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

Final Report

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Disclaimer

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Executive Summary

About This Report

The World Bank's Latin American and Caribbean Region Transport Unit (LCSTR) asked researchers at the Global Metropolitan Studies Center at the University of California, Berkeley (UC Berkeley) to help develop a framework and advise on methods and approaches for integrating CO2 concerns into urban transportation in Latin America and the Caribbean (LAC[1]). The UC Berkeley team conducted an analysis of the current portfolio of World Bank transport projects in the region and carried out interviews with Bank staff working in the region. The review of the World Bank's work was followed by a four-day workshop, held at UC Berkeley and attended by 17 members of the World Bank's staff. At the workshop, UC faculty presented information on greenhouse gas (GHG) science, issues, and impacts, other regions' responses to the GHG challenge, LAC urban transport problems and their GHG consequences, and opportunities for intervention to reduce GHG emissions in the LAC context. Presentations were interspersed with group discussions and commentary. Then, drawing upon the literature on GHG reduction strategies, LAC transport issues, the review of the World Bank portfolio and staff interviews, and the workshop discussions, the UC Berkeley team developed a framework for consideration of GHG emissions reduction strategies in the Latin America and Caribbean region. The UC Berkeley team also prepared guidance on methods and procedures that could be used to analyze GHG emissions, and developed recommendations on ways to enhance or strengthen the interventions proposed to the World Bank from the client countries.

This report presents the framework, discusses methods and approaches that can be used for transport project CO2 evaluation, and presents two case examples. A companion paper presents the findings from the portfolio review and interviews.

The introductory chapter presents background and context, describing the current and projected transport and greenhouse gas emissions situation in LAC. This chapter shows that the LAC region is a low carbon emitter on a per capita basis but its road transport emissions are high relative to its GDP. Furthermore, unless interventions moderate trends, the LAC region is expected to triple its CO2 emissions from road transport in the next twenty years, due to population growth and economic development.

Chapter two presents a conceptual framework for integrating CO2 considerations into urban transport with the aim of moderating CO2 emissions in Latin America. Strategies that can reduce transport emissions include improved vehicles and fuels, high quality transit, bike and pedestrian facilities, coordinated land use and transport, and improved traffic operations and management. Curitiba is an example of a Latin American city where integrated transport and land use planning has structured the city's growth and helped keep automobile use low. Bogotá is an example where the deployment of a bus rapid transit system has greatly improved urban transportation in a carbon-efficient way. Many more LAC cities could use strategies such as those pioneered by Curitiba and Bogotá to manage urban transport's carbon impacts.

Many of the transport measures that cities are pursuing and the World Bank is supporting in LAC urban areas are on track for reducing emissions compared to business-as-usual growth

[1] In this document LAC will refer to the Latin American and Caribbean region. Where data for the region are taken from the Organisation for Economic Co-operation and Development (OECD) or the International Energy Agency (IEA), Mexico, a member of the OECD, is included with the LAC region and excluded from the OECD unless otherwise noted.

projections. In some cases, emissions could be reduced even more by packaging measures together and improving organizational and technical capacity to coordinate across modes, manage traffic, and use pricing and regulation as a demand management tool.

Chapter three addresses ways to estimate the impacts of CO2 from urban transport projects. Formal models offer the most comprehensive analysis approach, but simpler analysis tools also can be valuable. Methods already in use in Latin America range from integrated land use-transport-emissions modeling producing detailed quantitative outputs, to surveys, counts, and analyses conducted specifically for a project, to quick-response approaches using spreadsheet calculations, elasticities, estimated data, and evidence from experience in other cities. Two case studies, presented in appendices to the report, illustrate ways in which CO2 impacts can be estimated.

Chapter four provides a summary of key points from the previous chapters and presents the authors' conclusions.

Summary of Key Findings

1. Latin America in the Global CO2 Context

Chapter one examines Latin America in the global CO2 context. While Latin America's global share of CO2 emissions is small, emissions from road transportation are high relative to income. The relatively high emissions are almost entirely due to the region's relatively high levels of auto use. Automobiles and light trucks typically account for around two thirds of the CO2 emissions in LAC metropolitan areas, despite their accounting for only a small share of total urban travel.

Emissions from road transport in LAC are expected to rise sharply in the coming decades if current trends continue. Using projections of passenger and freight activity, vehicle use, and CO2 emissions, a trends-extended rise in car use would push up overall CO2 emissions by a factor of three by 2030, even with fuel economy improvements. The increase in car use is in part a result of growing incomes and economic activity, but it also reflects the poor quality of transit and non-motorized travel options in many LAC cities.

Low carbon fuels and new vehicle technologies can help lower CO2 emissions and often have important health and livability benefits as well. However, the lower emissions per kilometer that these measures produce can be overwhelmed by rapidly growing kilometers of travel. This is expected to be the case in LAC. Further emissions reductions can be obtained by implementing good urban transport, including high quality transit, pedestrian and bicycle facilities, traffic management, and appropriate pricing of transport facilities and services. Such policies will improve services for large portions of the population, and are also likely to moderate the growth in car ownership and use and thus help hold back the increase in CO2 emissions.

LAC cities have the opportunity to contribute to the worldwide effort to reduce greenhouse gas emissions and can build upon notable LAC accomplishments in urban development and transportation to provide leadership on this pressing issue.

2. A Framework for Integrating CO2 Concerns into Transport

A framework is a conceptual structure intended to serve as a support or guide for action. Taking into consideration background and context, a framework outlines the broad set of ideas and principles that will guide future activities, identifying systems and subsystems and showing how

they interrelate. Chapter two provides the proposed framework for integrating CO2 considerations into transport plans, programs, and projects in Latin America.

The basic concept proposed for the LAC region is to analyze and take credit for reducing transport's CO2 emissions relative to what would happen in the absence of interventions. Such analyses also can be used to identify ways to enhance CO2 performance of transport investments. A systematic set of inquiries can be made that will integrate CO2 considerations into the broader process of transport and urban development in the LAC region. The steps are:

A) Determine the scope and scale of the proposed intervention, and the time frame of implementation. Will the intervention's effects be felt as soon as it is implemented, or will effects build up over time (e.g., as a vehicle fleet turns over) or perhaps decline over time (e.g., as traffic patterns change)? Will the intervention have a national, regional, corridor, or localized impact? Is the intervention designed to alter fuel composition, and if so, for how many vehicles? Will it affect vehicle types and the fuels they use? Will it alter vehicle ownership and operating costs? Will it affect the number of trips made, travel patterns, and mode choice? In the medium to longer run, is it likely to affect auto ownership, land use, and location choice? Are there ways that the intervention could be circumvented? Are additional steps necessary to maintain the effectiveness of the measure, e.g., enforcement of fuel standards, maintenance of vehicles, periodic signal re-timing for bus rapid transit? Are there other complementary or conflicting measures planned or proposed that need to be considered in evaluating the impact of the intervention, e.g., a parallel road widening, a major new development project?

B) Estimate the impact of the proposed project. Using formal models, special studies, quick response techniques or comparative case examples, analyze the project and its likely effects over the short term (e.g., the next two to five years) and where applicable, over the longer term (e.g., a 10-20 year period). For transport projects affecting travel behavior, analyze the resulting mode choices, travel patterns, traffic levels, fuel use and CO2 emissions. For interventions that are expected to have a regional or corridor-level impact, also consider likely changes over the longer term in patterns of location choices and land use and their effects on emissions.

C) Monetize the benefits and costs of the intervention. To estimate the CO2 saving co-benefits of a transport strategy, consider lifecycle costs including production or construction, operation, maintenance, and decommissioning. Consider travel benefits and costs as well as community and environmental benefits and costs.

D) Develop a business-as-usual case ("no project" alternative) for the target years of analysis in the absence of the intervention. Compare the results to those with the proposed project to gauge the amount by which the project will provide net benefits, including lower emissions, compared to no intervention.

E) Establish performance measures for ongoing monitoring and evaluation.

3. Methods for Evaluating the CO2 Impacts of Transport Projects

Estimating the CO2 impacts of transportation projects can be a complex matter because the estimates must account for system effects, now and in the future. Changes in the metropolitan region – population, economic activity, land use, the legal and regulatory environment – will affect the performance of transport projects and should be taken into account in preparing estimates of project performance. Likewise changes in transportation technology (fuels, vehicles, operations) and in the lifecycle costs of infrastructure should be accounted for.

Travel and its CO2 impacts can be estimated in a variety of ways, from formal modeling to sketch planning analyses and case study comparisons. In most analyses, several methods are used. For example, population, employment, and income forecasts may be taken from national or international sources and adjusted or updated for the local case. Mode choice may be estimated using a regional model or derived from a local survey. Traffic flow may be measured before and after or calculated and predicted with regional transportation models, traffic operations micro-simulation software, or simple spreadsheet models. The choice of methods will usually depend on the nature and size of the project to be analyzed, the quality of the data available, and personnel resources available for the analysis.

Estimating the CO2 impacts of interventions requires the analyst to combine information from travel and traffic models with information on the vehicles used, their occupancy, and their fuel-use characteristics. Standard coefficients published by the Intergovernmental Panel on Climate Change (IPCC) then can be used to convert fuel use estimates into CO2 estimates.

The most advanced method for carrying out these tasks today is an integrated transportation-land use model system. These models analyze and predict location choices and activities in which individuals, households, and businesses engage over different time frames, and estimate travel and its impacts from these broader analyses. The models sometimes include traffic micro-simulation, or they may be linked to separate traffic models. Integrated transportation-land use models have been developed in Europe, Japan, the US, and Latin America and have been applied in a number of cities, but they are not yet in common use, in part because of the high levels of data and advanced technical skills they require.

Simpler travel models estimate trip generation, trip origin-destination patterns, mode choices, and network flows including travel times and costs. Considerations such as the effects of a transport investment on land uses and location choices, vehicle ownership levels and vehicle type choices, and time of day of travel are either modeled separately or are provided as expert-developed scenarios.

Modeling has a number of well recognized limitations. Relatively few model systems include non-motorized modes, although development of walk and bike models has accelerated in recent years. Most models are carried out on data aggregated for sub-areas or corridors or a region, and if these aggregations are large, interventions that affect a small part of the city or a single corridor may not “show up” in model results. The impacts of transport changes on location and land use are ignored in some modeling systems, a practice that is increasingly viewed as problematic. Data requirements are heavy, and when data are not available analysts may rely on “default” values for model coefficients, the equivalent of assuming travel behavior in the application area is similar to that in the area where the model was estimated. Because of these difficulties, less sophisticated but more transparent approaches are often used instead.

Widely used “quick-response” approaches include using only one model from a model system, e.g., applying only the mode choice model to forecast changes in ridership due to improved transit travel times. Another simplified approach is to derive elasticities from models (e.g., changes in VKT with respect to changes in travel times) and use these elasticities to estimate the impact of proposed interventions. Retrospective or prospective surveys also can be used to estimate travel changes. These methods have their own limitations, e.g., modeling the effects of a traffic flow improvement only for the affected corridor ignores potential effects on other corridors; respondent recall may be poor; behavioral intentions often differ from actual behavior. Methods that rely on before-after evaluations of aggregate data, such as regional fuel sales or

measured emissions can be particularly problematic, since other changes in the region (e.g., population growth, economic upturns or downturns) can cloud the attribution of observed changes. What is needed is not just a before-after analysis but also without-project-with-project comparisons. This requires an approach combining models, estimates and observations.

For infrastructure investments, an important emerging method is Life Cycle Analysis (LCA), which accounts for total costs, energy use, emissions, and other key attributes of products and services from "cradle to grave" resource extraction and production or manufacturing through use and decommissioning or disposal. For transport project CO2 analyses, LCA would account for the emissions associated with producing fuels, constructing vehicles, stations and guideways, operating and maintaining the system, and retiring or disposing of worn out system components.

4. Conclusions and Recommendations

The final chapter of the report presents the study team's conclusions and recommendations. The principal conclusion is that while the LAC region is already a good performer with regard to CO2, its activities to improve transportation also reduce CO2 and packages of projects could achieve even more. Systematically incorporating CO2 concerns into transport planning, project development, and analysis would provide a sound basis for such further accomplishments.

The World Bank could encourage CO2 minimization in the following ways:

First, the World Bank could provide more technical assistance for travel surveys, traffic counts, emissions measurements, and fuel-use measurements. Good data are a critical building block for any evaluation and such data are needed to build better models for analysis and forecasting, not just for CO2 purposes but for a broad array of urban planning and economic development tasks.

Second, the World Bank could encourage and assist local authorities to develop modeling capabilities for travel demand, traffic operations, and life cycle analysis. Such modeling capabilities would enable more sophisticated analyses of growth, development, and travel, and also would enable more explicit and formal consideration of the longer-term impacts of World Bank-supported projects. This latter capability is important because road and transit projects might increase the ability of people to make longer trips and lead to, or reinforce, development in more distance parts of urban regions. Better analysis of system-wide changes due to projects could result in changes in project design to avoid undesirable side-effects.

Third, the World Bank could provide assistance to both local and national governments to evaluate strategies such as stronger fuel economy standards, stronger emission standards, congestion pricing, parking pricing, and tolls. Some of these measures may be politically difficult, yet they have been effective where used, with proven impacts on vehicle use, mode choice, and vehicle fuel intensity. Information on the benefits and costs of such measures could increase the comfort level with which such measures are regarded and over time could expand the kinds of choices local and national authorities make.

Treating CO2 considerations as a regular, required element of Bank plans, evaluations, and projects would signal the importance of action on the topic, and recognizing that many transportation projects reduce greenhouse gases from what would otherwise occur lays the groundwork for more vigorous action in the future.

5. Case Studies Applying the Framework

Two case studies applying the framework to LAC projects and showing how available methods and data can be used to estimate CO2 emissions are included as appendices to the report.

Mexico City: CO2 Reductions from Metrobús

Photo courtesy of CTS, Mexico City.

The Metrobús BRT project in Mexico City was conceived of as a way to simultaneously reduce traffic congestion (caused by high volumes of paratransit "colectivos" and growing private auto use) and improve transit service in a major corridor. The project aimed to improve bus speed, convenience, and reliability and thereby improve transport for the poor, attract riders away from cars and colectivos, and reduce air pollution and CO2 emissions from colectivos and automobiles. The project was implemented at a cost of approximately USD $80 million in 2005. It involved construction of the BRT stations and exclusive lanes and retirement of the colectivos formerly plying the route, replaced by new articulated buses using conventional diesel fuel.

The Metrobús project did not explicitly aim to reduce CO2 emissions, but it nevertheless cut CO2 emissions associated with the Insurgentes corridor by about 10%, or 50,000 tonnes/year. This amounts to about 0.25% of total transport emissions in the Mexico City region, a substantial achievement for a project that serves only one corridor in a very large metro area. About one-third of the emissions reduction comes changing vehicles; the rest comes from changes in traffic flow and from mode shifts. If Metrobús had acquired hybrid articulated buses like those currently in use in Seattle and elsewhere, an additional 3,000 tonnes of CO2 would have been saved, but at high extra cost.

A cost-benefit study done by Mexico's Instituto Nacional de Ecología found total transport benefits of at least USD $15 million/year from Metrobús. Using values of CO2 that bracket current literature and practice, USD $250,000 could be added to the benefits if CO2 were valued at USD $5/tonne, or as much as USD $4.2 million at a CO2 value of USD $85/tonne. The benefits included fewer local pollutant emissions, lower travel times on Insurgentes, and less wear on the roads because of the reduced number of vehicles (buses). CO2 is not critical for the project's benefits at the lower value and not decisive at the higher value, but especially at the higher level, the CO2 benefits are significant in comparison to the total benefits.

These analyses were possible because the region had a good data base on vehicles, fuel economy, and emissions, a product of World Bank technical assistance provided in the early 1990s. New field observations of traffic and on-board surveys of passengers had to be carried out to estimate most travel changes, however.

Santiago de Chile: CO2 Reductions from Cycle Paths

Photo courtesy JC Goicoechea, SECTRA, Santiago.

As part of a long-term vision of urban development, in 2004 Santiago de Chile built a number of cycle paths connecting various municipal districts. Since then, it has developed into a bikeway network with close to 200 km of facilities. The World Bank-administered project, funded by the Global Environmental Facility (GEF), financed the construction of about 10 km of bikeways and the lighting for another 10 km of new bikeways in three municipal districts. Advocates hope for a network of close to 700 km of bikeways by 2012.

Consultants implemented an intercept survey to evaluate the bike paths' impacts. From the survey, they determined that slightly under one-third of all bike trips would not have been made without the cycle paths, and that half of the bike trips were for recreation. The number of cyclists who reported previously using cars for the trips now on bike was used to estimate the automobile kilometers of travel removed. With a fuel use simulation program, the fuel saved and emissions of CO2 (and other pollutants) were then estimated. Close to 1,000 tonnes of CO2/year were eliminated by the bike path investment.

An analysis of CO2 saved, fuel saved, travel time reductions, and the net reduction in accidents showed a total annual project value of about USD $628,000. CO2 valued at USD $10/tonne accounted for less than 2% of this total. Even at USD $85/tonne, the CO2 benefits would have reached around 10% of the total project benefits. At either level, however, the analysis showed the added value of CO2 co-benefits of a sound cycle project.

The analysis demonstrates the value of field observations and project surveys in transportation project evaluation. However, Santiago also had a relatively recent travel survey against which to calibrate these observations and surveys, as well as a good data base of vehicles, their fuel use and emissions, and a model for fuel use calibrated for local conditions. The project-specific survey used together with these available tools resulted in a sophisticated evaluation.

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Preface

Today, Latin America is a small contributor to the world's emissions of greenhouse gases. Latin American and Caribbean (LAC) countries' emissions are a fraction of those of the US, China, and India. However, the region's car ownership, use, and emissions are higher than would be predicted on the basis of population or GDP, and car traffic clogs the streets and pollutes the air of many LAC cities. Furthermore, LAC carbon emissions from transport - mostly cars - are predicted to grow three-fold by 2030 as both auto ownership and vehicle-kilometers traveled expand. The total emissions will still be small compared to those of OECD countries, but they will not be trivial.

LAC cities are developing new transport facilities and services in order to boost economic development and increase opportunities for the poor and the growing middle classes. How can the region moderate carbon emissions while expanding transportation?

Low-carbon fuels and cleaner vehicle technologies are part of the answer. Compared to today's vehicles and fuels, such strategies could achieve carbon savings of up to 30% per vehicle kilometer by 2030. However, because the projected growth in the number of motor vehicles and their use is so large, LAC CO2 emissions are expected to increase substantially, even after accounting for improved vehicles and fuels, if current trends continue.


Left: Cyclist in heavy traffic on the Circuito Interior Mexico City.
Right: Smoking bus in Porto Alegre, Brazil.
Photographs courtesy of Lee Schipper.

Additional CO2 reduction can be attained through well-planned urban transport investments. Many LAC cities are already steering transport growth in more carbon-efficient directions by investing in high quality public transportation and new facilities for bikes and pedestrians. These travel choices improve accessibility for a large portion of the population while managing traffic, cutting pollution, and moderating CO2 emissions.

LAC leadership in implementing new travel options is creating models from which others can learn. Cities such as Curitiba and Bogotá are already widely emulated for their creative investments in urban planning and bus rapid transit. These activities provide good transport while reducing carbon emissions, and their success puts pressure for change on countries that have been slow to adopt carbon reduction policies.

Additional investments in transportation facilities and services that increase access and quality of life while also cutting carbon would benefit cities in Latin America and around the world. Transit, pedestrian and bicycle facilities, improved traffic management, and coordinated

transport and land use are important low-carbon access and mobility strategies. Most cities could also gain by strategically coordinating transport investments, creating networks of transit operating on traffic-managed streets and arterials conveniently reached by bikeways and pedestrian ways and serving mixed-use neighborhood and commercial district centers. In addition, most cities could benefit from pricing policies for fuels, parking, and other transport services that better reflects marginal social and economic costs. Such pricing is not only efficient but can generate revenue that can be used for further transport improvements.


Left: Buses unloading in Curitiba.
Right: Transmilenio bus scoots by a traffic jam in Bogotá.
Photos courtesy of Lee Schipper.

Reducing the CO2 emissions from LAC urban transport as population and incomes in urban areas grow is a challenging goal, but it is one that many LAC cities are already pursuing. Substantial additional gains seem achievable. This report reviews the challenges and opportunities and offers a framework for evaluating the CO2 consequences of transportation choices in the years to come.

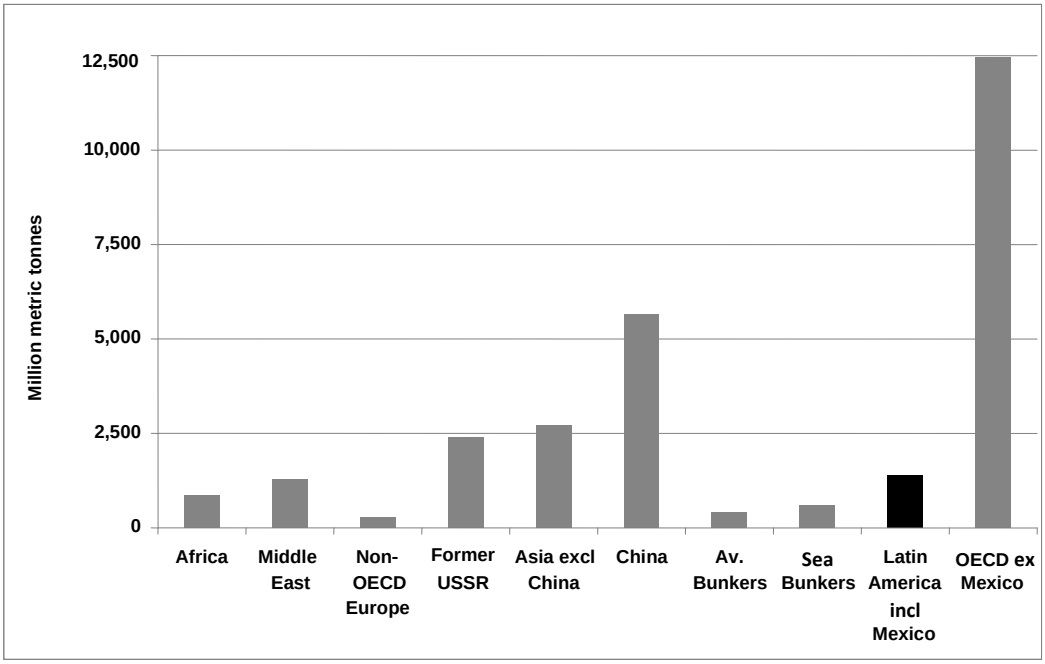
1. Latin America and the Caribbean in the Global CO2 Context

A. Global GHG and CO2 trends – Where is Latin America and the Caribbean?

There is broad consensus that greenhouse gases (GHG) are warming the planet.[2] Many human activities produce GHG emissions, but roughly two thirds of the total anthropogenic emissions comes from fossil fuel combustion for transportation, buildings, and industry (2005 data). Anthropogenic greenhouse gases (including methane and small quantities of other potent GHG, as well as CO2) also come from agriculture, mining, natural gas production, landfills, and industrial processes. Land use changes that remove CO2-absorbing plants contribute to the problem.

