furthermore, did the presence of the bicycle facilities affect pedestrian travel in the project area? Bicyclists surveyed reported collisions with pedestrians, but pedestrians were not surveyed as part of the evaluation study. Additional information about the transportation context is needed to fully evaluate the bikeways project.

iii. Emissions

How does the bikeway project affect emissions of greenhouse gases from transport in Santiago?

Steer Davies Gleave conducted the evaluation study of the bikeway project area. This firm designed the study, collected data before and after the project's implementation, and analyzed evaluation data. They collected a baseline of bicycle flows in 2003 and 2004 at sites with and without the bikeway infrastructure. After the construction of the bikeways, they collected bicycle user and opinion data in 2005 and 2006 through intercept surveys, and collected data about post-project bicycle flows at the same locations used for collecting baseline flow data. This firm also documented the settings of the bikeways with photographs, and information about safety from secondary sources, from bicyclists in surveys, and through observation.

Recent travel survey data for Santiago reported in the evaluation showed that bicycle trips account for 1.9% of all trips (an increase from 1.6% in the 1991 O-D survey), and almost 5% of non-motorized trips (see Table 1).

TABLE A.2.1. Mode Shares for Non-Motorized Trips, 2001 O-D Survey for Santiago

		Mode share	
Mode	**Daily trips**	**% of all trips**	**% of all non-motorized trips**
Bicycle	303,887	1.9%	4.8%
Walking	5,978,312	36.7%	95.2%
All non-motorized	6,282,199		

Source: Steer Davies Gleave, 2007a.

Steer Davies Gleave carried out intercept surveys and flow measurements at various locations in the project area, with and without the new bikeways. The following are some of the characteristics of the bikeway users and their travel behavior, measured in 2006:

- On winter weekdays, 90% of the bicyclists were men (87% spring), 10% were women (13% spring); depending on the counting method, women were 14% to 18% of riders on Sundays in winter (20% spring). Surveyors counted higher concentrations of female riders in Ñuñoa and areas east of Santiago. The evaluation suggested that "better safety conditions" in these areas may explain the higher counts of female riders, but it is not more specific about what these safety conditions are.

- The average age of bicyclists is about 33 years old.
- Trade workers and "dependent workers"—non-independent professionals who are likely to be salaried—accounted for 57% of the bicyclists surveyed, and students accounted for 17%.
- On weekdays, about 60% of the trips were to work, and on weekends about 65% of the trips were for recreation.
- Counts at various locations with bikeways showed higher bicycle flows on the bikeways than on other parts of the road environment: depending on the method of counting, flows were 67-81% on bikeways (81-82% spring), 9-21% on streets (7% spring), 9-10% on sidewalks (10-12% spring), and 0-2% on medians (0-1% spring).
- Fourteen percent of the bicyclists surveyed said that they'd been in a bike accident on the bikeway they were using at the time of the survey, and 50% of these accidents were with pedestrians or other bicyclists.

Bicycle flows increased by 26% in the spring and 17% in the winter at measurement locations where bikeways were located, and by 8% and 3% in the spring and winter, respectively, at measurement locations without the new bikeways. There was a gender difference in the use of the bikeways: the proportion of women was higher on streets with bikeways compared to streets without bikeways.

The bikeways did attract new riders. Surveys of bikeway users showed that about 40% of the bicyclists surveyed would not have made the exact same trip before the bikeways were built. The modes used prior to the construction of the bikeway were microbus (47%), walking (8%), metro (6%), drive (5%), with 4% traveling by motorcycle, taxi, or a passenger in a car. ***Thirty percent of the trips would not have been made without the new bikeways.*** Men made 74% of the induced trips. Fifty-six percent of the induced trips were for recreation. Of the 60% of bicyclists who were making the same trip before, 88% were using the same route. (Steer Davies Gleave, 2007b)

Tables two through four present additional information from the evaluation about bicycle flows and survey responses regarding alternatives to the bicycle.

TABLE A3.2. Measures Bicycle Flows in the Project Area, 2004-2006

Total measured flow (veh/day)	Spring 2003	Spring 2005	Spring 2006	Growth rate, 2004-2005	Growth rate, 2005-2006	Total growth rate
Average weekday	5,212	7,158	7,048	18.70%	-1.50%	11.70%
Sunday	3,473	4,280	3,322	11.60%	-22.40%	-1.40%
Total measured flow (veh/day)	**Winter 2004**	**Winter 2005**	**Winter 2006**	**Growth rate, 2004-2005**	**Growth rate, 2005-2006**	**Total growth rate**
Average weekday	3,629	4,410	5,020	22%	14%	19%
Sunday	1,962	1,181	2,065	-40%	75%	3%

Source: Steer Davies Gleave, 2007a.