Figure 1.1 shows the origin of CO2 emissions from all fossil fuel combustion by region of the world. About half of the total CO2 emissions comes from OECD countries (excluding Mexico), about 20% from China, and only 7% from Latin America[3]. On a per capita basis, the world average was 4.3 metric tonnes of CO2/capita while that from LAC was only 2.5 tonnes/capita.[4]

Figure 1.1 CO2 Emissions from All Fossil Fuel Combustion by Country or Region in 2006



Source: International Energy Agency (IEA, 2008).

Figure 1.2 shows global CO2 emissions another way, by main energy consuming sector (as shares) in 2006. Figure 1.3 shows the pattern for Latin America only (including Mexico) in the

[2]See the Fourth Assessment report of the Intergovernmental Panel on Climate change (IPCC, 2007).
[3] The IEA and OECD count Mexico with "OECD North America" in their statistics. Unless otherwise stated, this study moves Mexico into LAC. All data are for direct combustion only.
[4] In this work carbon or carbon dioxide is always given in metric tonnes of CO2. One tonne of CO2 weighs 44/12 as much as one tonne of pure carbon. (A carbon atom has a weight of 12, and each oxygen atom has a weight of 16, giving each molecule of CO2 an atomic weight of 44.) "Combustion" includes both stationary and mobile sources. Conversion from quantities of fuel (in liters, tones, or energy units) is made with coefficients supplied by the IPCC.

same year. Interestingly, as Figure 1.3 shows, road transport represents a full one third of the total CO2 emissions in LAC, higher than the world average share.[5]

Figure 1.2 CO2 Emissions for Entire World by Sector in 2006 (total 4.3 tonnes/capita)

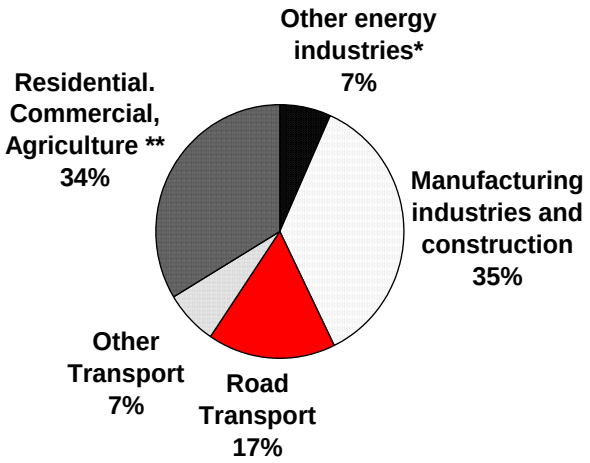
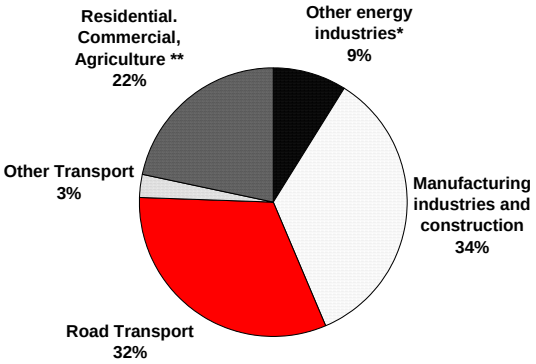


Figure 1.3 CO2 Emissions for LAC by sector in 2006 (total 2.5 tonnes/capita)



In explaining differences in CO2 emissions among regions or countries, the most obvious factors are population and level of development, as measured by per capita income. But a host of additional factors share in explaining differences – geography and local climate, degree of urbanization, land uses, fuel mix, and the efficiency of energy use. (IEA, 1997) Differences in policies, available technologies, and fuel prices shape the latter factors.

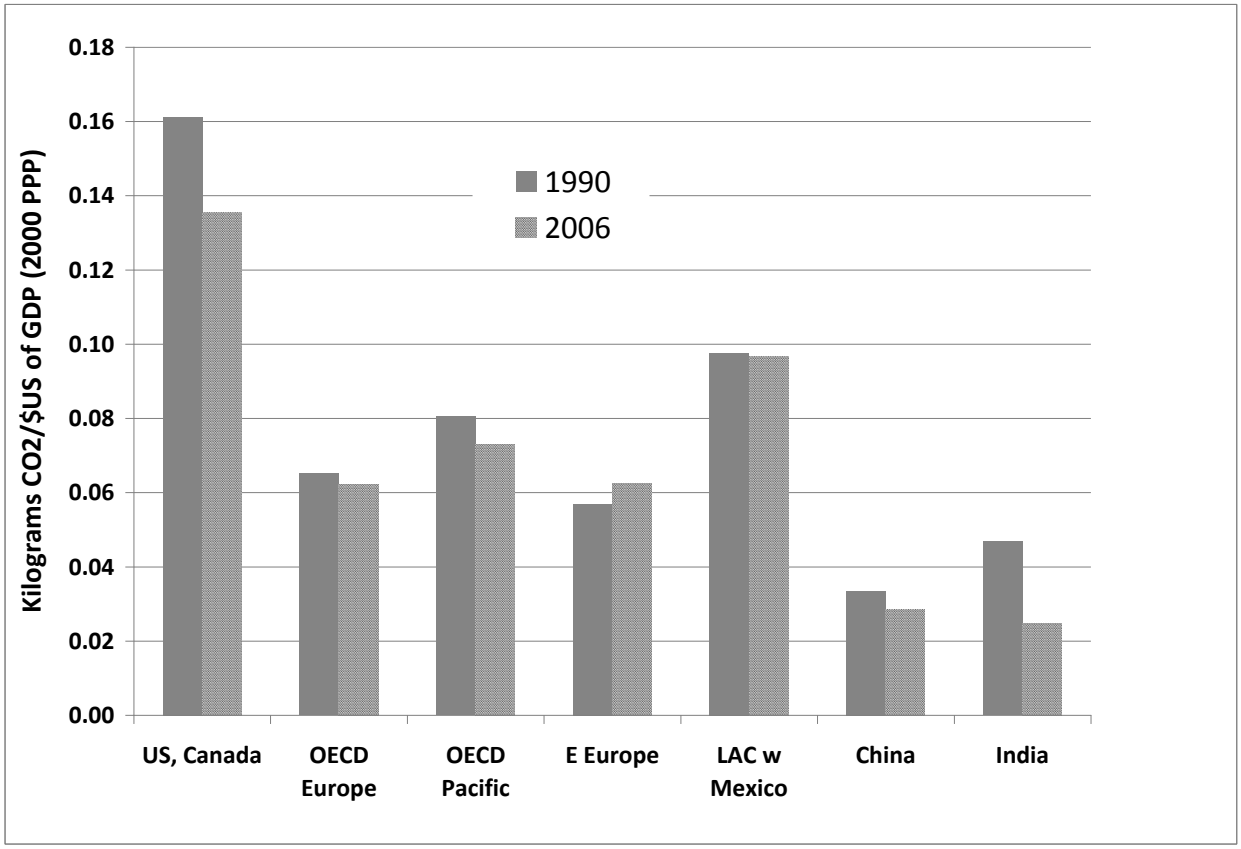
[5] In these two figures, emissions for electric power production are allocated to the sectors where electricity is consumed, which has very little impact on transportation (because of low electricity use) but nearly doubles the emissions counted for residential, commercial and agriculture. Note that transportation's emissions are almost solely CO2.

The transport share of global emissions has risen slowly but steadily since 1971. (IEA, 2008) The LAC region also reflects this upward trend. Figures 1.2 and 1.3 show that in comparison with the world as a whole, LAC CO2 emissions are more heavily from transport, which produces 35% of the LAC's total emissions compared to a 24% transport share of the world total. Further, the LAC transport emissions are heavily due to road transport, which accounts for over 90% of LAC's transport emissions.

Figure 1.4 shows that for the world as a whole, the transport emissions/GDP ratio has declined by about 20%. (IEA, 2008) However, regional differences are large, with some regions showing increases in the ratio while others have achieved substantial decreases. For LAC, the ratio of road transport CO2 emissions to GDP has declined slightly, by less by 0.5%/year. In other words, LAC transport emissions have increased at almost the same rate as GDP has grown.

IEA data indicate that the LAC emissions increases were driven in large part by the rising importance of fossil fuels for transport, especially in populous Brazil. Emissions from other sectors in LAC grew less rapidly than those from road transport. Thus the importance of road transport in the LAC emissions story has increased over time.

Figure 1.4 Ratio of Road Transport CO2 Emissions to GDP for Regions, 1990 and 2006



Source: IEA 2008.

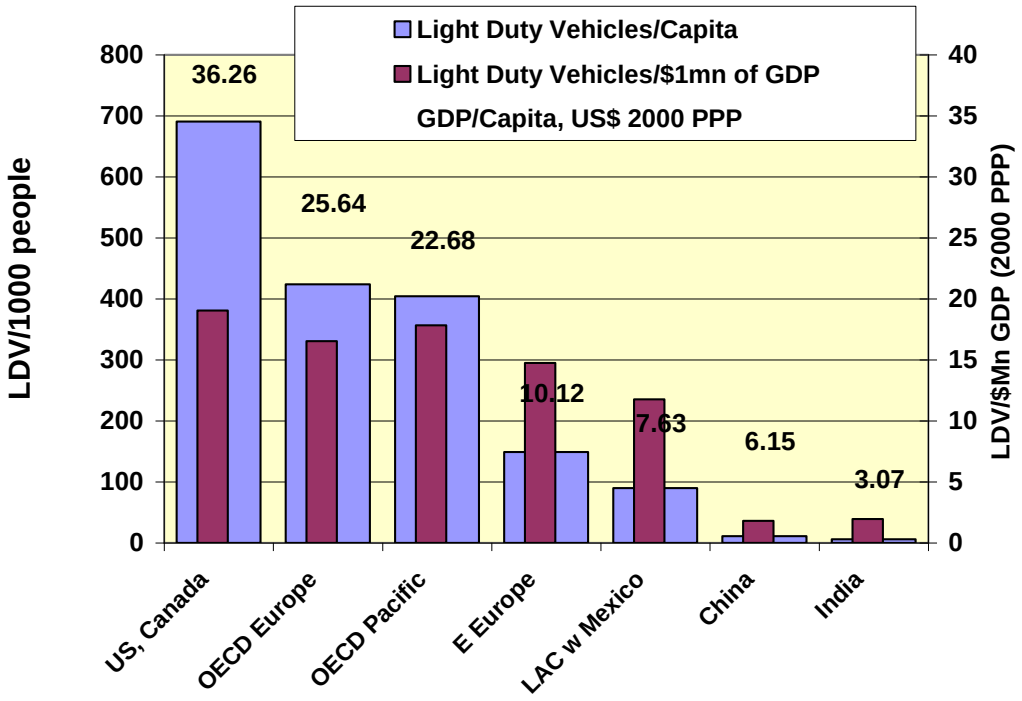
B. Road Transport in Context in LAC: Motorization and Emissions in Urban Regions

An understanding of CO2 emissions from road transport in the LAC requires a clear picture of the vehicle fleet and vehicle use (in vehicle-km). Data on vehicle ownership and yearly usage have been developed by International Energy Agency and the World Business Council for Sustainable Development (WBCSD, 2004) and are used here, with some modifications.

i. Vehicle Ownership

Figure 1.5 shows light duty vehicle (LDV) ownership in different regions, relative to both population and GDP, in 2005. Among the developing regions shown, Latin America had a per capita ownership of light duty vehicles of 86 vehicles per 1,000 people – mostly private cars, SUVs, and light trucks[6]. The high level of motorization in Eastern Europe is explained in large part by a rapid increase in cars bought used after 1990 and stronger presence of Western European automobile manufacturing in Eastern Europe after that time.[7] Even though China and India have much larger populations, the per capita auto ownership is very low and even the absolute numbers of LDVs in those two giants are still well below the number in LAC.

Figure 1.5 Light Duty Vehicle Ownership vs. Income and Population, 2005, Selected Regions



Source: IEA MoMo Database (IEA, personal communication, 2009).
Notes: 10-20% of these light duty vehicles are commercial vans or pickups. GDP/Capita in USD $1,000 (2000 PPP) shown above each region.

[6] LAC has high auto ownership in comparison to the Middle East and Africa, not shown in the table, although some oil rich nations in both regions have higher car ownership.
[7] Defined by WBCSD to include Albania, Bulgaria, Poland, Romania, Slovakia, and all of the former Yugoslavia, with a per capita GDP in 2006 of USD $10,500, or roughly 30% higher than LAC according to OECD national data.

ii. Vehicle Use and Emissions in LAC

Data estimated by the WBCSD's Sustainable Mobility Project (WBCSD, 2004) and more recently refined by the International Energy Agency (IEA, personal communication, 2009) provide information on vehicle types, their energy intensities, and the average km driven each year for LAC countries.[8] CO2 emissions by vehicle type can be calculated from these data. Table 1.1 presents the results.[9]

Table 1.1 Road Transport Emissions in LAC 2000 by Vehicle Type: The Role of Light Duty Vehicles

Vehicle type	Vehicles (100,000)	Km / year	Energy, EJ	Emissions Mtonnes CO2	Share of total CO2 emissions
LDV Pass.	**40,127**	**13,000**	**2.11**	**155.4**	**41.7%**
Motorcycles	6,948	7,500	0.05	3.0	0.8%
Minibuses	930	40,000	0.21	14.1	3.8%
Busses	511	40,000	0.20	14.5	3.9%
LDV freight	4,459	13,000	0.23	16.2	4.4%
Med Truck	5,385	22,000	1.15	77.6	20.8%
Heavy Truck	2,314	50,000	1.38	92.2	24.7%
Total			5.33	372.9	

Source: WBCSD Sustainable Mobility Project and IEA.

Note: 1 EJ (exajoule=10^18 joules) = 24 MTOE (million tonnes of oil). Data adjusted to include Mexico. Emissions for rail were included in the original Sustainable Mobility Project spreadsheets but are omitted here.

Table 1.2 Estimated Urban Share of Traffic and Emissions by Vehicle Type, LAC 2000

Vehicle type	Urban Share of VKT	Urban VKT, Billion	Vehicle Occupancy People	Passenger km, Billion	Emissions MTonnes CO2	Share of urban CO2
LDV and motorcycles	**80%**	**453**	**2**	**907**	**127**	**61.5%**
Mini Buses	80%	30	20	595	11	5.5%
Buses	50%	10	50	511	7	3.5%
Light Truck	80%	46			13	6.3%
Medium Truck	50%	59			39	18.8%
Heavy Truck	10%	12			9	4.5%
Total		510		2013	208	100*

Source: Original calculations.

For the LAC region as a whole, about half of road transport emissions are for passenger traffic, the other half for freight travel. The dominant vehicle type is light duty vehicles, most of which

[8] The IEA used their "MoMo" model (Fulton and Cazzola, 2009) for the Sustainable Mobility Project work and is currently developing it further. This includes a major effort to develop a set of data on vehicles in use by fuel type, fuel use per vehicle per kilometer, and total fuel use totals that match figures reported by each country to the IEA.

9 The total fuel use for each particular fuel and vehicle type is calculated using the estimated numbers of vehicles, distance/vehicle, and fuel/distance, with national road fuel use as tabulated by the IEA used as the control total.

are passenger cars.[10] For this study, we further estimated the urban share of traffic (VKT) and emissions, as well as passenger kilometers traveled. Results are shown in Table 1.2.[11]

Table 1.2 shows that about 60% of all road transport emissions in LAC appear to be associated with urban areas, with light duty vehicles responsible for well over half of the urban emissions.[12] Further assuming that LDVs in urban regions have average occupancy of two people, motorcycles one person, minibuses 20 people, and large buses 50 people, we estimate that in 2000, two trillion passenger km were produced in these motorized modes in LAC urban areas.

Data from major metropolitan regions of LAC are consistent with the estimates of urban traffic and emissions generated from national and regional data for specific cases. Table 1.3 and Figure 1.6 show the results for Mexico City in 2006. The data come from the region's emissions inventory, which is updated every other year.

Table 1.3 CO2 Emissions, Vehicles, and Traffic, Mexico City, 2006

Vehicle type	Mtonnes CO2, all fuels	Vehicles (100,000) all fuels	Billion VKT, all fuels
Cars	10.49	3,395.8	46.31
Taxis	2.60	155.1	10.38
VW Bus Colectivos	0.70	39.7	2.64
Other Colectivos	0.74	36.1	2.54
Pick Up	0.83	133.4	3.48
Other veh < 3 t	0.63	81.6	1.80
Truck Tractors	1.63	60.9	1.38
Autobuses	1.87	43.1	1.79
Other Veh < 3 t	0.54	100.8	2.20
Motorcycles	0.37	180.7	4.47
Totals	20.40	4,227.3	76.98

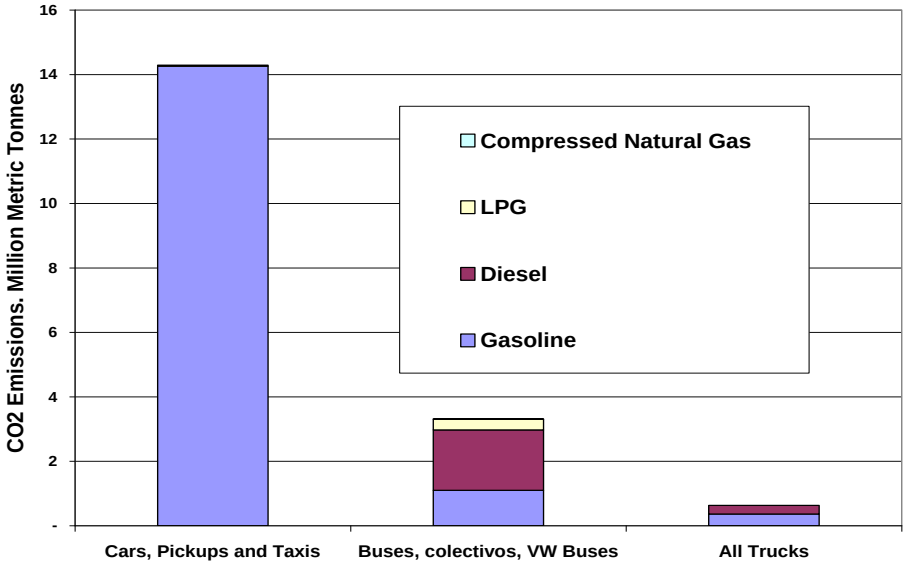
Source: Mexico City Emissions Inventory (SMA, 2006).

10 LDV, or light duty vehicles, include all cars, vans, pickups and SUVs, of which an estimated 10% are for strictly commercial purposes and counted under LDV freight.

11 Data for Table 1.2 are based on recent International Energy Agency refinements of country-level data from the Sustainable Mobility Project (WBCSD, 2004), provided to us for this work by the (Private communication with IEA, 2009). To develop urban area estimates from the country-level data, we assume that 80% of car, motorcycle and minibus fuel is consumed in or around urban areas, largely because the incomes to support car ownership as well as mini-bus use are 80% in urban areas. We estimate that 50% of large bus traffic is in cities, but that 90% of the truck activity, the other half of the bus activity, and 10% of car traffic is intercity. The term "urban area" is thus used loosely here to exclude emissions arising from long-distance intercity road traffic as well as traffic confined to rural areas. Since congestion tends to be much worse in urban areas than elsewhere, and congestion tends to boost fuel use per km, our assumptions for apportioning fuel use probably underestimate the urban share. To estimate passenger kilometers, we assume the vehicle occupancies shown in the table. Finally, to estimate emissions, we assume that the urban fleet characteristics and fuel types are the same as those for the national reports. Since urban vehicles may be somewhat cleaner and better maintained than those in rural areas, this may overestimate the urban portion of emissions.

12 Rail is excluded from the table, but urban rail, mostly electric-powered, contributes very little emissions from electricity generated to run it in even countries and cities with the most urban rail, e.g., European countries (or cities like Paris and London). See Schipper and Marie (1999).

Figure 1.6 CO2 Emissions from the Main Classes of Transport Emitters of CO2, Mexico City Metropolitan Area, 2006



Source: Mexico City SMA Emissions Inventory estimated by vehicle, distance, and fuel intensity.[13]

The results show that in Mexico City CO2 from transport arises overwhelmingly (68%) in individual vehicles, i.e., cars, pickups, taxis and motorcycles. (SMA, 2006) Traffic is also dominated by the same small individual vehicles, which account for almost 83% of VKT. Interestingly, Mexico City car ownership is lower than that in many other large Mexican cities, so the share of emissions in light duty vehicles may be even higher in other Mexican urban areas where there are more cars per capita. This also implies that the light duty personal vehicle fleet in other Mexican cities is an even greater contributor to CO2 emissions than it is in Mexico City.

Patterns for Santiago de Chile (Escobar, 2007), Bogotá (Giralto, 2005), and Sao Paulo (Vasconcellos personal communication, 2008; Melor de Alvares, personal communication, 2008) are similar. Light duty vehicles account for less than 25% of travel, but more than 60% of VKT and CO2 emissions in these urban areas.

Light duty vehicles are also at the heart of congestion in LAC cities (as in most of the world). An extreme but not unusual example is shown in Figure 1.7, where cars illegally crowding into the contra-flow lane in Mexico City are shown getting out of the way of an oncoming bus (from which the photo was taken). High car use and high levels of congestion are key reasons why surface transport by bus or trolley sharing the same roadways is slow, and in this case the cars even slow the contra-flow bus lane. And the heavy flow of traffic along the wide boulevards of LAC cities makes pedestrian crossing difficult and cycling almost impossible, despite the attempt by the pedestrian in Figure 1.8 below.

[13] Combis are Volkswagen buses, while Microbuses are colectivos, mostly 29-36 passenger compartments fitted to 2-3 tonne trucks.

Figure 1.7 Cars In Contra-flow Lane of Eje Central, Mexico City, Hurrying to Exit the Lane as a Bus Moves Against Their Flow

Photo: Lee Schipper.

Figure 1.8 Pedestrian Stranded Trying to Cross the Periférico in Guadalajara

Photo: Carolyn McAndrews.

iii. Projections of Vehicles and Emissions to 2030 and Beyond

Present trends in the LAC region point to increasing auto ownership and use. LAC will probably approach Europe's level of motorization of the1960s by 2030, but with far more urban regions of over 5 million than Europe has even now.[14] Traffic in these largest cities tends to be the most congested. Thus the prospects for future traffic problems in the face of growing motorization in all these large LAC cities are daunting.

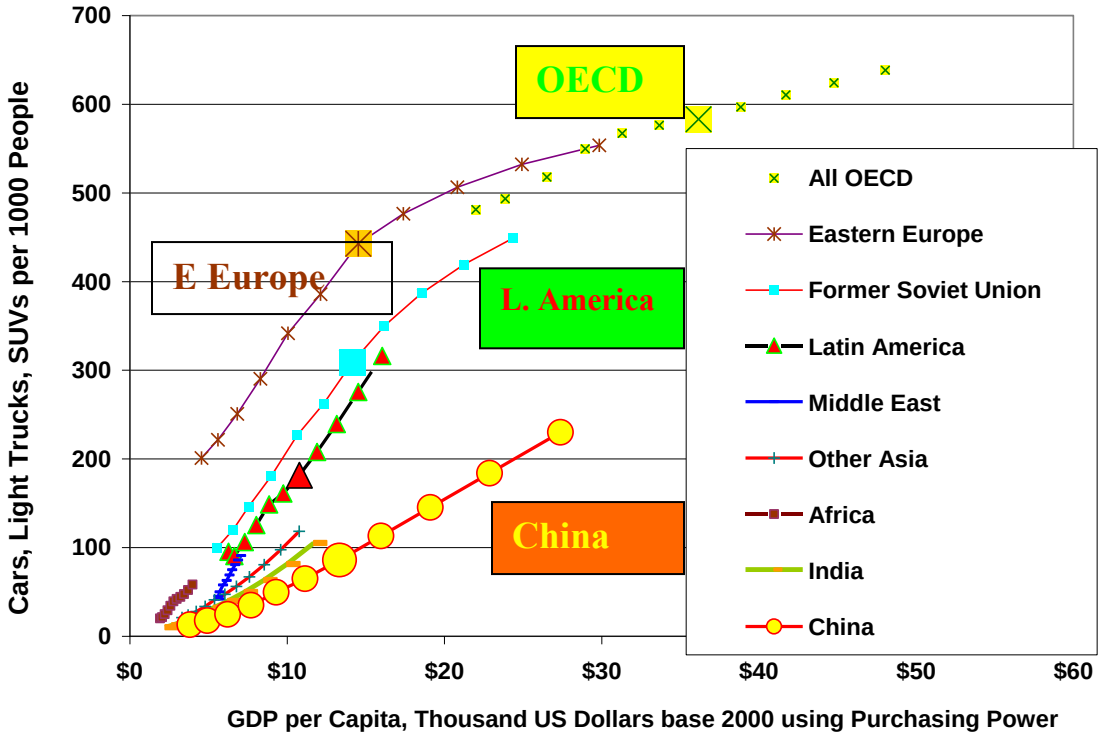
Figure 1.9 shows WBCSD (2004) forecasts light duty vehicle ownership for five year intervals, 2000 to 2050.[15] Per capita GDP is on the horizontal axis. The points for 2030 for Latin America,

[14] In 2004-6, LAC had four urban agglomerations with over 10 million (Mexico City, Sao Paulo, Buenos Aires, and Rio were all about 10 million). Europe had just one, Paris (just below 10 million). Between 5 and 10 million, Between 5 and 10 million LAC had Lima, Bogotá, Santiago and Bel Horizonte, while Europe had London and Madrid, with Barcelona at 4.9 million. LAC had eight more cities among the world's 100 largest urban areas, Europe three more. (United Nations, 2007)

[15] Mexico is not included in LAC in this projection, but its car ownership is higher than that of Brazil and growth in recent years high, so including Mexico in LAC would raise per capita GDP and car ownership in 2000, the starting year for projections.

China, the OECD, the Former Soviet Union and Eastern Europe, have been enlarged to stand out.

Figure 1.9 - Sustainable Mobility Project Projections of Future Light Duty Vehicle Ownership by Region



Source: WBCSD, 2004.

According to this projection, by 2030, Latin America's per capita income will almost double, with per capita light duty vehicle ownership – predominately cars – rising to 200 per 1000 when Mexico is included, the level of "Eastern Europe" as defined by WBCSD. Further, the Sustainable Mobility Project projects that most of the growth will be in cars and light duty trucks, not two wheelers. This seems likely because: 1) there are so few two wheelers in Latin America, 2) automobile manufacture (or at least assembly) has been important in Brazil and Mexico, and to some extent Chile, for many decades. Mexico and Brazil also export to other LAC countries. This means that relative to GDP growth emissions could continue to rise faster in LAC than in other developing countries, where fuel-efficient motor scooters and e-bikes are a major portion of motorization.

The Sustainable Mobility Project foresees a more than tripling of total LDV VKT in Latin America by 2030 and a six-fold increase by 2050. The VKT growth is pushed up by growth in population, and LDV ownership increases are supported by rising affluence. The estimates are consistent with historical evidence from Europe and North America (Schipper and Marie, 1999; US BTS, 2009). However, the Sustainable Mobility Project did not foresee any major changes to transportation policy that could slow the rise in LDV use, including the kinds of measures discussed in this report. Thus the WBCSD projections should not be seen as inevitable, but as illustrative of where present trends lead.

Table 1.4 shows the WBCSD data for 2000 and projections for 2030 for light duty vehicle ownership over 1000 population, VKT per vehicle, and per capita VKT. Note that VKT per

vehicle is treated as constant, which is approximately the OECD experience from the 1970s and 1980s (outside of times with very high oil prices). Although other developing regions close the gap, LAC remains high.

Table 1.4 Global Projections of Light Duty Vehicles (LDV) and Use

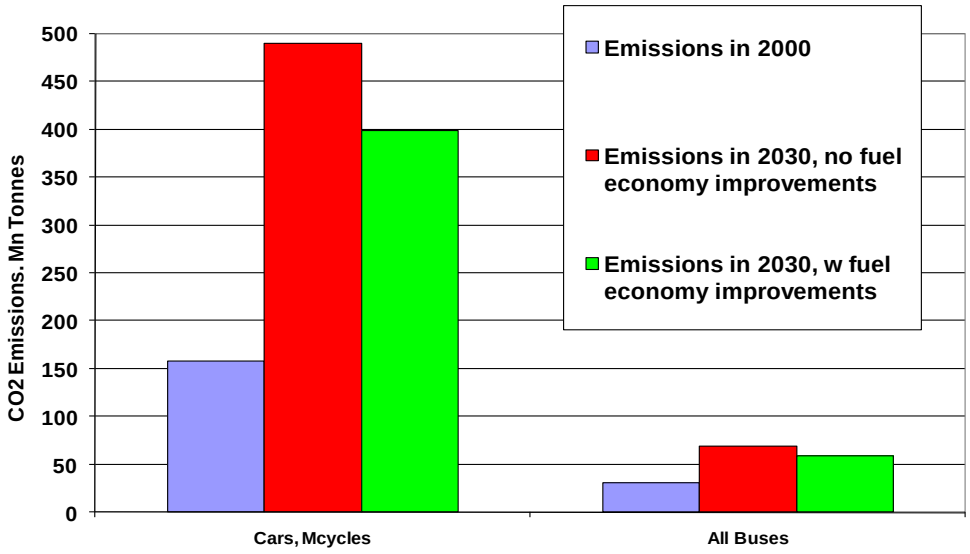
Region	LDV/1000		VKT/LDV		VKT/Capita 2030	
	2000	2030	2000	2030	2000	2030
OECD North America	779.7	825	17,600	17,600	13,723	14,080
OECD Europe	390.2	511.0	12,500	12,500	4,877	6,388
OECD Pacific	438.0	546.1	10,000	10,000	4,380	5,461
FSU	100.0	308.4	13,000	13,000	1,300	4,009
Eastern Europe	201.0	442.6	11,000	11,000	2,211	4,869
China	13.0	86.0	10,000	10,000	130	860
Other Asia	21.0	56.1	10,000	10,000	210	561
India	10.0	39.8	8,000	8,000	80	318
Middle East	42.0	68.9	13,000	13,000	546	896
Latin America	95.2	181.5	12,000	12,000	1,142	2,178
Africa	20.0	41.9	10,000	10,000	200	419

Source: WBCSD, 2004.

On-road fuel economy in LAC is projected to improve from an estimated 11.8 l/100 km in 2000 to about 9.4 liters/100 km by 2030 and to 8.3 liters/100 km over 50 years. The improvement is a drop of some 20% in fuel use per km. For comparison, the EU hopes that by 2030 its fleet will use less than 6.5 liters/100 km on the road, below the present value of 7.8 l/100 km, also a 20% improvement (Schipper, 2009). Since cars in LAC are smaller and less powerful than those in the EU, the high fuel intensity for light duty vehicles in LAC may seem odd. The explanation appears to be poor traffic conditions, as suggested by the relatively high in-use fuel intensities of small cars in the Mexico City, Sao Paulo, Bogotá, and Santiago emissions inventories. Models used to simulate fuel use in traffic in LAC, like MODEC (Goicoechea, 2007; Osses et al., 2000) or Mobile 6 Mexico and COPERT (COPERT, 2009; Rogers, 2006) show rising fuel use/km with greater congestion. If congestion continues to worsen in LAC cities, this gap between vehicles' potential fuel economy and real-world performance will increase, erasing some of the benefits of improved vehicles. Conversely, measures that reduce congestion lead to improvements in in-use fuel economy. (Skabardonis, 2004)

In fact, when the Sustainable Mobility Project projections for vehicles, VKT, and fuel economy for each mode are combined, but no other mitigation is included, emissions from passenger vehicles in LAC are forecasted to more than double by 2030 despite improvements in vehicle fuel economy (Figure 1.10). By 2050, emissions are expected increase to four times their current value (not shown). Emissions from trucks, not shown, grow less rapidly than those for cars, while emissions from buses are not seen as growing much at all. Indeed, while opportunities to reduce emissions per vehicle-km or passenger-km in buses should not be ignored, those reductions would be minor compared to the growth in emissions from light duty vehicles.

Figure 1.10 Sustainable Mobility Project Estimates of CO2 Emissions from LAC Road Transport. 2000 Actual and 2030 projected



Source: Sustainable Mobility Project, 2004.

How do these projections compare to those of other regions? Table 1.5, based on a business as usual forecast prepared for the Sustainable Mobility Project, shows that emissions growth in LAC is expected to be substantial, but will still be outpaced by that of other regions or countries. Some of the other countries start with lower individual motorization and are catching up over the forecast period. Others have higher overall incomes or rates of economic growth.[16] While on this basis the projections foresee LAC remaining a relatively modest contributor to total world CO2 emissions, it would still be a relatively high emitter from road transport compared to population and GDP.

Projected GHG emissions could change substantially if the basic factors driving them – incomes, vehicle fuel economy – are different from those assumed in Table 1.5. For example, a number of analysts believe that the vehicle fuel economies could be much higher. To illustrate how this might change emissions, Table 1.6 shows the effect of a global achievement of 6.4 liters per 100 km by 2030. Such fuel economy, consistent with current projections for the EU in 2030, would mean that Canada and the US would see a decline in CO2 production from LDVs rather than the WBCSD-estimated increase. LAC would still see an increase in emissions, but smaller one.

[16] Note that in Figure 1.8, China grows more in income (along the logarithmic income axis) than most other regions.

Table 1.5 CO2 Emissions from Light Duty Vehicles 2030 over 2000

Region	L/100 km 2000	L/100 km 2030	L/100 km Change 2030/2000	Total Emissions Change 2030/2000
OECD North America w/o Mexico	11.5	10.9	94.8%	132.4%
OECD Europe	8.0	6.4	80.8%	109.6%
OECD Pacific	10.6	8.2	77.7%	99.7%
Former Soviet Union	10.6	9.6	90.8%	272.4%
Eastern Europe	9.2	8.4	91.3%	166.3%
China	11.4	9.8	86.1%	664.1%
Other Asia	11.9	9.6	80.8%	322.6%
India	11.2	9.4	83.8%	459.1%
Middle East	12.0	9.5	78.9%	253.6%
Latin America w. Mexico	11.8	9.5	80.9%	250.7%
Africa	13.9	11.1	79.5%	313.3%
Total World	10.5	9.4	89.8%	159.6%
Developing World				355.1%

Source: WBCSD Projections.

Table 1.6 Effects of a Global Fuel Standard of 6.4 Liters/100 Km Achieved in Actual Traffic

Region	I Base Case: 2030 emissions w/ WCSD Fuel Economies	II 2030 Emissions w/ Global 6.4 l/100 km Fuel Economy	III 6.4 l/100 km Emissions as % of Base Case Emissions	IV Emissions Change 2000-2030 w. Base Case Fuel Economies	V Emissions Change 2000-2030 Using 6.4 l/100 km Fuel Economy
OECD North America	1623	952	58.7%	132.4%	77.6%
OECD Europe	535	532	99.5%	109.6%	109.1%
OECD Pacific	219	171	77.7%	99.7%	77.5%
Former Soviet Union	229	153	66.7%	272.4%	181.8%
Eastern Europe	82	63	76.5%	166.3%	127.2%
China	303	198	65.2%	664.1%	433.0%
Other Asia	174	116	66.6%	322.6%	214.9%
India	103	70	68.0%	459.1%	312.3%
Middle East	67	45	67.5%	253.6%	171.2%
Latin America	29	198	67.2%	266.8%	179.2%
Africa	168	97	57.9%	313.3%	181.3%

Source: Columns I and IV WBCSD 2004. Columns, II, III and VI, this study.

C. Summary: The Transport - CO2 Challenge

Present levels of CO2 emissions from road transport in LAC are high by developing world standards. Not coincidentally, per capita ownership and use of light duty vehicles in LAC are also high. In urban regions, around 70% of CO2 emissions from road transport arise from the use of light duty vehicles, which are by far the most common vehicle on the streets and in general the greatest contributors to both congestion and pollution as well. The high CO2 emissions from road transport in LAC can be seen as a symptom of transport problems caused by high car ownership and use. Addressing these transport problems likely would reduce car use and fuel consumption somewhat, which would reduce CO2 emissions as well.

The data and trends-extended forecasts for vehicle ownership and use, fuel economy improvements, and predicted emissions present serious challenges for transport policy-makers in LAC and elsewhere. Without additional interventions, emissions will grow substantially during a period where combating global warming would necessitate their substantial reduction. The large forecasts of increased VKT in LAC also would increase traffic in urban regions, which in turn implies worsening congestion and other transport problems (unless increases in road capacity keep pace with or exceed traffic growth).

Strategies that improve the fuel economy of LDVs and bus fleets are likely to reduce emissions per kilometer by 20% by the year 2030, according to current projections. Yet this important step still leaves emissions from road transport in LAC more than doubling over the same period. Even a major increase in fuel efficiency over and above the projected levels would still result in significantly increased emissions in LAC. This means that there is reason to consider additional interventions.

If reductions in transport emissions are to be achieved, many analysts now conclude that the growth in individual vehicle use must be moderated and transit vehicle use and non-motorized travel increased in relative importance. Further reductions in CO2 emissions can be accomplished through changes in urban development and transport paths, not just in LAC but around the world. Such changes could reduce growth in vehicle ownership, vehicle use, or both.

2. A Conceptual Framework for Integrating CO2 into Urban Transport

A high percentage of CO2 emissions in LAC cities are from light duty vehicles, principally cars. Absent strong intervention, travel (VKT) in light duty vehicles is likely to triple by 2030, and CO2 emissions will also increase. Can urban transport interventions moderate this increase?

Good transportation is a critical ingredient for growth, and most developing countries need to expand their transport systems in order to support economic development, address social equity concerns, and reduce environmental impacts. As transportation activities expand, decision-makers who wish to minimize CO2 emissions will invest in collective and non-motorized travel modes and manage and moderate car use. Such investments, coupled with strategies that improve vehicles and fuels, will produce a multimodal transport system that uses carbon far more efficiently than one that is dominated by motor vehicles.

High quality public transit, safe and convenient facilities for pedestrian and bicycles, responsive multimodal traffic operations and management, and well-coordinated transportation and land use are key elements of a balanced multimodal transport system. Effective pricing, regulation and enforcement policies also can contribute to improved transport system performance. Such interventions are attractive because they deliver significant benefits of mobility, accessibility, environmental quality, social inclusion, and economic opportunity. In most cases they also deliver CO2 emissions reductions.

CO2 emissions are a global concern, but their local consequences are not always apparent. Interventions that deliver local benefits are more likely to win political support. Further, the monetary value of CO2 emissions reductions tends to be low in comparison with other transport benefits such as time savings. For these reasons, CO2 is not likely to be the main reason, or even one of the explicit reasons, for pursuing transport measures that produce CO2 co-benefits. However, measures that are good investments based on their transportation benefits will often produce CO2 benefits as well. In some cases the value of the CO2 reductions are a significant share of the overall benefits of a project.

To assure that the CO2 effects of transport measures are fully considered, a framework is required that explicitly considers them at each step of transport decision-making, from policy formulation to system planning to project development and implementation. In this chapter we present such a framework.

A framework is a conceptual structure intended to serve as a support or guide for action. Taking into consideration background and context, a framework outlines the broad set of ideas and principles that will guide future activities, identifying systems and subsystems and showing how they interrelate. It is not a best practices manual or a toolbox of evaluation techniques, although a framework may advise the identification and dissemination of best practices and the development of better evaluation tools.

The framework presented here is designed to lead transport agency staff and their consultants and advisers through a process of assessment that will both evaluate the CO2 consequences of proposed transportation actions and uncover opportunities for enhanced outcomes. The process helps analysts examine the scope, scale and time frame of interventions, the relative role CO2 savings play as co-benefits to other widely recognized transport project outcomes, and the impact on CO2 emissions of a transport intervention against a background of overall transport activity and emissions, which usually increase over time.

A. Determining the Scope and Scale of the Intervention and Time Frame for Implementation

A framework for integrating CO2 into transport requires at the outset an examination of the scope and scale of the intervention as well as the time frame over which it will be implemented and will operate. Is the project designed to change a wide range of development characteristics of the metropolitan region, or to improve conditions in a particular corridor or district? Will the intervention directly or indirectly change land uses and population densities or land and property values? Will the intervention affect the entire system (e.g., a tariff reform) and therefore the entire metro region as well, or is it aimed at particular vehicles and fuels without changing the transport level of service (e.g., using hybrid buses for center city circulator services)? Will it be implemented in the short term or will it require a phased implementation over many years?

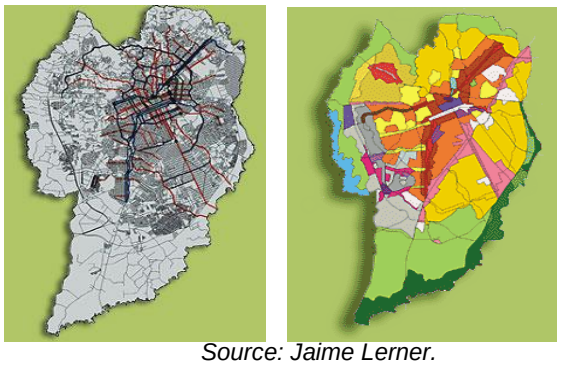
i. Urban Development: Moderating Auto Use and Avoiding CO2 Emissions through Excellent Urban Planning

Urban development is an outcome of many forces and processes. Population and demographics, the regional economy and employment base, income per capita and its distribution, the density of development and the mix of land uses, the types and levels of urban infrastructure and services provided, and architecture and urban design all contribute to shaping urban form. Transportation is one of the key elements in the urban development process, and transport in turn is shaped by the levels and patterns of urban development. Urban development strategies can have a strong influence on the amount of transport that is needed, the distances that are traveled, the modes that are used, and the conditions of travel. Coordinated transport-land use strategies aim to harness these relationships to create healthy economic growth, high quality natural and built environments, and greater social equity.

In Latin America, Curitiba, Brazil, a city of about 2 million in a region of about twice that size, is a prime example of a city that has successfully guided growth through a broad urban development strategy, of which transportation is an integral part. (Lerner, 2009) Curitiba is one of Brazil's wealthiest cities with high car ownership but low car use, showing that a relatively affluent community need not be car dependent or carbon intensive if the region develops with a good transport system.

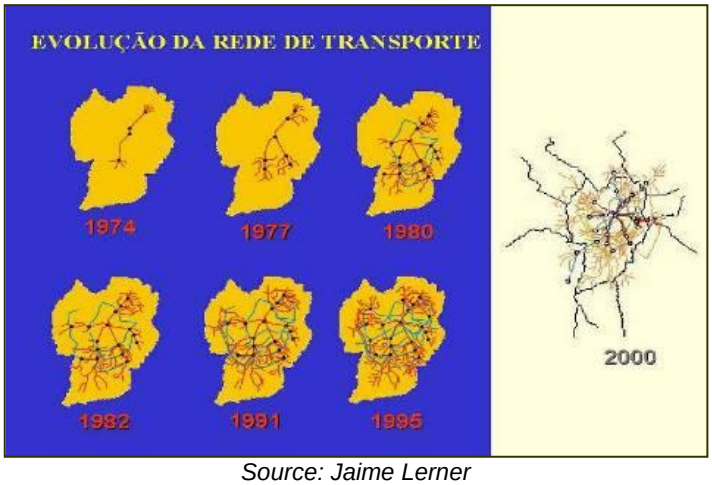
Curitiba's master plan, outlined by Mayor Jaime Lerner in 1965, integrates transportation, urban development, social welfare planning and community and economic development rather than planning separately sector by sector. The plan aimed to focus growth along major arteries connecting the city center to new industrial and commercial zones, and set about to integrate transportation and land use planning to provide jobs, housing, and commercial services, and good connections among them. Figure 1 shows the configuration of main arteries (left) in a recent year and the densest and most built up regions (right, in the red and dark brown) in the early 2000s. Figure 2 shows how the BRT network and its feeder lines evolved over time. The transport network was explicitly used to shape urban development, and vice versa.

Figure 2.1 Map of Curitiba Transport Network and Intensity of Land Uses



Source: Jaime Lerner.

Figure 2.2 Evolution of the Curitiba Transport Network



Source: Jaime Lerner

The plan also aimed to provide all districts of the city with good schools, parks and recreation facilities, and clinics. The resulting land use pattern is amenable to walking for many trips (since schools and services are within walking distance in the communities) and is also amenable to transit use for longer trips (since retail, office and industrial districts are well connected to residential areas by bus, and the bus network offers nearly seamless transfers and predictable travel times). Because the planned multi-nodal development avoided over-congesting the center, the city was able to create a pedestrian network, now expanded to nearly fifty blocks, in the downtown area. Figure 2.3 shows a famous pedestrian zone. Local merchants were opposed to the idea initially but the mayor created arts in the street for children and this turned public opinion, including merchant views, in support of the pedestrianization (Figure 2.4).