Table A.2.3 Modal Alternative to the Bicycle, Winter 2005-2006, Intercept Survey

	Weekday		Sunday	
Alternative mode to bicycle	**2005**	**2006**	**2005**	**2006**
Micro	59%	68%	23%	33%
Metro	8%	11%	4%	6%
Motorcycle, scooter	3%	4%	2%	4%
Auto, driver	4%	4%	5%	5%
Auto, passenger	1%	1%	1%	1%
Taxi or colectivo	1%	1%	0%	1%
Walking	15%	8%	23%	20%
Would not have made the trip	7%	2%	34%	29%
Other	2%	0%	8%	0%

Source: Steer Davies Gleave, 2007a.

Table A.2.4. Modal Alternative to the Bicycle, Spring 2005-2006, Intercept Survey

	Weekday		Sunday	
Alternative mode to bicycle	**2005**	**2006**	**2005**	**2006**
Micro	54%	62%	23%	27%
Metro	11%	9%	4%	4%
Motorcycle, scooter	5%	3%	2%	3%
Auto, driver	5%	4%	5%	5%
Auto, passenger	1%	1%	1%	1%
Taxi or colectivo		2%	0%	1%
Walking		13%		24%
Would not have made the trip	1%	6%	34%	33%
Other	10%	1%	23%	4%

Source: Steer Davies Gleave, 2007a.

Steer Davies Gleave also conducted telephone interviews in 2006 with 800 residents in the project area. Thirty-one percent of respondents were students, and about 27% were “dependent workers in the private sector”. Their most commonly made trips were to work and school. About 26% of these trips were made by walking, about 25% by bus, about 18% by driving, about 17% by metro, and about 5% by bicycle. The average travel time was 25 minutes, and about 70% of the trips were made within the project area. About 34% of respondents said that they use a bicycle, and 42% said that they regularly use the bikeways when they ride. (Steer Davies Gleave, 2007b)

iv. GHG Emissions Calculations for the Project

The project evaluation by Steer Davies Gleave calculated the GHG emissions and emissions of local pollutants saved by substituting bicycle trips for auto trips. They reported that the evaluation method they used is an adaptation of the calculation methods in the document, “Plan Maestro y Diseño de Físico de Obras” by GEF, the World Bank, Sectra, and CGTS. (Steer Davies Gleave, 2007b)

Estimation of Demand for Bicycle Trips

The analysis used the 2001 O-D survey for the baseline year (2001), and assumptions of the growth in bicycle trips to project hypothetical, cumulative demand for bicycling within and between municipal districts in the project area for workdays and weekends for the period 2001-2006. Weekend bicycle trips were assumed to be 0.84 of weekday trips, which is the proportion found in the 2001 O-D survey. The three growth scenarios were: slow growth (1.7% between 2001 and 2006), medium growth (1.7% between 2001-2003 and 5.2% between 2004-2006), and optimistic growth in bicycle trips (1.7% between 2001-2003 and 15.4% between 2004-2006). The results of this estimation are presented in Table 5. The growth scenarios are based on measured increases in bicycle flows at representative locations.

TABLE A.2.5. Bicycle Trips in the Project Area by Growth Scenario, by Type of Day, 2006

	Bicycle trips/day					
Growth scenario	**Slow**		**Medium**		**Optimistic**	
Type of day	**Weekday**	**Weekend**	**Weekday**	**Weekend**	**Weekday**	**Weekend**
Intra-neighborhood Providencia	6,040	5,078	6,685	5,621	8,825	7,419
Intra-neighborhood Ñuñoa	5,538	4,656	6,130	5,154	8,092	6,803
Intra-neighborhood Santiago	24,599	20,682	27,228	22,892	35,940	30,217
Inter-neighborhood Providencia	1,085	912	1,201	1,010	1,586	1,333
Inter-neighborhood Ñuñoa	1,498	1,259	1,658	1,394	2,188	1,840
Inter-neighborhood Santiago	2,701	2,271	2,989	2,513	3,946	3,317
Total	41,462	34,859	45,891	38,584	60,576	50,930

Source: Steer Davies Gleave, 2007a.

Estimation of Vehicle-km Reduced

The analysts used information from the intercept survey of cyclists about how many of these trips would have been auto trips—between four and five percent—to estimate the daily trips within and between municipal districts that would have been made by car. The analysis then expanded this figure to represent annual trips saved, assuming 350 travel days in the year, 100 weekend days and 250 weekdays. The analysis did not estimate saved emissions from microbus, metro, or taxi trips.