Figure 2.3 Modern Street Scene in Curitiba

Photo courtesy of Jaime Lerner.

Figure 2.4 Children Panting on the Street, 1972

Photo courtesy of Professor Allan Jacobs, UC Berkeley

Street design has dedicated space to buses and given them priority treatment. Major arteries contain exclusive lanes dedicated to buses, as well as mixed traffic lanes. Over time, stations have been developed along the exclusive bus lanes with operational and design features that increase efficiency and speed service, including raised boarding platforms or tubes for level boarding and alighting and prepayment of fares. In addition to the express buses operating on the dedicated lanes, rapid buses operate on a variety of routes and local buses and inter-district and feeder services operate between the arterials and for shorter trips to stations.

The resulting high quality transit service has proven to be very popular, providing fast, safe, and reliable transport. The buses serve over a million passengers a day and include many middle class riders, including auto owners. Curitiba has very high car ownership by Brazilian standards but relatively low car use, according to Santoro (1999). Unfortunately there has never been a travel or vehicle use survey undertaken for Curitiba to fully document its performance, but comparisons with other Brazilian cities of similar population and geography suggest that a large amount of car use and CO2 emissions has been avoided.

In large part, Curitiba's success is largely that it did NOT just focus on transportation, but integrated it into an overall development program implementing a master plan that is both long term and amenable to updates as new ideas and opportunities have emerged.

The value of coordinating transport and land use planning can be seen in other cases, and the negative consequences of ignoring the interrelationship also can be observed. Bertaud (2003) provides an extreme example, comparing Atlanta, Georgia (metro population 5.1 million), the US city with the longest trips and highest overall level of sprawl, to the (much older and slower growing) city of Barcelona, Spain (population nearly 4 million in the metropolitan region). In the 1990s, Atlanta's density was approximately 6 persons per hectare. Barcelona, squeezed by the Mediterranean to the east and mountains on most of the north and northwest, had 171 persons per hectare. In Barcelona nearly 80% of the population lived within 500 meters of a major bus or metro line, and about a third of the travel was by transit. (ATM Barcelona, 1997) In Atlanta, only a small fraction of the population was located near transit, and over 90% of trips were made by auto. The result was almost five times more CO2 per capita emitted from light duty vehicles in Atlanta than in Barcelona. While geography and history, fuel prices, household incomes, and city size are surely all part of the explanation for the observed differences, urban land use and transport policies also are surely major factors in the high carbon impact of Atlanta.

Around the world, many cities have developed urban plans with the objective of creating attractive residential neighborhoods with most services easily accessible by walking or biking and steering larger-scale commercial development to transit corridors and mixed use centers. Such urban plans are frequently linked to policies intended to preserve natural features and important agricultural lands. Transportation investments are a key element of the plan and are evaluated as part of the overall development objectives. Cities such as Amsterdam, Copenhagen, Stockholm and Portland, OR, are well known for their integrated policy plans that both shape the city and protect natural features and agriculture. (Cervero, 1998)

Cities also have taken steps to recapture urban land and rebalance transportation systems in their city centers. In the US, San Francisco, Boston, and Portland all removed major freeways and returned the land the freeways had consumed to other urban uses. Seoul has transformed its urban center by tearing down an elevated highway and re-establishing an urban creek, surrounding it with an urban park and mixed-use development supported by high quality transit. (Cervero, 2006) The removal of the freeways in each of these cases not only created important economic development opportunities for the cities but also greatly reduced environmental harms including noise and exposure to emissions.

In sum, strong urban plans have been shown to provide an effective framework for economic development, environmental improvement, social equity, and public health, with transportation and urban development serving as instruments for accomplishing these outcomes. CO2 reduction can be an implicit or explicit part of such plans. Thus encouraging urban-plan development and implementation can be an important way to both improve transportation effectiveness and reduce carbon emissions.

Questions that should be posed in considering the effects of a project or other intervention from an urban planning context are the following:

1. *Does the region have a long-term development plan linking land uses and transport? Have the plan's impacts been analyzed for future years? Is CO2 one of the impacts analyzed?*
2. *Do the projects or other interventions being considered fit into this plan?*
3. *Are proposed collective transportation projects serving dense corridors or well planned outlying regions?*

4. *Is the intervention providing homes, businesses, schools close to transit corridors? Are such projects being undertaken in parallel by private or public authorities? Are there potential sites for such development?*

5. *Are there projects to create new, outlying districts not served by transit? Have the impacts of these projects been analyzed?*

ii. Good Transport: Improve the Transport System to Achieve Better Performance with CO2 Reduction as a Co-Benefit

Even if a region does not have a broad based urban development plan, a systematic approach to transportation planning and implementation can produce a transport system that fosters economic development and social equity while reducing CO2 emissions as a co-benefit. A recent World Bank report (World Bank, 2008) presents a strategic approach to improving urban transportation. The strategic approach aims to a lower the share of travel in motor vehicles and increase the use of collective modes, and uses financial instruments (such as congestion pricing) to manage vehicle use and generate revenues, In addition, the approach aims to develop institutional capacity (e.g., the ability of authorities to enforce rules on pollution, safety, and transit fares and level of service) as a necessary element of good transport. Strategic steps include linkages to national authorities, who are usually those who have the power to address fuel standards and vehicle fuel efficiency, and to land use planners, whose regulations can promote development readily served by collective transport and non-motorized transport.

Implementation of this strategy will reduce CO2 intensity of the present system – the ratio of CO2 emitted to total travel – and keep it from rising as rapidly as in the past. Such a transport strategy also will alter land development opportunities and help create a more accessible and flexible urban pattern.

Bogotá, Colombia is an example of a Latin American city that has successfully implemented a transportation-focused strategy on a large, multi-corridor scale. The Bogotá BRT system, Transmilenio, operates on several corridors and is accompanied by auto restraints, parking restrictions, bikeways, pedestrian improvements. Some land use initiatives also were proposed as part of the plan.

Transmilenio is a bus rapid transit system running on several major corridors of this city of 7 million. The first lines were implemented during Mayor Enrique Peñalosa's term in office. Currently there are 84 km of BRT lines. Additional lines are planned to eventually provide service throughout the metro area, although some local politicians are arguing to complement the BRT with a metro. As of this writing the issue is undecided.

Transmilenio partially replaced a system of often dirty and unreliable private buses with high quality, fast, frequent and reliable bus rapid transit and did so at relatively low cost in a short period of time. The BRT system uses articulated buses on express lanes serving stations modeled after light rail stations. On major trunk routes both a local lane and an express lane are provided, allowing for very high capacity as well as a choice of service type. Private operators under contract to Transmilenio are paid by the kilometer of service provided. Contract provisions cap the service mileage for vehicles and require daily cleaning of the buses. The resulting service carries about 1.2 million passengers a day, or about 20% of transit ridership. (Ardila, personal communication, 2009) In 2005, the time of the last travel survey, Transmilenio had about 10% of all trips, cars 16%. Suarez (2006) estimated about 10% of Transmilenio

riders formerly used cars. Further, the service has reportedly attracted users from a wide range of social classes. Local and feeder buses operated on an open entry system by private owners continue to carry the majority of riders, however, and in some cases compete with Transmilenio.

In addition to Transmilenio, the Peñalosa Administration implemented auto restraints, including car free days and removal of a large numbers of parking spaces from city streets. Complementary public works include a pedestrian /transit street in the city center and expansion of the bikeway system to about 300 km, with connections in many locations to the BRT system. The bikeway system reportedly has attracted both recreational trips and purposeful, destination-focused travelers (estimated by one local planner to now carry 5% of total travel).

Suarez (2006) estimated that the combination of bus substitution and mode switch (saved about 1.5 petajoules of fuel (both diesel and gasoline), or about 80,000 tonnes of CO2 annually. Former Mayor Peñalosa made the point repeatedly that his emphasis was on improving transport, with these savings of CO2 a co-benefit of a transport revolution for Bogotá.

Figure 2.5 The Old (Colectivo) and the New (Transmilenio) in Bogotá

Photos: Lee Schipper.

Mexico City began with a more modest approach toward BRT, initially building it in a single corridor. The project, on the major arterial Insurgentes, was developed primarily to relieve congestion. The city's own bus company RTP and privately owned and operated colectivos competed along much of the corridor, and the "bus only" lanes along the curb were usually congested with cars and delivery vehicles. A Metro line had been considered, but soil tests indicated it would be impossible to build a Metro line there. BRT became the favored strategy as a result.

The initial route, inaugurated in 2005, ran 19.5 kilometers from Indios Verdes, a major terminal for buses serving the northern suburbs of the region and beyond, to Dr. Gálvez in the south. It also served with the busiest Metro line in Mexico City. In 2007 the BRT was extended to the Universidad Nacional Autónoma de México (UNAM). It currently carries over 300,000 passengers a day or about 1.5% of all trips in the region.

Metrobús operations in the main Insurgentes corridor have saved almost 50,000 tonnes of CO2 every year.[17] More than two thirds of this CO2 savings came from modal switch and improved traffic. The remainder came from more fuel efficient vehicles.

The success of the BRT in this corridor led to the city adopting a region-wide vision and plan for BRT. A second line, Eje 4 Xola, opened in December 2008, and the current Mayor plans many more.

As these examples illustrate, both system plans and individual projects improving transportation services can both improve travel opportunities and reduce CO2 emissions. Complementary projects such as improved feeder services and pedestrian and bicycle facilities can augment the results. On the other hand, competing facilities or services could also reduce the effectiveness of projects and this needs to be taken into account. Key questions that should be asked about transport strategies include the following:

Key Questions:

1. *Does the proposed transport project meet existing needs for service, or is it designed to meet future needs?*
2. *What trip purposes will the project serve and how many of the trips would be made, by what modes of travel in the absence of the project?*
3. *What will be the socioeconomic characteristics of the travelers and what other travel choices will they have?*
4. *Have the impacts of the project on location and land use been taken into account? Does the project support infill or does it open up new areas for development, and if the latter, are there land use plans in place that are transit-oriented?*
5. *Is the project scaled to the system level or is it focused on a particular district or corridor? If the latter, how will it interact with the rest of the system?*
6. *What additional interventions would strengthen the performance of the proposed project (e.g., along a BRT corridor, advanced signal systems, pedestrian improvements, bike lanes and parking at stations)? Can these interventions become part of the project?*
7. *Are there other projects being proposed that could reduce the efficacy of the proposed intervention, e.g. new highways?*
8. *If new vehicles are being acquired, are they clean and fuel efficient compared to existing public transport vehicles? Will they require new fueling and maintenance facilities?*
9. *Will new staff skills be required to maintain and operate the project?*
10. *Do existing policies on transit fares, fuel price, parking, and congestion management support shifts towards collective transport?*
11. *Are the agencies responsible for critical elements of transportation system management and enforcement, e.g., traffic signal timing, enforcement of parking regulations and traffic laws, on board with the proposed intervention and empowered to support it through their actions?*

[17] See the appendix to this report for a detailed analysis.

iii. Cleaner Vehicles and Fuels

CO2 emissions can be addressed directly by influencing the choice of vehicles and fuels, and to some extent the operation of vehicles. (Sperling and Cannon, 2007) However, there is a lively debate over the most efficient and effective policy actions to reduce carbon emissions from vehicles and fuels (OECD, 2007), as well as over the extent to which changes in fuel prices might induce travelers to switch modes, travel less, or acquire less fuel intensive cars (WBCSD, 2004).

Improving vehicle efficiency and encouraging low-carbon fuels are important elements of any long-term CO2 strategy. Most of the required policy measures – fuel taxes and carbon taxes, vehicle efficiency standards, or both, as well as fuel standards (and perhaps long-term low carbon fuel research and development) have to be carried out at the national level. However, urban policies can complement and reinforce national policies by creating incentives for the purchase and use of low carbon vehicles and fuels.

The US was the first to establish national standards for vehicle fuel efficiency (Greene, 1999; Schipper, 2009), although the standards remain well below the efficiencies obtained through pricing and regulation in other developed countries. Canada followed with a Voluntary Agreement with motor vehicle manufacturers on fuel efficiency (Lawson et al., 2009). More recently voluntary agreements have been established for the EU (Fontaras and Samaras, 2007), Japan (Sano, 2008), and China (Wagner, et al., 2009).

The US, Japan and the EU have all moved to tighten their standards recently, and Mexico is considering a similar program of standards. (Carbonell, 2008) In the EU case, the voluntary agreement failed to reach its interim goals by 2008 and is slated to be replaced by a stronger, mandatory target. Like the US system, the EU system will mandate sales-weighted tested fuel economy and/or emissions averages and levy penalties if these are not met. In the US case, recent government policy changes will lead to moderate improvements in vehicle efficiencies but the proposed standards will be below the EU levels.

The mandatory standards in the US have proven effective, though they also have been criticized by some. Alternative approaches including high fuel taxes can also lead to the purchase of more efficient vehicles. (Schipper, 2009)

In most countries there is interest in low-carbon fuels, particularly biofuels. Internationally, Brazil is the leader in biofuels production with its low carbon ethanol from sugar cane, and Brazil's substitution of sugar-cane based alcohol for gasoline is considered the best national example of a low carbon fuels strategy. (Goldemberg, 2006; Goldemberg 2008)

Because there are concerns about the broader impacts of biofuels, including effects on land use, food supply, and poverty, their impacts have been studied widely. The impacts of biofuels, including their potential for greenhouse gas and other emissions reductions, have been investigated both for the Brazilian case and more generally (Dondero and Goldemberg, 2005; Goldemberg and Guardabassi, 2009). While Goldemberg and Guardabassi maintain that Brazil's approach to sugarcane-based ethanol is both sustainable and could be developed in other regions producing cane sugar, work by Searchinger et al. (2008) warn that expansion of any kind of land-intensive biomass production might push farmers to produce food on less

productive land, with more GHG emissions than otherwise, eating significantly into the CO2 gains of the biofuels production. In addition, as the US experience with ethanol made from corn (maize) shows, not all biofuels are low carbon, especially if life cycle analysis is carried out (Farrell et al., 2006).

At present, the ability to produce substantial quantities of biofuels at reasonable prices is unclear. Even Brazil's large production of bio-ethanol has stagnated, as IEA data show, resulting in a rise in the share of gasoline and diesel among fuel sales there, essentially a "re-carbonization". As of this writing, it seems possible to achieve large-scale production of low carbon biofuels within the next 30 years, say 20% of expected road fuel demand, but a breakthrough in costs is required. (IEA, 2004; OECD, 2007; IEA, 2009) Some are more optimistic about the prospects for biofuels to provide most of the liquid fuel for the US by 2020 through a massive conversion of the US light duty vehicle fleet. (Spatari, et al., 2009) However, Spatari et al note that only Brazilian ethanol and some US corn ethanol is competitive with gasoline at USD $2.50 a gallon, the approximate 2008 wholesale prices excluding taxes and only Brazilian ethanol at under USD $2 per gallon wholesale. Should large quantities of biofuels appear at a reasonable cost, they could reduce, but not eliminate, CO2 emissions in transport from its growing baseline, as IEA noted. (IEA, 2004)

Urban regions have little direct regulatory sway over fuel economy of new vehicles or the production of less carbon intensive fuels. However, they can develop programs to purchase buses and other fleet vehicles (e.g., service trucks) that are highly efficient and/or use low carbon fuels, or to reward private owners who do so. Urban regions also can choose to promulgate hybrid rather than conventional buses and vans, as Seattle has done for articulated diesel hybrid buses. The resulting fuel/km savings are on the order of 20% (Chandler and Walkowicz, 2006). Finally, urban regions can enforce traffic improvements that will allow all vehicles to achieve better on-road fuel economy. Traffic signal timing can reduce fuel use by 5% to 30% depending on initial conditions, for example. (Skabardonis, 2004)

Stockholm has developed an aggressive city-led low-CO2 emissions vehicles program that complements national actions aimed at improving fuel economy and exploring low carbon fuels. (Paedam, 2009) The vehicles and fuels strategies were also supported by a national CO2 tax on gasoline and diesel of approximately USD $0.35/liter in 2009 on top of other taxes totaling close to USD $1/liter.

Stockholm's low CO2 vehicles promotion has three components. Starting in 1992, the city procured low-CO2 vehicles for its own fleet. The procurement phase was a way of testing and demonstrating the performance and fueling of "clean vehicles". In the second component, the city's regional bus company, Stockholms Lokaltrafik, began to acquire diesel buses modified to run on ethanol. The company now has over 500 such buses.

The third component of Stockholm's approach was to incentivize households and businesses to acquire "clean vehicles" even before this happened at the national level. Initially limited to electric and ethanol vehicles, the definition of "clean vehicle" was expanded by Stockholm authorities to include any non-petroleum vehicle, any conventional car emitting less than 120 gm/km of CO2 in tests, and gasoline hybrid vehicles. Stockholm itself procured 500 flex fuel vehicles from Ford and together with Malmö and Gothenburg set out definitions of "clean vehicle" ahead of those that the national government set. At the national level the most commonly acquired vehicle ran flexibly on ethanol or gasoline, followed by biogas, followed by a limited number of low carbon gasoline vehicles. Various national tax measures were used to reduce the cost of the car.. Local incentives included exemption of bio-fueled-vehicles from the

Stockholm congestion pricing fee, as well as free on-street resident parking for biofuel vehicles, and free parking for biofuel delivery vans. “Clean vehicles” also have identifying registration tags. Because nearly half of all new cars are purchased by companies for employees (Schipper and Price, 1994), a taxation differential was introduced on these schemes at the national level making “clean vehicles” much more attractive to acquire than conventional gasoline cars. This change was especially important because previously company cars National and local authorities also devoted special attention to increasing the availability of both ethanol and biogas in stations, even requiring that every station selling over a certain volume of fuel have ethanol available.

Stockholm carried out very detailed monitoring and analysis of the program to assess its effects. The evaluation tracked availability and sales of each “clean” fuel, changes in the company car market, and the effects of ancillary policies such as free parking and exemptions from congestion pricing At the end of 2008, about 5% of the cars at the national level and 8% in Stockholm (where the incentives were stronger) were ”clean. However, the collapse of world oil prices has had apparently disastrous effects on the road fuel ethanol sales Sweden, and this has led to a decline in the effectiveness of the program, By fall 2008, the price of gasoline had fallen almost 30% from its peak while that of ethanol had moved up slightly. Sales of ethanol in December 2008 were barely a quarter of their peak level in the summer of 2008, The result is that many flex fuel vehicles were are being operated on gasoline (based on the drop in sales of ethanol) and market interest in the purchase of “clean” vehicles has sharply declined. Thus the Stockholm program cannot be declared an unqualified success.

The Stockholm case shows that a city can stimulate acquisition of low-CO2 fuels and vehicles. However, a policy focused on fuels alone, even in an environment of heavy taxation for CO2 and other reasons, still remains subject to the movements of the international fuel market.

When fuel and vehicle strategies are being proposed, key questions that might be posed are:

1. *Are national policies in place that support the use of low carbon fuels for the vehicle fleet as a whole or for specialized fleets such as buses, trucks, and taxis?*
2. *If biofuels, compressed natural gas, or other alternatives to gasoline and diesel are being considered, has a full fuel cycle or life cycle analysis been carried out to measure how much CO2 these fuels embody, compared to the fuel being replace?*
3. *Are national policies in place (price incentives such as taxes, technology regulations such as vehicle standards) that support the development, purchase and use of fuel-efficient vehicles?*
4. *Do emissions saving new vehicles require special infrastructure investments, such as natural gas compression or special tanks to hold very clean fuels? Do costs and benefits estimates include full life cycle emissions and leakage of vehicles and fuels across project boundaries? Are polluting vehicles that are replaced by clean ones scrapped or just sold or used elsewhere?*
5. *If efficient transit vehicles (such as hybrid buses or vans) are being considered, are they “cost effective’ in the view of the transit providers, i.e., at the provider’s rate of interest and payback time? If a carbon price is added to the cost effectiveness calculation, at what price does the acquisition become cost effective?*
6. *At what scale is a proposed vehicle or fuel strategy cost-effective? Can it work if only a small number of vehicles or a small number of fueling stations are introduced, or does it*

require a large scale application to be effective? Would a larger-scale application increase cost-effectiveness?

7. *Considering all investments in advanced vehicle technology, fuels, or biofuels, what are the expected savings in fuel and/or CO2 relative to the incremental investment costs? Would similar investments elsewhere in the system to improve service and boost ridership save greater amounts of CO2 per passenger-km provided?*

iv. Time Frame and Longevity

In addition to determining the scope and scale of the proposed intervention, it is important to consider its time frame for implementation and for effective impact, i.e., its longevity. One consideration is the useful life of the project. For example, if a project will take five years to design and construct and then will have a useful life of 30 years, the benefits and costs will need to account for that period. Another consideration is that effectiveness of a project may change over time. For example, vehicle fuel economy and emissions reductions tend to decline as a vehicle ages, and can do so quite quickly if the vehicle is not well maintained. Traffic operations projects such as traffic signal timing can lose effectiveness in a few years; periodic retiming is necessary because traffic conditions change, often rather quickly. Pricing strategies likewise have to be updated as costs and incomes change or they will lose their effectiveness. Major capital projects may take many years to implement or may be implemented in phases rather than all at once, and so their benefits may not flow for some time. In addition, some projects will gain in acceptance and popularity over time; pedestrian districts and bike projects may fall into this category. The reverse is also true: for example, carpooling was popular in the US several decades ago but has substantially declined in popularity in many urban areas, including ones where other collective modes have registered ridership gains. Finally, if a project depends for its success on a particular subsidy or the support of a particular leader, it may fail if that subsidy ends or the leader leaves office.

Key questions to ask about the time frame and longevity of a proposed intervention include these:

1. *Have the proposed interventions been designed with implementation and effectiveness time frames in mind? Can an intervention's performance be expected to degrade or to increase over time, and if so, how does the plan for the intervention handle this change?*
2. *If the intervention is part of a broader program, how tolerant is that program of these time frames and unforeseen changes in them?*
3. *Are the implementation and operation processes iterative enough to enable new information about important conditions to update the intervention?*
4. *Are plans and institutions for future monitoring, tracking, updating, evaluating consistent with the expected time frames for implementation and effectiveness?*
5. *Is there an agreed-upon procedure to account for changes in population growth, economic growth, or major land-use changes and how they might affect the project and its estimated CO2 impacts?*
6. *Is there capacity and funding in place to monitor the project's impacts?*

B. Estimating the Impact of the Proposed Project

Understanding the scope, scale and time frame of a proposed intervention helps to determine its likely impacts. Transport projects are planned with the expectation that they will produce benefits such as improved access (or reduction of barriers), more route or mode choices, improved travel time, less congestion, lower travel costs, greater safety and security, and lower pollutant emissions. Costs of the projects typically include construction, operation, and maintenance costs as well as negative externalities such as community disruption, noise, air and water pollution, and damage to species or habitat. (NAS, 1997) Analysts must identify these costs and benefits, their timing and duration, and wherever possible monetize them in order to allow a consideration of benefits vs. costs. While the valuation of each externality or the value of time and other variables in a transport model may vary from place to place, planners must consider many of these variables in order to estimate the value of CO2 along with other changes arising from a transport intervention. Formal models, quick response techniques, or comparative case examples can be used estimate the expected impacts of the intervention. For interventions that are expected to have a regional or corridor level impact, likely changes over the longer term it may include altered patterns of location and land use and their effects on emissions.

Chapter three provides an overview of methods for transport project analysis and forecasting. It also discusses how to add fuels and emissions calculation to the analysis.

C. Monetizing Benefits and Costs

Transport planners and economists monetize project outcomes or benefits and costs as a means of valuing the various impacts transport projects have on users and others. This allows decision-makers to weigh tradeoffs both among variables like travel time and costs, as well as among travel variables and externalities such as air pollution, safety, noise, and CO2.

Maddison et al. (1996) reviewed externalities as a general problem, as well as how they were addressed in the UK, Sweden and elsewhere, reviewing estimated costs of air pollution, accidents, congestion, road damage, and CO2. MacKenzie et al. (1992) reviewed some of the estimated values of externalities for the United States. Transport Canada (2008) estimated various external costs of transport for all modes of intercity and urban transport. The key conclusion is that most studies of CO2 damages yield small values compared with damages from other transportation-related externalities. Conversely, transportation project benefits excluding CO2 are likely to be much larger than those from CO2 alone. This is why we refer to reductions in CO2 emissions from transport projects as “co-benefits” of those projects.

CO2 emissions are complicated to monetize. Since CO2 is a collective problem, difficulties arise because different people place different values on the damage from CO2 and their willingness to avoid such damages. Moreover, costs and damages accumulate over time, both because of the long slow build up and long residence time of CO2 in the atmosphere and because the damages themselves take time to build up – in an uncertain way. Using a low discount rate, Stern (2006) attributes a global damage value of USD $85/tonne of CO2. Nordhaus (2008) argues that Stern’s discount rate is far too low, Nordhaus uses a much lower damage cost of only USD $7.40/tonne CO2 in 2005 dollars, slightly more than what Mexico City was first offered in 2005 for CO2 reductions from Metrobús. While few authors agree over the “right” carbon

price, all agree that the price or tax should be equal all over the globe for optimal reduction of CO2 emissions from a baseline, which is by no means the case today.

The low carbon price Nordhaus argues for at present, USD $7.40/tonne of CO2 in 2005 dollars, would hardly change the price of gasoline, even in the United States. It works out to about 2 US cents/liter, compared with the current (May 2009) price of approximately 60 US cents/liter. This low price would not have a large impact on decisions about vehicle choice or fuel use, much less transport projects.

Even putting a high value on CO2 and fuels rarely makes them the dominant considerations in a transport project. Table 2.1, from Harrington (2008; see also: Parry et al., 2007) illustrates this point by compiling estimates of the costs of highway driving in the US. While the ranges are wide and would vary from location to location, the general principle is clear – the valuation of the climate externality is small compared to congestion, local air pollution, safety and in some cases energy security.

Table 2.1 Range of Reported External Costs per Mile of Driving for the US, US Cents/Mile[18]

Externality	Low	High	Range from Parry, 2007	Comments on LAC situation
Air Pollution	1	14	2.3	Values are probably higher for LAC cities because of higher levels of air pollution, even after adjusting for quality-adjusted value of life. See Vergara et al 2002 and Harvard School of Public Health 2003.
Climate Change	0.3	1.1	0.3-3.5	Value widely disputed (Nordhaus 2008; Stern 2006) and certainly dependent on national and local situation.
Congestion	4	15	5-6.5	Does not apply to all travel. Depends on value of time and wage rate.
Accidents	1	10	2-7	Depends on valuation of accidents and life. See INE 2006 for MC perspective.
Energy Security	1.5	2.6	0-2.2	Values depend on local energy supply situation.

Source: Parry, 2007, as modified for this project

From Table 2.1 it appears that CO2 <u>by itself</u> is unlikely to sway major transport investment decisions. The low figure, USD $0.003/mile, works out to Nordhaus' value, while the higher value is USD $25/tonne. The high value is still less than 1/3 of that advocated by Stern. Even if the high Stern CO2 cost were imposed, e.g., as a tax on fuel, it is hard to imagine the transport system, not to mention the urban system, taking on a different evolution because of this CO2 price. But the benefits of CO2 reduction can still be important and may be large enough in some cases to affect the design of a project or the priority given to it.

[18] These costs per mile can be converted into costs per unit of fuel and cost per unit of CO2. At an average US fuel economy of 20 MPG (the average for household vehicles in 2002), the lower range of CO2 costs implies a cost per tonne of CO2 of USD $6.60/tonne, while the higher range in column three implies a cost of nearly USD $85/tonne of CO2. Nordhaus (2008) suggests values closer to USD $12/tonne CO2, while Stern (2006) favors the higher range.

To estimate the costs and benefits of a proposed intervention, an evaluation method or set of methods must be used that allow the analyst to evaluate both short term and longer term impacts. For many projects, costs are incurred before benefits start to flow. There also are ongoing costs for operations and maintenance, which may be offset by revenues in some cases, as well as externality costs and benefits. Since benefits and costs incurred in the future are of less value than those incurred today, a discount rate must be applied to the future stream of costs and benefits in order to determine the net present value of the proposed project.

While there remains debate over the appropriate discount rate, many agencies have established guidelines or software packages for use in benefit-cost analysis, specifying or offering advice on appropriate discount rates for different types of project. Such guidance may also include default values for key elements of costs and benefits for various project types.

A benefit-cost approach has been applied to Mexico City's Metrobús on the heavily traveled Insurgentes corridor. (INE, 2006) Table 2.2 shows the value of travel time savings, fuel savings valued at the 2007 price, and CO2 savings quantified at USD $5/tonne as well as at USD $85/tonne. A description of these findings and the methods used to calculate them is found in the case study for Mexico City in Appendix 1. The total annual CO2 reduction was approximately 50 000 metric tonnes of CO2.

Table 2.2 Annual Benefits of Metrobús Project

Nature of annual benefit or savings	Low CO2 value (USD $5/tonne)	High CO2 value (USD $85/tonne)
Time Savings of Bus Riders	$1.32	$1.32
VKT external costs -- reduction in traffic	$2.19	$2.19
Air Pollution Reduction /Health Benefits	$3.00	$3.00
Fuel Savings from bus switch	$3.68	$3.68
Fuel saving, mode switch car to bus	$3.66	$3.66
Fuel savings to parallel traffic	$1.56	$1.56
CO2 reduction from bus switch	$0.09	$1.75
CO2 reduction, mode shift car to bus	$0.13	$2.58
CO2 reduction in parallel traffic	$0.05	$0.87
Co2 Reduction, total value	*$0.27*	*$5.20*
Reduction in accidents/death (not estimated)		
Total first year annual value US$ Million (2005)	$15.69	$20.62

Source: CO2 and fuel calculations made in this study,
Based on Rogers 2006; other savings taken from INE 2006.

Table 2.2 shows that for the lower CO2 price, the "value" of CO2 saved by the Metrobús project is almost nil compared to other benefits of the project. For the higher CO2 price, the CO2 represents almost 25% of the other benefits included.

The proportions of the three terms of CO2 savings bear comment. The largest savings come from modal shifts, almost entirely cars to Metrobús. The substitution of large articulated buses for smaller buses and colectivos (i.e., paratransit) was the second largest source of savings, while the smoothing of traffic along the Insurgentes corridor contributed the third main source of

CO2 savings.[19] Each of these measures was implemented to improve transport in the corridor. CO2 was reduced, but that reduction was not a necessary or sufficient condition for Metrobús to be considered "successful". Instead, the CO2 reduction was a co-benefit to a transport strategy.

Indeed, if the Metrobús project were evaluated only against CO2 savings, the cost per ton of CO2 saved would be excessive relative to its capital costs. But clearly the project is NOT simply a CO2 project and the benefits are far greater than CO2 alone, as the partial evaluation presented in Table 2.2 shows.

Note that the measures leading to overall transportation project savings of CO2 include none addressing CO2 emissions directly, through fuels and vehicles. Mexico City authorities tested two diesel hybrid buses that used roughly 20% less fuel per seat-km than conventional diesel buses. Even an optimistic outcome from using hybrid buses would have yielded very small savings (approximately 3,000 additional tonnes of CO2/year) compared with the main project components shown in Figure Table 2.2: shifts from cars to buses, improvements to parallel traffic, and the actual substitution of fewer, larger buses for many smaller ones. At the extra cost of these buses over conventional diesel articulated buses (USD $100,000-200,000), the savings in fuel (at USD $ 0.48/liter) and CO2 (at USD $85/tonne of CO2) the monetary benefits would be small.[20]

An important point that the Metrobús example illustrates is that significant CO2 benefits can flow from transport projects that are cost effective overall but would not be cost effective if evaluated only on the basis of their CO2 reduction benefits. Furthermore, the strategies that produce the largest direct CO2 reductions (usually fuel and vehicle strategies) are not necessarily cost effective on their own.

One concern that some observers have raised is that transportation improvements often lead to greater transport activity, which will increase overall transport emissions. Yet more transport activity is needed in many areas, especially in developing countries such as those of the LAC. A broader perspective is required in such cases.

First, the appropriate comparison is not project emissions vs. current conditions, but project conditions vs. conditions that will prevail if the project is not implemented. This is usually the "trends extended" scenario. Further, Kopp (personal communication, 2009) has suggested that an appropriate metric would be maximizing the welfare from every kg of CO2 emitted rather than minimizing the CO2 emissions from every unit of transport. Such a metric would credit transport projects for all their benefits, not simply focus on CO2 savings.

Evaluation of transport interventions requires good data, models, and staff expertise. Key questions that might be asked about these issues include:

1. *Do urban authorities have data and models that permit measurement or estimation of changes in travel times and costs, exposure to pollutants, accidents, wear and tear on roads, CO2 emissions, etc?*

[19] The details of derivations are given in the Mexico City case study included as an appendix to this report.
[20] Metrobús, the largest operator, obtained a loan for buses at 10.5% nominal interest and a five-year payback rate (Schipper et al., 2007). With these parameters, the capital recovery factors was close to 25% while the payback of fuel and CO2 was only half that rate.

2. *Do urban authorities have data and models that permit monetization of the costs and benefits of the project? What are the interest rates and payback times used in evaluations?*

3. *If data and models are not available, do urban authorities have the staff skills or other resources to carry out before-after studies and trends extended evaluations, including data collection as needed for such studies?*

4. *What are the major benefits for the projects being considered? How robust are the results? Do the benefits accrue throughout the population or only to particular groups? Are there particular benefits (or new costs) that accrue/fall on lower income groups?*

5. *Could CO2 impacts be improved by making modifications to the project, e.g., by using low carbon vehicles and fuels, adding pedestrian and bike facilities along the right of way?*

6. *For a range of assumptions about health costs, time values, carbon values, fuel prices, etc., how does the importance of projected CO2 savings vary?*

7. *What are the interest rates and payback times used by operators to evaluate benefits? Are these consistent with the values from the economic and professional literature?*

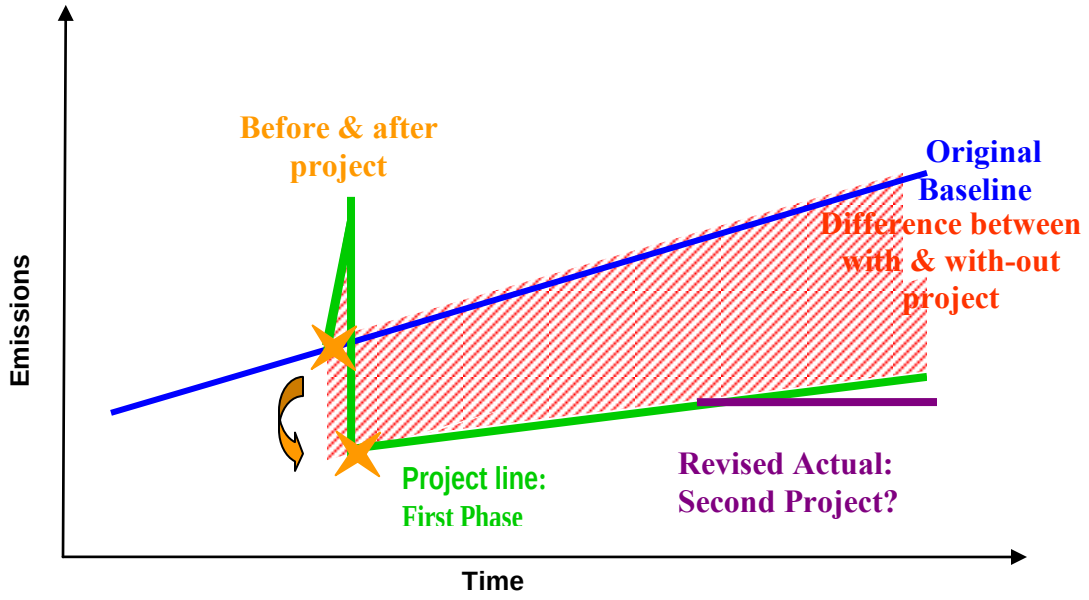
D. Comparing Project Impacts to the "No Project" or Business-As-Usual Alternative

Just as project benefits and costs change over time, the "no project" alternative also changes over time. These changes must be taken into account and are especially important for projects with a useful life greater than a few years.

In a fast-growing urban region, changes in a decade or less can be considerable. (See, e.g., Lefevre (2007) for Bogotá and Santoro (1999) for Curitiba.) Large transport projects can have almost immediate impacts, as both Transmilenio (Lefevre, 2007) and Metrobús (Rogers, 2006) demonstrate, but the impacts change as new network segments are completed (and as urban development responds to new contours of accessibility (see Muñoz-Raskin, 2007 for Bogotá). At the same time, population and economic growth change the metropolis, sometimes outpacing the effects of new policies and investments.

In this context, "savings" from a project will usually lead to lower fuel use or CO2 emissions than would have occurred in a business-as-usual situation, i.e., with exogenous growth and change but without the project. Figure 2.5 illustrates the kind of comparison to make. The diagram could symbolize a specific corridor, a part of a city, or an entire metro region.

Figure 2.5 A Moving Baseline (Business as Usual) and a Project Outcome



Source: Rogers and Schipper, 2005; Schipper and Cordeiro, 2007.

The solid blue line in Figure 2.5 represents emissions as projected under a business-as-usual baseline, i.e., no new projects or policies. In the example shown, emissions rise over time because population and incomes are rising, more individuals use cars, traffic worsens, and the urban region expands (increasing trip lengths). The spike where the project is initiated illustrates what often happens when projects themselves cause temporary disruptions during construction or during their initial phase.

A project or intervention can change both the absolute level of emissions – the "project line" in green in Figure 2.5 -- quickly and the slope of the change in emission over time. What is illustrated in Figure 2.5 has been exaggerated to differentiate the baseline from the actual development because of a project or policy. Note, however, that the slope of the project line has been drawn to be less than the slope of BAU. This illustrates another important outcome, namely that projects and policies can slow the rate of growth of CO2 emissions relative to that rate of growth in the BAU case. Some projects might lower the absolute level of emissions briefly, only to see growth return at the same rate as before.

Analysis of the business as usual case is normal in many regions. In the US, a comparison is required for a project vs. no project, or "build/no build", as part of environmental impact studies. In a key study leading to the Stockholm congestion pricing system, Transek (Transek AB, 1997) modeled traffic in Stockholm in 2010 with no change in trends, with a cordon pricing scheme (similar to what was implemented in 2006) and with a road pricing scheme with variable prices per kilometer depending on location and time.

Key Questions:

1. *Do urban authorities have a baseline forecast of urban growth and activity that can be used as the "without project" comparison? How far into the future have forecasts been prepared, e.g., 5, 10, 20, 30, 50 years?*
2. *Are the traffic and travel data recent enough to give a robust portrayal of traffic and travel before implementation of the interventions is being considered? Are there on-board surveys of riders of collective transport?*
3. *Is there a network of cameras or sensors to record traffic levels? Is there a network of ambient air quality monitoring stations and are monitors well located and sufficient in number?*
4. *For projects being considered, would ongoing monitoring and data collection provide the information needed to evaluate the project's short and long term impacts, such as ridership and modal shift, traffic flow changes, etc? If not, are there plans to conduct special studies for project evaluation?*
5. *Are models available that are capable of simulating the impacts of changes in economic activity like a boom or slow-down, faster or slower population growth, acquisition of new kinds of vehicles (low cost mini-cars, motor cycles, etc)?*
6. *Are there institutions with budgets to support long-term measurement, modeling, and monitoring of the development of the region, its land uses and its transport system, vehicle activity, fuel use and emissions of criteria pollutants?*
7. Establish measures of performance for ongoing monitoring and evaluation of the major expected benefits and costs of the intervention, as well as changes in CO2 emissions.

E. Establishing Performance Measures for Ongoing Monitoring and Evaluation

The previous steps estimate the performance of a proposed intervention using modeling and/or evidence from analogous projects. It is advisable, in addition, to monitor projects during and after implementation to track costs and benefits and see if the projects perform as predicted. Since performance also may be affected by exogenous factors (e.g., actual population and economic growth, technology changes, etc.), some of which may differ from forecasts, this step requires investment in transport and fuel use data gathering, travel and emissions modeling capability, and methods for observing traffic flow and speeds.

Monitoring can be complex and costly, and it usually is necessary to select a set of key indicators or performance measures that will be used to evaluate the project. Typical performance measures are travel times and travel costs by mode for key origin-destination (O-D) pairs, ridership or traffic volume by mode and O-D, pollutant concentrations at key locations, emissions by vehicle type, and speed by mode for various times of days and locations or corridors. Reduction in CO2 can be one of the measures of performance that is monitored as long as travel and fuel use data are available, since it can be calculated from such data.

Questions that should be asked about performance monitoring include the following:

1. *For projects being considered, are there plans to monitor short and long term impacts, such as ridership and modal shift, traffic flow changes, etc.?*
2. *Do local authorities have the tools to monitor performance of the various elements of the transport system – e.g., regional travel surveys, transit ridership counts, on-board surveys of transit riders, traffic sensors monitoring traffic volumes, speeds, and queue lengths, air pollution monitoring stations vehicle fleet inventories, travel surveys? Are these tools up to date and deployed at sufficient times and locations to produce useful data?*
3. *Do local authorities have the budgets and staffing to support long-term measurement and monitoring of the transport system and its impacts?*

F. Summary

This chapter presents a framework, that is, an outline of the broad set of ideas and principles that we recommend as a guide to activities aiming to integrate CO2 considerations into transport planning for the LAC. A series of questions that can be asked to help guide the process are presented.

Key ideas in the framework include the following:

CO2 reductions must be measured against a business-as-usual or trends -extended base case. This is especially important for projects that have a long useful life.

CO2 reductions will rarely be large enough to justify, by themselves, the costs of a transportation intervention. However, CO2 reductions can be a valuable co-benefit of transport projects implemented to improve accessibility and mobility, reduce pollution, etc.

A robust evaluation approach would consider the scope, scale and time frame of the proposed project, its likely impacts, the value of those impacts, and the costs and benefits of not implementing the project. It also would include monitoring (field evaluations) of the project over time.

A valuable metric for CO2 projects in areas undergoing rapid economic development would be the benefits per unit of carbon emitted, rather than carbon reductions per se. The benefits per unit of carbon metric acknowledges the desirability of growth and improved access and mobility.

Further applications of this Framework are found in Appendices 1 (Mexico City) and 2 (Santiago de Chile).

3. Methods for Assessing the CO2 Impacts of Transport Projects

Estimating the CO2 impacts of transport projects requires the analyst to combine information on the flows of people and vehicles (number, origin-destination, and length of trips made, mode of travel used, network conditions during the time of travel, vehicle occupancy) with information on the types of vehicles used and their fuel-use characteristics, to produce an estimate of fuel used. Standard coefficients published by the Intergovernmental Panel on Climate Change (IPCC) can then be used to convert the estimate of fuel combusted into CO2 and if necessary into other greenhouse gases.

The choice of specific methods for assessing transportation projects' CO2 impacts can be a complex matter, both because of the nature of the analysis problem and because, at least at present, data are not always available for some of the key variables and must be approximated. The analysis problem is complex because transportation is an open system characterized by feedback among its several elements as well as multilayered interactions with the broader environment. Most interventions therefore have not only direct effects but secondary and tertiary effects, which can be significant and which often depend on initial conditions. Feedback in transportation systems occurs in multiple ways. Congestion at terminals and on networks affects travel times and therefore can alter mode choices, destination choices, and even the number of trips made. In the longer run congestion also can affect location choices of both households and businesses. Changing costs of transport likewise can have effects that reverberate through the transport system. However, the scale of transportation interventions varies widely, and some will have a region-wide impact while others will affect only on specific locations or corridors.

In addition, most transportation interventions will have an influence over a number of years, and their performance is likely to change over time. This sometimes is a characteristic of the intervention itself – rail systems become noisier due to wear and tear as they age; fuel efficiency standards for new cars are increasingly felt as the vehicle fleet turns over. However, the influence of a transportation intervention also may be affected by exogenous changes in the metropolitan region in which the project is located. Changes in population and demographics, the regional economy, and household and business location choices are among the many factors that can have an important effect on travel behavior and transportation system performance. Three examples illustrate this point: First consider the effects of changes in household income on travel behavior. As incomes rise, households often increase the number of discretionary trips they make. They also may move to larger housing units with more conveniences and purchase an automobile. Second, consider the effects of business location decisions on travel, Businesses may locate or relocate in office complexes along peripheral highways to avail themselves of modern facilities and services, often at lower cost than in the central city. The relocation is likely to affect the housing location choice of their employees as well as the employees' travel choices. It also may reduce the market for transit downtown.

Even nominally "technical" changes can have price and performance effects that can affect travel demand as well as system costs and performance. For example, low carbon fuels are sometimes more costly than conventional fuels, and advanced bus designs are more expensive than conventional buses. To the extent that such costs are reflected in consumer prices and are significant, they could alter travel demand.

Since the CO2 impacts of transportation interventions are a function of these complex changes, a thorough evaluation of transportation interventions would include their consideration. The anticipated impacts of the intervention would then be compared to a forecast of what would

happen without the intervention, i.e., a business-as-usual or trends-extended case. The difference that the transport intervention makes to CO2 emissions then can be determined. The CO2 effects of individual elements of an intervention, e.g., the relative importance of increased transit ridership vs. more fuel efficient buses – also can be examined.