The intercept survey showed bicycle trip lengths were 5.36-6.27 km within neighborhoods and 8.43-10.58 km between neighborhoods. The analysis used these trip lengths to estimate the annual reduction in kilometers traveled by car for each of the scenarios.

Estimation of the Saved Emissions

The analysis determined the CO2-equivalent emissions by accounting for both CO2 and methane emissions. The analysis also accounted for the proportions of the fleet with and without catalytic converters, and the effect of cold starts. Calculations were constructed with data about local traffic flows and median speeds.

The evaluation considered two options for calculating the CO2-equivalent emissions: the carbon balance method and the figures outlined by GEF. It used the carbon balance equation, and additional equations for calculating emissions of methane for vehicles with and without catalytic converters from COPERT III. (See Table 6.)

TABLE A.2.6 Emissions of CO2eq Reduced, COPERT Formula, 2006

	CO2 emissions reduced (tons/yr)			CH4 emissions reduced (tons/yr)			Emissions CO2 equivalent reduced (tons/yr)		
Growth scenario: slow (S), medium (M), optimistic (O)	**S**	**M**	**O**	**S**	**M**	**O**	**S**	**M**	**O**
Intra-neighborhood Providencia	102	113	150	0.04	0.04	0.05	103	114	151
Intra-neighborhood Ñuñoa	80	89	117	0.03	0.03	0.04	81	90	118
Intra-neighborhood Santiago	357	395	521	0.13	0.14	0.19	359	398	525
Inter-neighborhood Providencia	31	34	45	0.01	0.01	0.02	31	35	46
Inter-neighborhood Ñuñoa	34	38	50	0.01	0.01	0.02	34	38	50
Inter-neighborhood Santiago	74	82	108	0.03	0.03	0.04	75	83	109
Total	678	751	991	0.242	0.268	0.354	684	757	999

Source: Steer Davies Gleave, 2007a.

The results show that CO2 emissions were reduced between 684 and 999 tons/yr, depending on the growth scenario, accounting only for reduced car trips. Additional savings may have occurred due to other reduced trips e.g. by taxi but are not counted.

viii. First and Second Order Effects

As we noted in a previous section, the emissions analysis for the project did not consider the effects of the bikeways on traffic patterns, and therefore does not account for whether the bikeways that took lanes away from vehicle traffic might have increased congestion in those areas (or in other areas) or resulted in VKT increases due to circuitous route choices to avoid areas with the bikeways.

C. Costs and Benefits of the Project

The project evaluation by Steer Davies Gleave also presented estimates of reductions in emissions of local pollutants, accidents, time savings, and fuel savings. Consistent with the framework, according to their estimate the tons of CO2 saved is a small figure compared to the size of the problem, and when monetized, they are small compared to the other co-benefits of the project. (See Table 4.6.)

TABLE A.2.6 Summary of the Economic Evaluation of the Bikeways Project, Slow Growth Scenario, 2005

Item	Annual benefit (USD $)
Reduction in GHG emissions (678 mt/year)	8,558
Fuel savings	166,234
Travel time savings	344,627
Reduction in accidents due to infrastructure	133,903
Costs of accidents due to mode shift	-24,473
Total 2005	628,850

Source: Steer Davies Gleave, 2007a.

Note: Exchange rate $550 per US$. GHG reduction estimate based on $10/ton CO2.

The consultants' cost-benefit calculations assumed USD $10/ton of CO2 reduced. If this assumption were changed to that of Stern (Stern, 2006) and instead used US $85/ton of CO2 reduced, the benefits of the CO2 reductions would still be small than the other benefits of the project.

D. Conclusions for Informing Project Design and Evaluation with the Framework

The bikeways project did facilitate bicycle trip substitutions for auto trips in the short run, but the analysis should also account for a long-run scenario in which the bikeways could help to maintain bicycle mode share in the face of increasing motorization. Also, it is possible that bikeways make the central neighborhoods safer and more attractive, and thus a more attractive housing and business location choice than they otherwise would be.

The bikeway network in Santiago has expanded since the GEF-funded pilot study, and it would be worthwhile to evaluate bicycle travel behavior in different neighborhoods. This is supported by the study by Ortúzar (Ortúzar et al., 2000) that found potential bicycle mode shares as high at 10% in other sectors of the city, whereas the potential bicycle mode shares were lowest in the relatively high-income neighborhoods of Santiago, Providencia, and Ñuñoa.

Finally, according to the project evaluation CO2 emissions reductions were a minor co-benefit compared to the monetized benefits of fuel savings, accident reductions, and travel time savings. Again, this signals the need to interpret and evaluate the potential of a project in the broader context of good transportation and metropolitan development.