Models are often used for these assessments because they can represent travel choices and system performance under a variety of conditions and essentially "sort out" the contributions that various changes and interventions make. However, reasonable estimates of the CO2 impacts of urban transport interventions can be prepared in a variety of ways, from using an advanced integrated land-use transportation modeling system to applying simple spreadsheet calculations. Simplified approaches typically ignore secondary and tertiary impacts and often focus on short term effects rather than those that evolve over time. However, they are often faster and less expensive to apply.

The choice of evaluation method(s) should reflect both the type of intervention contemplated and its scale and scope, as well as resource availability and the extent to which accuracy is critical. For many projects, simplified approaches may be the most practical, because data and resource limitations may put more comprehensive and detailed approaches out of reach. In many cases, the most robust analysis strategy will be to use several methods, in effect checking the work in several ways. Expert judgment and evidence from the literature can be useful in helping to shape an evaluation plan and in assessing the reasonableness of results.

Data for transportation project assessments can be taken from periodic travel and activity surveys and ongoing traffic monitoring reports, or can be collected in special studies done for the project. When local data are not available and project studies are not possible, data from national data bases or other, reasonably similar metro areas can be used, adjusted to reflect local conditions if need be. However, it is worth considering the development of a longer term program to systematically improve data, analysis tools, and local analysis capacities. While any one project for an urban area might not justify a major data collection and modeling effort, it nevertheless might be appropriate to invest in data and methods, since these assets then will be available for future projects, and can be applied to many issues, not just global warming.

This chapter provides an overview of methods and evaluation approaches that can be used to estimate the CO2 impacts of transport projects. It also addresses ways of dealing with a problem that arises all too frequently: what to do when local data are not available. Finally, the chapter identifies some issues to watch out for in preparing or reviewing CO2 analyses, including the risk of unintended consequences and the value of analyzing institutional capacity for implementation in parallel with the technical assessments.

Local data and models are always the best source of information for transport (or other) analyses because consumer behavior reflects the local context and that context can differ considerably. In part this is a function of income differences; the quality of services also can make a big difference in choices. Evidence from cross-national comparisons has shown that status and habit also have an influence, although income and service quality are stronger impact. For example, owning and using a car is a strong status symbol in some countries, and is a commonplace appliance elsewhere. For these reasons we have emphasized the need to invest not only in projects but in data and analysis capabilities, including local capacity to develop and utilize these resources.

A. An Overview of Transportation Analysis and CO2 Estimation Methods

Evaluation of the CO2 impacts of transportation interventions requires that the analyst first estimate the transportation effects of the intervention and then calculate the resulting fuel use and CO2 emissions. Therefore, the types of methods available for transport analysis will be reviewed here briefly. More details can be found in a variety of widely available textbooks, manuals, and websites. (See for example Ben-Akiva and Lerman, 1985)

Transportation models are frequently characterized as demand models or operations models, although most "demand" models also utilize information about, and indeed frequently model, the networks and facilities as well Operations models are used to analyze network capacity and design and to develop control strategies, i.e., lane layout and restrictions, traffic signal timing for streets and highways, and station capacity and line scheduling for transit.

Transportation demand models utilize information about the urban area – the regional economy (e.g., the number of jobs by type of job), the characteristics of the population (demographics, employment, income), location and land use (e.g., number of establishments by type, square meters of floor space by type of establishment) - together with information on the transportation system (network links and nodes, capacity, speeds, etc. by mode, patterns). Models are built to relate observed travel patterns and behaviors to these data. The models then can be used to forecast changes in urban conditions as well as the effects of policy and project interventions.

Characteristics of the population and the economy are usually obtained from national or regional statistics and forecasts. Land use and location are often taken from regional databases on current conditions and for future years may be either modeled or specified based on city plans and expert judgment. Transportation system characteristics are measured or, for future conditions, specified. Vehicle fleet characteristics may be derived from on national, regional or local data sets and studies, or may be forecasted using vehicle ownership and vehicle type choice models. The time of day that various types of trips are made may be specified based on survey data, or may be modeled as a decision process.

Travel surveys are used both to gather information on trip making for various activities and to relate the reported activities and travel to household and individual socioeconomic characteristics such as age, sex, occupation, income, vehicle ownership, and location in the region. Information on transportation facilities and their operations (streets and highways, transit, and sometimes non-motorized modes) is used to determine the levels of service offered in different areas.

A set of models is usually developed to allow analysis of the multiple dimensions of travel, estimating trips by trip purpose, location, origin-destination pattern, transport mode, and time of day, as well as the routes used and the resulting flows and speeds on networks. The models are specified (i.e., variables are included) to show the relationships between travel and dependent socioeconomic factors and transport-land use conditions. The data are used to estimate coefficients for each variable and the resulting models can be used to forecast how travel will change if the underlying traveler characteristics or transport system characteristics change. Such changes can be the result of a specific intervention or set of interventions, e.g., a new transit line, added highway capacity, congestion pricing, higher transit fares, or can be the result of changes in the region's population and economic activity, e.g., population growth, higher rates of workforce participation, higher incomes, aging of the population.

Operations models use much more detailed information on highway and transit than is used in the typical demand model network representations. They typically include lane by lane design details for each link. On the other hand, they typically assume demand is fixed and exogenous.

Using the results of transportation models together with data on the vehicle fleet, the types of fuels used, and fuel intensity by mode, CO2 impacts can be estimated. The analyst can perform a detailed analysis, using model outputs on operating conditions (e.g., link level speeds and vehicle occupancies by mode), or can simply use model outputs on vehicle kilometers of travel by mode together with average fuel use per km and carbon content of the fuel.

i. Integrated Transportation-Land Use Models

The most advanced method for carrying out travel demand analysis today is an integrated transportation-land use model. Such models analyze activities in which individuals, households, and businesses engage over different time frames, including household and business location choices, and estimate the resulting travel and its impacts. The models increasingly address not only trip generation, destination choice and mode choice, but also vehicle ownership decisions, decisions on what time of day to travel, whether or not trips will be linked together, and more. They are integrated in the sense that information on travel times and costs from changes in the transportation system affect choices such as location and auto ownership. Many of the models include pedestrian and bicycle networks as well as detailed highway and transit networks. Outputs from the models include location choices, number of trips by trip purpose, origin-destination, and time of day, and travel times and costs by network link and time of day, and increasingly include emissions and fuel use by fuel type for each mode. Alternatively, demand model outputs may be input into separate models to estimate network performance, fuel use and emissions.

Integrated transportation-land use models have been developed in Europe, Japan, the US, and Latin America and have been applied in a number of cities (See, e.g., de la Barra, 1989, Wegener, 1998; Echenique, 2004; Hunt, et al., 2005). Recently some of these models have also included advanced microscopic traffic operations analysis methods. (U.S. FHWA, 2009) However, integrated h models are not yet in common use. For one thing, these models are still under development and their performance is still being evaluated. For another, they require large amounts of high quality data and advanced modeling skills, neither of which is readily available in most cities (including those of the high income nations). As a result, many areas use somewhat simpler modeling approaches that treat land use, auto ownership, time of travel, and details of network performance as outside the model system.

v. Standard Travel Demand Models

A fairly standard travel modeling process is shown in Figure 3.1. In practice, many variants of this process are used, some more complex and sophisticated that that shown, others less so. Standard travel models forecast trip generation rates, trip distribution (origin-destination patterns), and mode choices, and use this information to estimate flows on networks and the resulting travel times and costs. Most models do this for two or more time periods (e.g., peak, off peak) and for several trip purposes (e.g., work, shopping, social-recreational.) The standard travel demand models do not model vehicle ownership issues nor do they forecast future land uses and location choices. These are treated separately, either through separate modeling processes or through the exercise of expert judgment. For example, future land use forecasts

are often scenarios developed by experts who assess where and how much growth will occur based regional population and economic forecasts, local plans and policies, and an assessment of business and household preferences.

The basic unit of analysis in these standard models and their sub-models may be aggregate, producing travel information for subareas of a region (often called Travel Analysis Zones or TAZs), or may be disaggregate and behavioral, where the unit of analysis is the household or the individual. For example, an aggregate trip distribution model represents flows between an origin and a destination as a function of the "productions and attractions" in the two TAZs and the "friction" (travel time and cost) of traveling between the O-D pair. A disaggregate approach might treat the flow between, e.g., a home zone and a shopping district as a matter of shopping destination choice, where the probability that a traveler would choose to shop in a particular zone would be a function of the traveler's income and other socioeconomic characteristics, that zone's attractiveness compared to other alternative destinations, the respective travel time and costs between zones, and in some formulations, the mode choices available.

Whether the specifications are aggregate or disaggregate, the basic outputs are much the same: the number and length of trips made, by time of day and trip purpose, origin and destination, mode of travel, and route; as well as speeds and flows on networks (transit, highway).

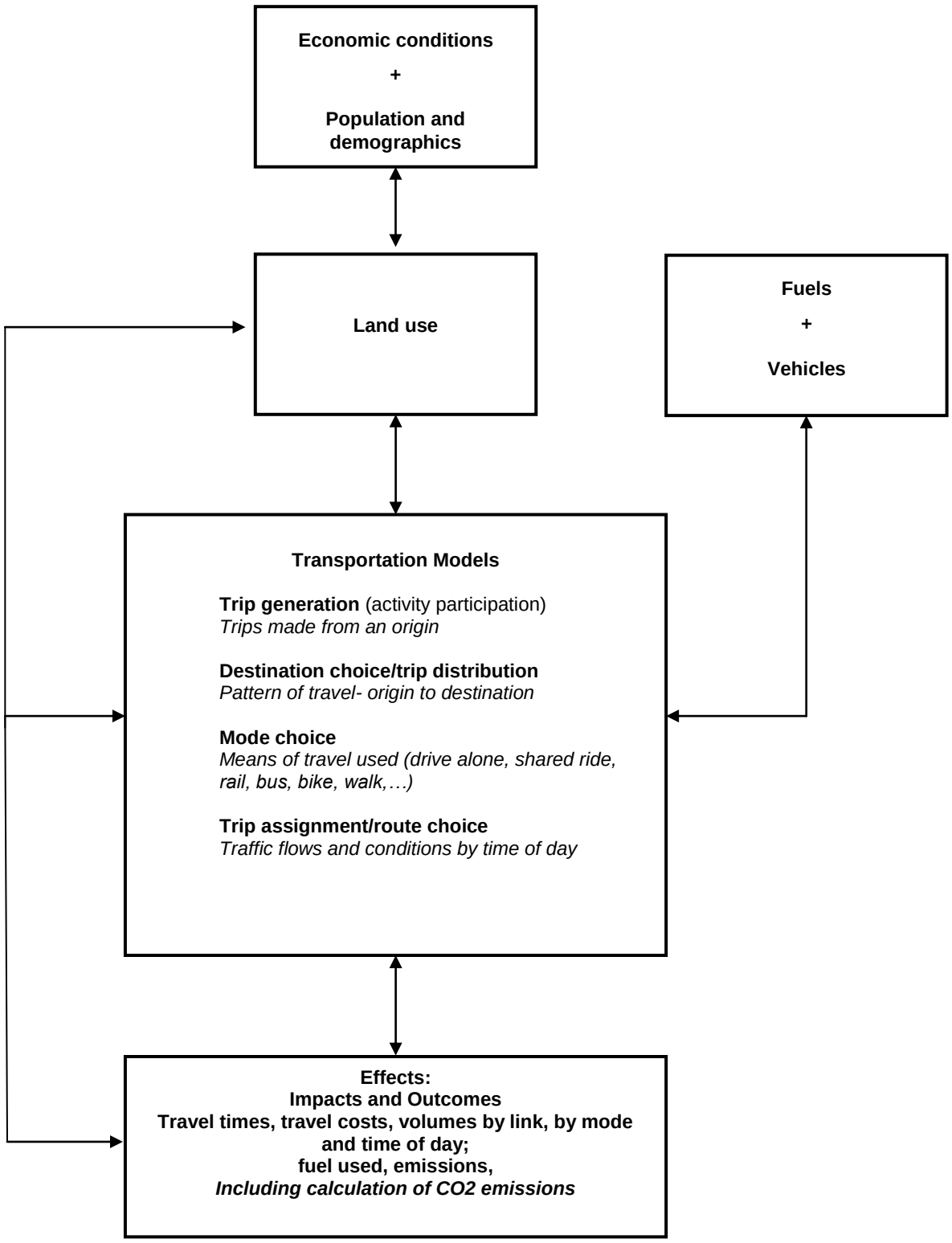
The sophistication with which network modeling is done in this process varies widely in practice. It is generally considered standard to run the models iteratively. That is, the travel times resulting from loading the network with the first iteration of travel estimates (which in congested networks will be considerably slower than design speeds) are 'fed back" to the trip generation or trip distribution and mode choice sub-models and the model system is rerun until it reaches an "equilibrium", i.e., the changes from run I to run J are less than or equal to a specified acceptable difference or tolerance level. However, some model systems estimate trip generation in ways that are insensitive to the transport network and so consider congestion effects only for trip distribution and mode choice.

vi. Sketch Planning Methods

Sketch planning methods are simplifications that allow analyses to be conducted more quickly and at lower cost, though often with some loss of detail. Sketch planning methods are frequently used to conduct demand analyses, especially for projects that affect only one corridor or subarea. A common sketch planning method is to extract a model from a regional travel model system and use it to conduct analyses without exercising all the other modeling steps. Examples include the use of a mode choice model to estimate the ridership of a new transit system or use of a destination choice model to examine the effects that a new shopping center is likely to have on retail travel patterns. The drawback of this approach is that it ignores potential impacts that might be revealed by other modeling steps, e.g., the shopping center traffic may increase congestion, which in turn could affect both its attractiveness as a destination and also could alter other travel and activity behaviors.

Another commonly used sketch planning approach is to use elasticities derived from advanced or standard travel models (e.g., changes in mode choice with respect to travel time, changes in VKT with respect to changes in fuel price) to perform simple calculations in spreadsheet applications. The limitation of this approach is that the elasticities may apply only in a narrow range around the point at which they were estimated.

Figure 3.1 A Typical Travel Demand Model Structure



vii. Traffic Operations Models

Traffic operations models are designed to analyze the details of network design and operations. The most advanced of the models can represent, e.g., the effects of lane additions and reductions, restricted lanes (e.g., bus only), weaving /merge sections, design features such as roundabouts, and operation strategies such as traffic signal timing, ramp or cordon metering, and priority treatment of high occupancy vehicles. The models produce detailed analyses of speed, flow, stops, delays, and in some cases accelerations and decelerations. They treat demand as exogenous, i.e., they operate on traffic count data and external estimates of future traffic counts (often, anticipated growth rates or percent increases in traffic, assuming the travel pattern does not change). Like demand models, they can be formulated in aggregate or disaggregate ways; disaggregate methods represent each vehicle in the traffic stream.

Traffic operations models require information on current and projected traffic conditions and network design. Most require detailed traffic counts by time of day, including turning movements, queue lengths, etc., as well as speeds on a link by link or lane by lane basis. They also require details about facility design and operations including current traffic signal timing. With these data, traffic operations models can produce more detailed estimates of traffic performance (speeds, accelerations and decelerations, idling, etc.) than the more abstract networks used in demand modeling. Some traffic operations models also produce estimates of fuel and emissions directly.

Traffic signal timing models are a special purpose version of traffic operations models. Given traffic counts and turning movements, they produce plans for signal timing that minimize delays or achieve other specified objectives. Some signal timing models can be run to minimize fuel consumption, for example. Specific models vary in complexity and sophistication, with some able to optimize performance of a large number of signals in a system and others able to handle only one corridor, or in some models only one signal, at a time.

While traffic operations models are usually used on their own, they sometimes are linked to travel demand models, especially when network details or details of fuel use and emissions are important. Recent advances in travel demand modeling are increasing the sophistication of the network models they use, however, and so the distinction between the model types may be fading.

viii. Post Processors for Fuel Use and Emissions Estimation

Because many commonly used versions of travel demand and traffic operations models do not directly calculate fuel use and emissions, analysts use post-processors to perform these tasks. The post-processors take the output from travel demand models (e.g., vehicle miles of travel by link, link speeds, etc.) and use these estimates as input into fuel and emissions calculations. A variety of fuel and emissions models are available at different levels of detail. Among those that model specific vehicle types or categories and driving cycles are two developed by the US EPA, Mobile 6 and MOVES (for Motor Vehicle Emission Simulator), as well as COPERT, an emissions model developed in Europe, and Mobile for Mexico.[21] Still another detailed emissions model is MODEC, which was developed for Chilean conditions and uses the output

[21] These US emissions models are discussed on the US EPA website for the Office of Transportation and Air Quality – see http://www.epa.gov/otaq/models/mobile6/r02035.pdf, and http://www.epa.gov/otaq/models/moves/index.htm.) COPERT, is discussed at http://reports.eea.eu.int/Technical_report_No_49/en Mobile for Mexico is at http://www.sma.df.gob.mx/sma/links/download/archivos/ie06_criterio_pw23oct08.pdf

of a travel and traffic model ESTRAUS. (Goicoechea, personal communication, 2006; de Cea et al., 2008)

At the other end of the spectrum are straightforward spreadsheet models that use simplified representations of travel and emissions (e.g., total travel in km * share by each mode* fuel used by the mode* emissions per unit of fuel burned = emissions). The "ASIF" formulation (Schipper, Marie, and Gorham, 2000) is such an approach, bringing together aggregate data on vehicle kilometers of travel by mode with average fuel use per kilometer and the CO2 content of fuels. (Fuel use also can be expressed per passenger kilometer by dividing fuel use per vehicle kilometer by passengers/vehicle, i.e., average vehicle occupancy.

ix. Life Cycle Analysis

A complementary analysis approach that can provide improved information on CO2 impacts is Life Cycle Analysis (LCA) Manufacturing and eventually disposing of vehicles, building and maintaining transport facilities, and producing fuels all create emissions of CO2 and other greenhouse gases. A full costing of the CO2 impact of a transportation project would consider all of these elements.

LCA is extremely important for measuring the full CO2 impacts of switching fuels. Alternative forms of gasoline and diesel produced from coal, oil shale, heavy oil or other hydrocarbon sources can entail significant emissions during production. Biofuels similarly may be associated with major releases of CO2 or other greenhouse gases directly in their preparation or indirectly due to the way in which, and the land on which, the biofuels feedstocks are grown. For some fuels, the amount of carbon emitted in their production offsets a large share (in some cases, nearly all) of the savings they would yield per liter of fuel or per km of travel.

For example, a liter of US gasoline contains 31.7 megajoules (MJ) and emits 74 gm of CO2 for every MJ of energy released, and 19 additional grams from the fuel cycle delivering the gasoline. Ethanol releases 73 gm of CO2 for every MJ. If ethanol is made from cellulosic feedstocks, such as switchgrass, the Argonne Laboratory's GREET model predicts only 12 gm of net CO2 added to the atmosphere because the rest was absorbed when the ethanol feedstock was grown. Ethanol produced from Brazilian sugar has a net addition of 28 gm/MJ, still quite small compared with gasoline. Ethanol from corn produced in the US, however, has a net emissions including LCA of 69 gm/MJ. Thus while US corn ethanol has lower CO2 emissions per unit of energy than gasoline, the advantage is less than 20% because most of the "bio" energy is replaced by fossil fuels for processing. (ANL, 2007) If the long-term impacts of devoting land to biofuels on other land uses are counted, some biofuels may lead to a net increase in greenhouse gas emission compared with gasoline or diesel (Searchinger et al., 2008). These results are very sensitive to the processes and feedstocks used, and will vary from country to country as well.

LCA also can be used to take into account the CO2 associated with electricity for conventional traction (Metro, commuter rail, light rail and trolley bus) as well as electric vehicles whose batteries are charged from the power network. Similarly, LCA offers estimates of the CO2 impact of building a road or a transit system's guideways, stations, and vehicles, which may be comparable to several years' worth of operation. MacLean and Lave (2003) present comparisons of the energy and CO2 associated with vehicles, fuel production, and fuel consumption. Except for some very large heavy rail systems (Chester, 2008) most of the CO2 associated with transport is that that arises in producing and burning fuel.

Lifecycle analysis is not likely to be crucial to deciding for or against large transport infrastructure projects. However, it can be decisive on determining whether alternative fuels, particularly alcohols and bio-diesels, really do reduce CO2 emissions relative to the petroleum based fuels they replace. The net reduction can be compared to any extra costs of producing the biofuel to see whether the cost of the CO2 reduction really merits the effort, compared to alternative fuels or even other investments to improve transport.

x. Summary of Methods

Table 3.1 summarizes a variety of approaches for measuring changes in transport systems and their effects on CO2 emissions. These start with travel data and modeling and then process results through various models or estimates of fuel consumption.

Table 3.1. Methods for Transport Analysis and CO2 Estimation

	Method	Description	Pros & Cons	Data needs	Use
1	Integrated transportation and land use models	Model transportation and land use /location choice processes , activity / travel choices, transportation system performance and their interactions	More theoretically sound and complete representation of transportation system and choice processes. High costs in terms of data, expertise, and time resources.	Economic and population data and forecasts, current & permitted land uses by parcel /small area; transport networks & prices; travel /activity survey incl. socioeconomic info. & vehicles owned.	Estimates account for a changes in land use and location, travel choices, network performance, fuel and emissions may be outputs or may require pos-processing
2	Standard ("four step") transportation models	Model trip generation, trip distribution, mode choice, and network assignment.; many variants including aggregate and disaggregate formulations.	Vary in quality and sophistication. Treatment of land use as exogenous can be a problem if major investments that shape growth are being considered.	Same as for integrated models, but data requirements often lower, especially for aggregate models	Estimates can capture major choices and elements of transport systems.
3	Sketch planning methods	Quick response methods that extract a model such as mode choice or destination choice and apply it separately from the rest of the model system, or use elasticities derived from models to estimate changes.	Less data intensive and time consuming to run than full travel demand models; less comprehensive. Elasticities are very simple to apply, but results may only be valid for changes within narrow range	Only the data needed for the particular submodel, e.g. travel times and costs of competing modes for a mode choice model, land uses in each zone and travel times & costs between them for trip distribution	Examine a particular issue, e.g. mode choice, destination choice changes in response to a proposed intervention. Often used as first-cut with additional analyses if needed.
4	Traffic operations models (traffic operations, signal timing, etc.)	Model network design (e.g.., lane additions, weaving sections, restricted lanes), and operation strategies, such as .traffic signal timing and ramp or cordon metering	Produce more detailed representation of network features & detailed analyses of speed, and flow, stops, delays, accelerations, etc. Treat demand as exogenous.	Traffic counts and turning movements, speeds by time of day, facility design and operations details..	Design of facilities, traffic signal timing, other traffic operations;; can produce more detailed estimates of fuel use and emissions than the more abstract networks used in demand modeling.
5	Post processor models for CO2 estimation	Use output from demand or traffic operations models to calculate fuel use and emissions.	Quality of results depends on other models. Level of aggregation / detail also depends on other model outputs.	Data on emissions factors can be based on averages or can represent effects of, e.g., speed, idling, acceleration and deceleration.	Can be used to estimate CO2 emissions when other models do not have that capability.
6	Life Cycle Analysis	Account for "cradle to grave" emissions due to production / construction, operation, maintenance and disposal	Emerging method that can provide more comprehensive accounting of CO2 impacts of a project. Analysis can be data hungry and drawing boundaries can an issue.	Data on energy used in each step of process	Has been used to evaluate CO2 impacts of fuel switching, major infrastructure projects

B. A Note of Caution: Limitations of Modeling

Transportation forecasting models were first developed in the 1960s to help analysts estimate the effects of major transportation investments such as limited access highways and rail transit systems While our understanding of travel behavior and its relationships to traveler characteristics, urban form, and the transport choices available has moved far beyond the simple representations in these early modeling efforts, the same general methods are still being used in many assessments.

In the US, for example, the methods used in practice lag research and in many cases even lag best practice. In the 1990s, the US established the Travel Model Improvement Program (TMIP) to develop new modeling approaches that incorporated state of the art knowledge and methods, and the National Association of Regional Councils, the Environmental Protection Agency, and the US Department of Transportation sponsored guidance on acceptable practices in modeling and analysis. (See, U.S. FHWA, 2009) Despite these efforts, many US agencies still have not adopted improved methods and continue to use analysis approaches that omit many important considerations.

Several reviews of modeling practices and their strengths and limitations have been published over the past 15 years. Many can be found at the TMIP website (e.g., Harvey and Deakin, 1993) along with reviews of current modeling innovations. Rodier presents a review of model types in current use in a paper done to support California CO2 reduction efforts. (Rodier, 2008)

Shortcomings in commonly used transportation modeling approaches include the following:

- Treatment of land use as exogenous to the modeling system (ignores induced growth and changes in location patterns instigated by transport investments)
- Treatment of time of day of travel as fixed (ignores the ability of many travelers to adjust travel times to avoid congestion or peak period charges)
- Use of vehicle trip generation rates that are invariant and therefore do not reflect modal opportunities, land use mix, etc (overestimates traffic/auto demand and undervalues pedestrian, bike, transit travel and trip linking)
- Failure to feed back network travel times and costs into trip generation, trip distribution, and mode choice modeling steps (overstates performance of new investments by ignoring congestion effects on network performance)
- Failure to represent price accurately (e.g., parking price may be omitted as a variable or estimated as a subarea average)
- Overly simplified network representation (e.g., may classify facilities into only a handful or categories and may omit collectors and local streets altogether or represent them in a highly approximate fashion.)
- Omission of non-motorized modes of travel from the analysis.
- Overly large traffic analysis zones (interventions that affect a small part of the city or a single corridor may not “show up” in model results). (Harvey and Deakin, 1993)

Both more advanced analysis and practical experience have shown that these shortcomings can produce misleading assessments of transportation interventions. In particular, capacity increases (e.g., a highway expansion designed for traffic flow improvements) can shift time of travel, alter destination choices, support an increase in trip frequency, affect land values and change location choices. As a result, VKT may increase and the new capacity may be used up quickly. (Hansen and Gillen, 1998) Models that do not capture the feedback effects of transportation investments on trip making, location, and land use would simply estimate the initial traffic flow improvement and would miss the dampening effects of other changes set in motion.

Another limitation of standard travel models is that they are not designed to analyze some of the strategies of greatest current interest. Many demand management interventions are hard to represent adequately; for example, the impacts of employer incentives and other social marketing approaches that depend as much on group dynamics as on time and cost considerations are not easily represented in either traditional or advanced models. Urban design strategies also may be difficult to model with existing tools. Design features that have been found to have important impacts on mode choice, such as the quality of sidewalks and the presence of street trees or canopies offering shade and weather protection, are not represented in most models either specifically or as an element of a walkability variable. Further, the effects of design are often experienced at a micro-scale – the building, the block, the street – that is far smaller than the scale of most models (the traffic analysis zone.) In addition, land use variables are often only roughly related to design impact, e.g. using number of establishments as a measure of diversity of land use.

Operations models have their own limitations. Most are focused on motor vehicle operations and treat pedestrians in a simplified manner and bicycles not at all. Many of the simpler operations models treat intersection counts as independent and fixed and are incapable of assessing route choices.

More advanced models are better capable of addressing the complexities of travel behavior and its consequences. For example, several advanced model systems use detailed traffic operations models to represent networks, integrating the operations models with advanced land use and activity/travel models. However, as they are currently formulated, the application of these advanced models is heavily time-consuming and data-hungry. Partly as a result, the models are most frequently reserved for regional studies (e.g., analysis of the impacts of alternative urban growth and transportation investment plans and programs for a 10 or 20 year forecast year) and for major infrastructure investments (e.g., a major new transit line or a major new highway.). For individual projects of a smaller scale, analysts are increasingly using sketch planning methods derived from advanced models, together with data from field evaluations that are interpreted in light of specifics of the case at hand.

While sketch planning methods are often used because a broader modeling approach would be too expensive, another major reason for the use of sketch planning methods is their relative transparency. This is in part a recognition that changes in transportation and land use policies and practices succeed or fail on the support of elected officials and acceptance of the general public, and not on the fanciness of the analysis. Good analysis can help support decision-making by helping planners and engineers design projects more effectively, but clarity and quick response are important attributes as well. Hence simplified analysis methods (e.g., spreadsheet methods using results from research) are widely accepted, and can be extremely cost effective and valuable.

Regardless of the type of model used, transport models are only as good as the data used to calibrate them. In many urban areas this is a major problem. For example, if travel surveys are old, they may not adequately represent current behavior. If travel surveys are small, it may not be possible to represent infrequently chosen modes or modes that are important only in some districts. If speeds are based on posted limits rather than measured ones, both travel times and fuel use estimates can be highly inaccurate.

Despite these limitations, modeling is usually the best way, and sometimes the only way, to evaluate transportation projects including their CO2 impacts. Recognizing the limitations of modeling can help the analyst exercise caution in interpreting results and also can help identify needed modeling improvements.

C. Selecting an Analysis Approach

Whether to use an advanced model or a simpler one is partly a question of resource availability and partly a question of what issues need to be addressed given the proposed project and the context in which it will be implemented. Large, complex projects are likely to need comprehensive, sophisticated methods. A small, simple project is probably suitable for sketch planning methods. However, size alone does not necessarily determine the complexity of a project. Because context is important, a formulaic matching of methods to project size and scale is not advisable.

Consider a new BRT line intended to increase accessibility to jobs in the urban core from outlying areas of a region. Evidence from other analogous projects, including the experience of other countries, can help determine the issues that need to be considered. In many countries, radial transit lines were built between outlying districts and the central city. These lines enabled housing development in the outlying areas by providing them good access to employment. Suburban housing was followed by service establishments for the growing population, and then by employment centers, which located in the burgeoning suburbs to take advantage of the lower costs of land and the growing labor market there. Eventually new sub-centers emerged, spawned by the transit lines. These sub-centers increasingly compete with the central city for economic development, and employees there do not necessarily use transit to commute to work. (Warner, 1962)

Because such effects are known to occur, an integrated land use-transportation model would be apt for analyzing the transit line posited in this example. While an integrated land use-transportation model is fairly costly to develop and apply, it would be able to capture the potential land use effects of the investment.

Now suppose that a new BRT line is proposed that would connect the central business district to a series of long-established suburbs currently served by conventional buses operating in congested traffic. Should the effects on land development be analyzed? The answer is possibly yes, if the new line will increase accessibility significantly. However, if area is already largely built up, and the new transit level of service will be about the same as the current LOS, the opportunities and inducements for new development might be quite limited. Thus the transportation and CO2 analyses could focus on the effects of improved vehicles and the effects of improved travel time on mode choice.

Finally, suppose the proposal for separate lanes and signal priority for BRT proves infeasible and authorities decide to simply replace the existing buses with new, more fuel efficient buses of the same size and configuration. What analyses are needed? If the buses are used on the

same routes with the same travel times and costs, a good first-cut estimate of the CO2 effects can be calculated on the basis of the change in vehicle fuel efficiency alone. There may also be some effect on demand, because the newer buses are likely to be more reliable, cleaner and more comfortable, but absent changes in travel time and cost the demand changes are likely to be minor. If, on the other hand, the cost of new buses requires an increase in fares, the mode choice impacts should be evaluated.

This example shows that it is not only the size and type of project but also its objectives and the context that should help determine the analysis methods chosen. In general, if a project is likely to affect only one component of the transport system, e.g., vehicles, fuels, guideways, stations or operations, it is often sufficient to analyze the changes to that component only. If a project is likely to affect several or all system components, more extensive modeling is appropriate.

How can an analyst assess whether a project is likely to have limited or wide-reaching effects? The project justification should provide a first cut indication of issues to be addressed, but the analyst also should consider the potential for secondary impacts that could be significant.

Transportation theory offers guidance. Table 3.2 presents a brief list of key factors affecting different location and travel choices. By considering how a project affects these factors and choices and whether the magnitude of the impact is likely to be significant, the analyst can determine what analysis steps are suitable. In terms of the framework presented, what matters is whether a project or other intervention causes a big change in these factors different than what might have happened anyway. Large changes in per capita numbers of trips, trip distances, or mode choice will have important impacts on fuel use and CO2 emissions, both upward and downward. Changes in route choice could affect fuel use per kilometer upward if congestion and traffic delays change.

Table 3.2 Factors Affecting Location and Travel Choices

Choice	Key Factors Affecting Choice
Location of residence or business	Land/building costs, availability and suitability, accessibility (time and cost to other destinations), urban services, neighborhood characteristics
Number of trips (trip generation)	In the aggregate: population size and demographics, number of households and business units, business types; for the individual or household: income, activity participation, modal availability, accessibility
Length of trips (destination choice)	Travel time, travel cost, opportunities (destinations) available' income
Mode of travel	Travel time (access, in-vehicle, wait, transfer times) , travel cost, user age, income, physical condition; vehicle ownership, comfort, reliability, safety
Route choice	Link speed, stops and delays, reliability, cost

Case studies from the literature and the opinions of experts also can be of help in identifying probable impacts and in determining suitable analysis methods. Case studies can illustrate the issues that may arise with a particular type of project, and can illustrate evaluation approaches. Experts can review the project description and justification and synthesize their knowledge of the literature and practice with the situation at hand.

D. What to Do When Data and Models are Unavailable or Limited

A major problem that many urban areas face is that they do not have in hand the data and models needed to thoroughly evaluate transportation projects and their CO2 consequences. Data and models may be absent altogether or may be outdated or of limited suitability. The problem is especially acute for data on vehicle fleets and their fuel efficiency, but may also extend to travel data.

Good data and models are a worthwhile investment for a region. They can be used for a variety of purposes and projects. However, if time and cost considerations preclude a major expenditure on regional or citywide data collection and model development, there still are ways to proceed.

First, it is often possible to collect data for the specific project. The basic building blocks of transportation analysis – data on land uses, the transport network, population and the economy, and travel patterns – can sometimes be obtained at relatively low cost or even free from readily available sources. For example, a considerable amount of data on land uses can be obtained from satellite images which can be processed using available software or, for small applications, by hand. In addition, forecasts of population and economic activity are often available for major metro areas from national or international agencies.

If travel surveys are lacking, project-specific surveys can often be mounted. If data on vehicle fuel efficiencies are missing, sample measurements may be possible, but more likely data will have to be "borrowed." Taking values from literature, tests or estimates conducted in a region not too dissimilar to the one being analyzed may provide satisfactory results.

Two examples, both from Mexico, illustrate how data and modeling limitations have been overcome in recent projects.

i. Example: Mexico City's Metrobús BRT Evaluation

Mexico City lacked a recent travel survey as well as recent traffic counts suitable for use in evaluating its Metrobús BRT project in the Insurgentes corridor. Analysts therefore undertook several special studies to address particular questions of concern to decision-makers.

Retrospective questions in on-board surveys were used to identify how riders had traveled before Metrobús, allowing the analysts to estimate how many cars had been removed from the traffic stream due to the new transit service. These surveys allowed analysts to estimate CO2 reductions due to the new services.

Because development of Metrobús required removing two lanes of traffic to dedicate to the bus lanes, there was an expectation that this change in one of Mexico City's most heavily traveled corridors could have a major impact on parallel and cross traffic. To analyze the effects, traffic counts were carried out and photography, visual observation and on-board counts were used to determine the number of vehicles of each type and to determine vehicle occupancy for cars, colectivos and buses. A traffic operations model was then used to estimate traffic consequences. No modeling was done for other corridors or the region as a whole because the project impacts were not thought to be likely to have significant effects outside the immediate area. (Rogers, 2006)

The traffic models allowed a fairly detailed analysis of the traffic consequences. The vehicle classification and occupancy data allowed the results to be interpreted in terms of passenger movement (recognizing that a bus carries 50 or more people while a car usually carries only one or two.) Even without the traffic models, however, the data collected for the project would have permitted a simple evaluation of project impacts. For example, rough estimates of emissions changes could be made based on before-after traffic counts, vehicle classification studies, bus rider counts, etc. While such approaches typically require a number of strong assumptions, they may nevertheless provide a reasonable first order estimate of impacts.

Translating the traffic model results into their fuel use and CO2 consequences required additional information on the vehicle fleet composition – vehicle types, makes and models, and consequent fuel economies. Gathering data on the vehicles used along particular routes is a huge task, given the typically large and diverse stock of vehicles, and a commonly used simpler approach instead "bins" (classifies) vehicles by their main fuel-use characteristics (engine technology, fuel used, vintage.) This approach was used in Mexico City. The age and type of cars on Insurgentes estimated from photographs of traffic at different times of day. Fuel use was then determined using this Insurgentes fleet, rather than the citywide average fleet. Data on the kinds of vehicles on the route allowed adjustments by size and approximate fuel economy. The International Vehicle Emissions Model, or IVEM (Lents et al., 2004)[22] was then used to estimate fuel consumption as a function of speed for each group of vehicles observed on the corridor. (Rogers, 2006)

A much simpler approach would have been to assume the citywide average fleet and to use a spreadsheet model to estimated fuel and CO2 impacts. A spreadsheet model of the "ASIF" type is suitable for this (Schipper, Marie and Gorham 2000; Schipper and Cordeiro 2007). A represents total vehicle kilometers, S the shares of kilometers by mode, I the intensity (fuel use/km) for each mode and fuel, and F the fuel type, i.e., the CO2 content of each fuel, and putting in appropriate estimates of these values before and after the project, or with and without the project after a given time, gives differences in CO2 emissions. This "ASIF" approach does not calculate the changes in either kilometers driven or fuel intensity of each mode, rather helps the analyst identify the types of data needed and puts them in a simplified multiplicative framework. The approach still requires data vehicle kilometer data for each mode, vehicle type and fuel type, which are available for a number of cities in LAC.

ii. Example: Querétaro Bus Restructuring

A project for Querétaro evaluated how much fuel would be saved if bus services were restructured, the oldest and least efficient colectivos were phased out, and a BRT corridor was added. Because local data on the fuel use of the vehicle fleet were not available, Cordeiro et al. (2008) used Mexico City data on the fuel intensity of similar models of colectivos from Mexico City, together with observations on the kinds of colectivos and buses used in Querétaro and estimates of the distance they traveled in Querétaro, provided by operators.

Fuel use for the base case was estimated for each vehicle type as number of vehicles x km/vehicle/year x fuel use/km. A new service scenario then was studied which 1) cut the

[22] A number of models, including ones running in LAC countries, are available that carry out the simulations of fuel use based on traffic, vehicle and fuel characteristics, that are then summarized by the IVEM. Lents et al. (2004) discusses the IVEM and its uses in a number of LAC cities.

number of bus km provided in Querétaro by two thirds, based on a consultant study that had identified a severe oversupply, 2) culled the oldest and least fuel efficient vehicles from the fleet, running the new service configuration with newer, more efficient buses, 3) added a BRT service with a small number of dedicated BRT vehicles. The resulting fleet was about 600 relatively fuel efficient and clean buses (down from over 1,200) plus 13-18 BRT vehicles.

As Figure 3.2 shows, the reduction in bus km was estimated to produce major fuel and CO2 savings even if the remaining services continued to be offered by a fleet with the same characteristics as those of the base case. Providing services with more efficient buses would further cut fuel consumption and CO2 emissions substantially. The BRT services and the types of vehicles used for BRT made relatively little difference in the fuel consumption calculation because of their small share of the total fleet.

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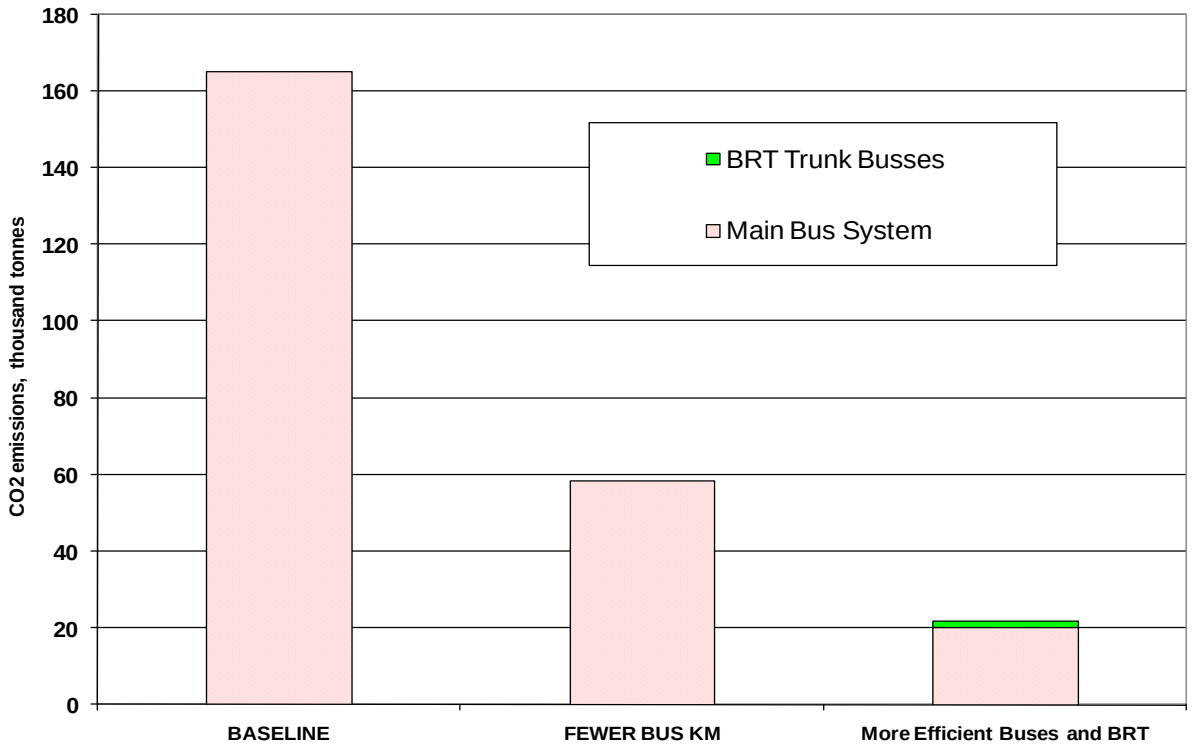
Figure 3.2. Steps to Reducing CO2 from Improving Bus Utilization in Querétaro



The use of "borrowed" fuel efficiency data from Mexico City deserves comment. While conditions in Querétaro are not identical to those in Mexico City, the use of these data saved considerable work in conducting the analysis and probably provided reasonable first-cut results. Confidence in the results was strengthened by collecting local data on the Querétaro fleet composition.[23] Mexico City traffic is arguably more demanding than that of Querétaro, and Mexico City is about 400 m farther above sea level than Querétaro, hence use of the fuel economy data from Mexico City probably overestimated real consumption/km in Querétaro.

[23] The original study done for Querétaro did not collect any fuel use data. Despite backing of the transport authorities for the EMBARQ study, operators declined to provide any fuel-use data or permit any surveying.

Still, the predominant change was in the number of vehicles and the distances driven, with a total change far greater than any possible error in fuel economy rates.

These two examples show that creative field work, carefully borrowed data, and simple methods can produce informative results. In neither case was a formal model exercised in full. Both cases used a combination of available data and data collected specifically for the project, data analysis, and limited model application to provide an assessment. In addition, both cases used expert judgment to determine which issues needed to be addressed and which ones could be treated as secondary or not critical to the decision.

The evaluation approaches we have discussed are general. In practice each case has to be studied on its own, and the best approach (or approaches) chosen. For complex, large-scale interventions, such as the Bogotá BRT network, conventional practice is to run the entire model system in order to account for a relatively complete set of impacts across the entire region. However, for smaller scale changes, it may be adequate to apply only a sub-model, e.g. use a mode choice model to study the effects of fare changes on transit ridership, or use a network model to study the effects of adding a lane to a facility on travel times (or, in the case of Metrobús, removal of a lane.) It should be emphasized that most of the tools required are standard for transport planning and urban growth forecasting. If a good transportation and urban growth planning and analysis program is in place, the additional steps needed to estimate changes in fuel use and CO2 are to 1) add information on the vehicle fleet and its use and 2) add information on in-use fuel efficiency. These two steps can be approximated with national data if need be. If on the other hand the basic regional modeling systems are not developed, special studies can fill in. However, while they do require an investment, it is definitely advisable to develop good analysis methods and datasets, which will be used multiple times over.

E. Flags – What to Watch for Before, During, and After a Project is Completed

Every transport intervention has its own risks and pitfalls and even the best projects and project analyses may run into problems or raise questions. Here we address three important considerations: the accuracy needed for CO2 analysis, unintended side effects that may change the impacts from those predicted, and institutional capacity to fully implement the project as proposed.

i. Accuracy of the CO2 Estimates

How accurate do estimates and observations of changes in CO2 emissions need to be? The general answer is accuracy must permit observation or modeling of the impact of the intended measures against a relatively noisy background of transport activity and fuel sales. While Metrobús reduced emissions in the Insurgentes corridor by some 10%, that impact was well under 1% of the total emissions from land transport in the Mexico City region. That small amount itself is less than the typical annual growth in fuel use region wide.

Reducing uncertainty has a cost. Both Santiago and Mexico City are well-described by their emissions inventories. That meant that the cost of getting an accurate estimate of the CO2 savings was laid mostly to measurement and modeling of the actual transport intervention. For the more likely case that no such emissions inventory exists, it would be difficult to make accurate estimates. A good transport emissions inventory is valuable since it is built from many important transport data as well as fuel and emissions data. It would be hard to justify building such an inventory from measurements, models, and estimates only to measure CO2 savings,

especially for a single project, but certainly important to have such an inventory as a planning and evaluation tool that can be applied to many projects.

ii. Unintended Side Effects

A number of unintended outcomes may affect a project's CO2 emissions significantly, as well as overall project outcomes. A happy example is offered by Metrobús, where the successful project attracted more ridership than had been predicted.

The energy required to accelerate a vehicle depends on its weight. Therefore, adding passengers to a vehicle increases that vehicles' fuel use. Metrobús, an articulated vehicle weighing some 18 metric tonnes, can carry up to 160 passengers sitting and standing for a gross weight of 26 metric tonnes, implying 50 kg/passenger. (SMA, 2006) Thus the passengers of a full bus would weigh around 8 metric tonnes, slightly under half the weight of the bus itself. But Metrobús initial ridership exceeded all forecasts and so initially the buses were very crowded and used much more energy than originally estimated. (Eventually the authorities added 20 buses to the original set of 70 to accommodate demand.)

Another set of unintended consequences that are fairly common could be termed "leakages", essentially transfer of activity and emissions from the project area defined as a corridor or district to other areas outside the project boundaries. For example, the colectivos displaced in Metrobús could have found their way onto other routes, consuming fuel and continuing to emit CO2, but not actually increasing the number of passengers hauled on those routes. Since they were melted down, this leakage was prevented. In addition, Metrobús may have caused a large number of cars to avoid the Insurgentes corridor completely, which may have contributed to the observed drop in traffic on Insurgentes. Assuming these cars have been removed from the system when they may have only moved to other corridors would overestimate emissions reductions.

The "rebound" effect is another unintended consequence. When low emission vehicles are exempted from tolls, congestion fees, or parking charges, or permitted to use special lanes, there is a clear risk that drivers will respond to this lower cost of travel by traveling more.

Another example of an unintended side effect resulted from Hoy no Circula, the Mexico City campaign to restrict car use one day a week according to the last digit of the license plate. The goal was to reduce driving and thereby emissions of local pollutants. However, the number of used cars in Mexico City increased markedly as drivers who could afford to do so acquired vehicles with a different final digit than their primary car. With two cars now available to the household, driving and fuel use actually went up, and with it the very emissions that were supposed to be mitigated. (Eskeland and Feyzioglu, 1997)

Some of these effects probably could have been identified ahead of time with better analyses, consultations with experts, and reference to the literature. For example, the changed travel times on Insurgentes and other routes could have been used to estimate traffic diversion to parallel corridors (which would have required data on those corridors). Also, evidence from the literature would have revealed that previous attempts at vehicle-based no-drive days were met with exactly the same consumer response (buy more vehicles with different no-drive days). That is not to say that all consequences can be anticipated, but it does point out the value of analyses (and a review of the literature) in providing foresight.

iii. The Four P's

While modeling can help elucidate project impacts, model results are not a substitute for expert judgment in evaluating projects before, during and after implementation. In particular, evaluators must exercise judgment to assess whether the institutional capacity exists to successfully implement a project. Institutional capacity can be evaluated in large part by asking about four topics that begin with "P": policy alignment, practices, performance, and progress.

Are the *policies* in place to support the project? For example, the hybrid buses evaluated in connection with the Metrobús project offered roughly 20% savings in fuel and CO2 compared with conventional buses. Hybrid buses would also show savings on conventional bus routes. But if bus operators have no incentives to adopt advanced technologies or low carbon fuels, then analyses or even demonstration projects may be futile, as early experience in Mexico City with ethanol and compressed natural gas buses showed. And if fuel prices are relatively low, the fuel cost savings of more efficient vehicles may be too small to offset the costs of more efficient vehicles.

Is needed policy adopted as law and does it have popular support, so that it is likely to be longstanding, or is it dependent on the leadership of a particular mayor, governor, or staff member whose departure might lead to a change in policy direction? Are there countervailing policies, , e.g., tax policies that favor company cars but not employer-provided transit passes, or a planned ring road whose impact might offset that of a collective transport improvement serving the same area? Such questions can help gauge whether the project is likely to succeed in the long run.

Are the *practices* right? Is there institutional capacity for data collection, planning, implementation, traffic enforcement, emissions monitoring, and evaluation of projects? A good example is Mexico City, where authorities have been collecting ambient air quality measurements, measuring emissions from existing vehicles to enforce pollution rules, and keeping a record of light duty vehicle use. This practice meant that estimations of Metrobús impacts had a true "base line" to use. Santiago and Sao Paulo have similar inventories but most LAC cities do not. Good data and analysis capabilities allow cities to identify, develop, and implement needed projects on an ongoing basis.

Is the *performance* on target? Did the project or policy produce the expected results? In the short term, authorities have to be able to see whether the performance is close to expectations. In the longer term, targets (absolute or relative), benchmarks (comparisons with other similar situations/projects) or thresholds (minimum levels of achievement, i.e., X % modal shift or more) are needed to gauge performance, make adjustments as needed, and aim for continuing improvement. For example, on Metrobús, there was extensive bunching initially, with as many as five buses arriving at nearly the same time. Better dispatch routines were used to cure that problem.

Over the longer run, is *progress* being made? Is ongoing monitoring being done to make sure that accomplishments are maintained and or improved upon? For example, Metrobús surveys riders every year, both to gauge customer opinions about service and to understand how the system is performing, considering on-time performance and mode shift.

F. Summary

There are three parts to evaluation of changes in CO2 emissions resulting from transport interventions. First, projected changes in travel and transport activity have to be compared with a baseline where no project or other intervention is present. Then the impacts of the project on transport activities have to be estimated through a combination of modeling and data analysis. The estimated changes in vehicle activity are used to forecast changes in fuel use, which can be converted into changes in CO2 emissions. The last quantity is then compared with modeled emissions in the zone of influence or city wide to show the overall impact of the project on CO2 emissions. Additional iterations can help determine whether there are project changes or enhancements that would improve CO2 performance.

Models are an important tool for evaluating transport projects. Integrated transport-land use models are the most advanced formulation for demand analysis and can address the key factors shaping location and travel choice. Simpler demand models can be appropriately used for many evaluations, however, and sketch planning approaches also can provide good results in many cases. Special purpose analysis methods including traffic operations models are useful for evaluating alternative network design and control strategies. Life cycle analysis is increasingly being used to account for the "full costs" of interventions, especially constructed facilities and alternative fuels or biofuels proposals.

CO2 estimates require that the transportation impacts of a proposed intervention be combined with information on the vehicles and fuel used and the fuel intensity of each vehicle type. This can be done in several ways, from using fuel and emissions models that calculate emissions based on link level speeds, etc. to simple spreadsheet approaches that use simple VKT by mode and vehicle, fuel combination together with emissions factors.

Selecting the appropriate methods for analysis is in part a function of the proposed intervention and in part a function of resource availability. Understanding the way that different interventions affect location and travel can help identify the analyses that may be needed. Reference to the literature as well as advice from experts also can be useful in flagging issues and identifying important analysis methods. Many areas have used a combination of borrowed data and new field work and analysis to overcome shortages in models and data sets.

Analysts also are paying increasing attention to the risks of unintended consequences of projects, such as rebound effects.

While models and analysis are useful, they are only as good as the data that go into them. A serious commitment to integrating carbon considerations into transportation entails a commitment to improved data on travel, the vehicle fleet, and fuels.

Finally, analyses of project impacts are only part of the evaluation picture. An analysis that considers policy, practices, performance, and progress to assess the likelihood of successful implementation is a necessary complement to predictions of what a successful project would accomplish.

Road transport produces a high share of CO2 emissions in Latin America and the Caribbean, around one third of the total. These road transport emissions arise predominantly from the use of light duty vehicles. In LAC urban areas, light duty vehicles account for only 25-35% of travel, yet they contribute roughly 70% of CO2 emissions. As the economies of LAC cities improve,

light duty vehicle ownership and use in is expected to grow, and CO2 emissions from transport are expected to increase in turn.

Since light duty vehicles are the source of most CO2 emissions from transport in LAC urban areas, action to restrain or reduce transport emissions must deal with these vehicles –their efficiencies, their numbers, and the conditions under which are used. Important improvements in fuel efficiency can be fostered by fuel economy standards and higher fuel prices. Additional fuel savings and CO2 reductions can be attained by investing in traffic management, transit, and non-motorized modes. These latter investments can help slow growth in CO2 while at the same time significantly improving the quality of transportation available to the majority of the LAC population.

4. Conclusions and Recommendations

Road transport produces a high share of CO2 emissions in Latin America and the Caribbean, around one third of the total. These road transport emissions arise predominantly from the use of light duty vehicles. In LAC urban areas, light duty vehicles account for only 25-35% of travel, yet they contribute roughly 70% of CO2 emissions. As the economies of LAC cities improve, light duty vehicle ownership and use in is expected to grow, and CO2 emissions from transport are expected to increase in turn.

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A. A Framework for Incorporating Restraint of CO2 Emissions in Transport Planning and Policy

This report has presented a framework for incorporating CO2 considerations into urban transport decisions, so as to reap the co-benefits of CO2 restraint arising from good transport and urban development. The goal is to use carbon efficiently, to get as much good transport as possible from each unit of carbon used.

The framework is intended to help guide project selection and evaluation. The first step in this framework is to assess the scope and scale of measures authorities wish to undertake to improve transport. The scope can vary from a broad urban development strategy to a strategy for switching certain vehicles to low-carbon fuels. The scale can vary from the entire region to single corridor or small neighborhood or a small subset of all collective transport vehicles. Multi-faceted, large scale projects will usually require more sophisticated data and analysis methods than projects that focus on a single aspect of the transport system or a single area or corridor.

The next steps are to model or otherwise estimate the potential CO2 impacts of proposed strategies and interventions, monetize their benefits and costs, and compare them to the "business as usual" case. An important part of this analysis process is the identification and assessment of ways in which a transport project and its CO2 benefits might be enhanced. Once a final design for the project is agreed upon, measures of performance that can be monitored over time should be selected.

In this framework, savings in CO2 are measured in comparison to what otherwise would occur, without the intervention. For most transport interventions, CO2 will not be the decisive factor for a project even at a high value of each tonne of CO2, but its reduction can be an important co-benefit.

B. Estimating the Impacts of Interventions on CO2 Emissions in Urban Transport: "You Can't Master What You Can't Measure"

Many approaches are available for estimating the changes in CO2 emissions that arise from urban transport projects. The key tasks are to determine how the intervention is expected to change travel behavior trip making rates, trip distances, mode choice, and routes used, and to evaluate how these choices affect the flow of vehicles. These travel estimates are then used together with information on vehicle type and fuel type to calculate fuel use. The resulting changes in fuel use can be readily converted into changes in CO2 emissions. Regional transportation-land use models and detailed transportation vehicle fleet and emissions inventories are the "gold standard", but simpler methods also can be used to produce reasonable fuel use and CO2 estimates.

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When resources are limited, special studies can be used to estimate the changes in travel and vehicle activity and default values can be used to estimate fuel use/km. In general the transport data tend to vary much more according to local conditions. Nevertheless, if the urban region lacks data and models for transport analysis, or has no data on actual yearly vehicle utilization and fuel use/km, it is worth investing in these items, because they will be useful for many projects.

C. Recommendations

Chapter 1 presented daunting projections of a near quadrupling of VKT from light duty vehicles in LAC by 2030. Is the realization of this projection as "Business as usual" inevitable? We do not believe it is. However, changing course from trends-extended requires both short-term action and a strategy for the longer term. Lenders and other international organizations can have a strong influence on projects through advice and analysis, as well as support for local capacity building. Urban regions should focus more on longer-term development and transport interventions that avoid the high car use seen in business-as-usual forecasts, rather than yielding to those forecasts and permitting car-dependent development dominate, as is implied by the projections. Activities also could encourage and support activities that aim to "get prices right" and to manage traffic more aggressively. Such approaches are widely viewed around the world as the elements of "good transport" as laid out by the recent World Bank urban transport strategy.

To develop more sophisticated, substantial transportation interventions and to account for their full impacts, tools for planning and evaluation have to be strengthened. A better mobile sources inventory (as Mexico City has built developed in part with World Bank assistance) is one tool that allows local planners to see the transport-fuel-CO2 connection. Improved models and data both illustrate the transport or urban development advantages of better transport and show the direct benefits of a project as well as the co-benefits – CO2 savings.

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Reducing the growth in CO2 emissions from transport is <u>not</u> the biggest challenge transport and LAC urban planners and urban development authorities face. Inadequate transportation is still a problem for many of the region's people, especially the poor. Congestion chokes many urban areas, negatively impacting the economy, the environment, and public health. Addressing these transportation issues – achieving the "good transport" called for in the recent World Bank Strategy Paper – is the bigger policy challenge for transport and urban authorities.

Fortunately, the same policy initiatives and interventions needed to develop good transport services will yield CO2 co-benefits. Excellent transit, safe and convenient non-motorized modes of travel, and appropriate traffic management (including pricing) have been shown to moderate auto ownership and use in cities from all over the world - in LAC as well as in the EU, Japan, Korea, and even some US cities. By investing in these same transport services, it should be possible for LAC cities to slow the rise in CO2 emissions from their main source in urban transport, individual light duty vehicles. Combined with strong efforts to reduce the CO2 intensity of individual vehicles, the LAC region could see a considerably different evolution from the business as usual projects presented here. Taking on the development and transport challenges, as Curitiba, Bogotá and Mexico City have done, is clearly the first step. Technological changes are needed and will be valuable, to be sure. But even making every vehicle in the world CO2 free overnight will not meet the enormous challenge from urban transport today faced by every person getting to work, school, or shopping. It is for this reason that CO2 concerns must be integrated into larger transport and urban development trajectories.

The World Bank could encourage CO2 minimization in the following ways:

First, the World Bank could provide more technical assistance for travel surveys, traffic counts, emissions measurements, and fuel-use measurements. Good data are a critical building block for any evaluation and such data are needed to build better models for analysis and forecasting, not just for CO2 purposes but for a broad array of urban planning and economic development tasks.

Second, the World Bank could encourage and assist local authorities to develop modeling capabilities for travel demand, traffic operations, and life cycle analysis. Such modeling capabilities would enable more sophisticated analyses of growth, development, and travel, and also would enable more explicit and formal consideration of the longer-term impacts of World Bank-supported projects. This latter capability is important because road and transit projects might increase the ability of people to make longer trips and lead to, or reinforce, development in more distance parts of urban regions. Better analysis of system-wide changes due to projects could result in changes in project design to avoid undesirable side-effects.

Third, the World Bank could provide assistance to both local and national governments to evaluate strategies such as stronger fuel economy standards, stronger emission standards, congestion pricing, parking pricing, and tolls. Some of these measures may be politically difficult, yet they have been effective where used, with proven impacts on vehicle use, mode choice, and vehicle fuel intensity. Information on the benefits and costs of such measures could increase the comfort level with which such measures are regarded and over time could expand the kinds of choices local and national authorities make.

Treating CO2 considerations as a regular, required element of Bank plans, evaluations, and projects would signal the importance of action on the topic, and recognizing that many transportation projects reduce greenhouse gases from what would otherwise occur lays the groundwork for more vigorous action in the future.

5. 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.

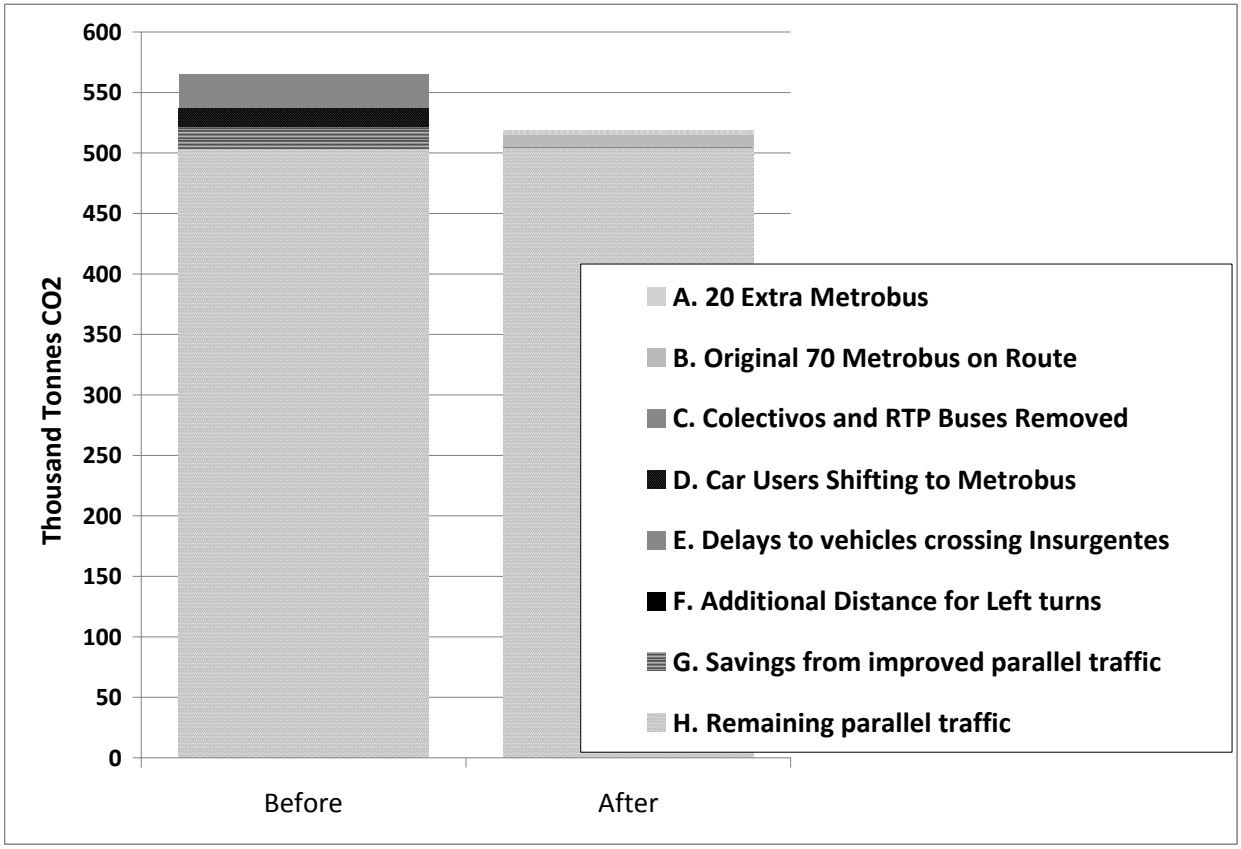
The Metrobús project undertook no specific measures to reduce CO2 related to vehicles or fuels other than the reduced fuel use from buses running in a protected BRT corridor. An option to acquire diesel hybrid buses for this project was evaluated. The hybrids would have saved only slightly more than 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	**15,610**

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.*	
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.[24] 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.[25]

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.

[24] INE did not monetize either the fuel saving or the CO2 co-benefits.
[25] 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.[26]

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,

[26] 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.[27]

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

27 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.[28] 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.[29] 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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[28] 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.

29 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.[30] 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.

[30] 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.[31] 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

[31] 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.

informative, the impact of such a price as applied to all or most vehicles in the same region should not be overlooked.

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).[32] However, Volvo Bus announced a lower-cost 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.[33]

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.

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[32] 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 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.

[33] 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.

iv. Hybridization of Colectivos and Taxis

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?*

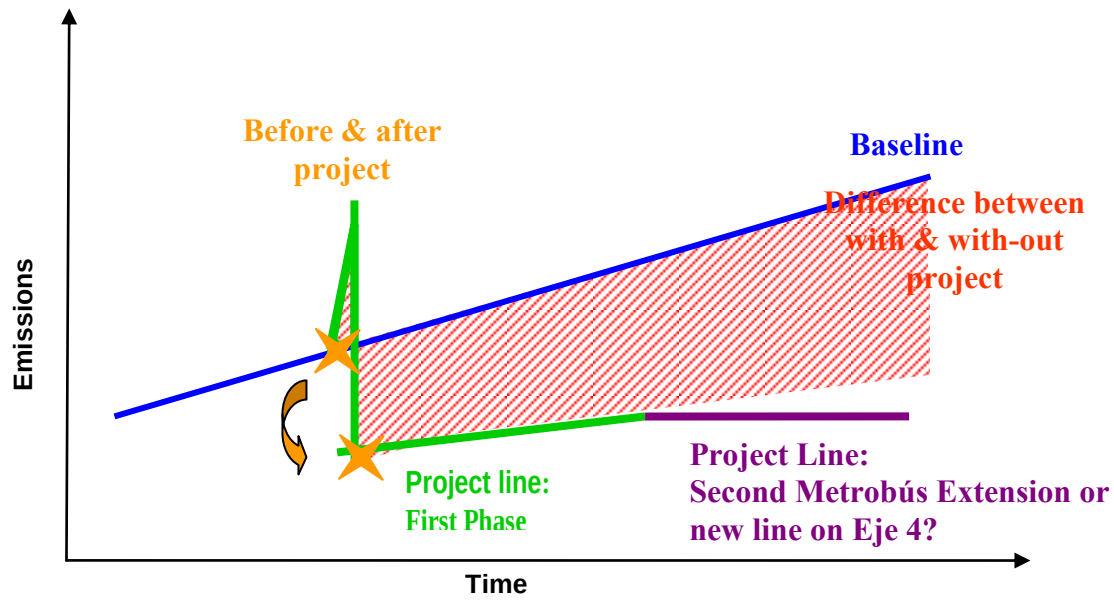
D. Longer Term Impacts

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.

6. 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	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.

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8. Glossary

ANL	Argonne National Laboratory
ANTP	Associação Nacional de Transportes Públicos
ASIF	aggregate travel activity, share of travel by mode, (carbon) intensity of fuel, and fuel use per kilometer, factors affecting transportation carbon dioxide emissions
BAU	business as usual
BRT	Bus Rapid Transit
CGTS	La Coordinación de Transportes de Santiago
CNG	compressed natural gas
CO2	carbon dioxide
COPERT	computer program to calculate emissions from road transport
CTS	Centro de Transporte Sustentable de México, A.C.
EJ	exajoule
ESTRAUS	Modelo de Equilibrio Oferta-Demanda para Redes Multimodales de Transporte Urbano con Múltiples Clases de Usuarios
EU	European Union
GDP	gross domestic product
GEF	Global Environmental Facility
GHG	greenhouse gases
GJ	gigajoule
gm	gram
IEA	International Energy Agency
INE	Instituto Nacional de Ecología
INEGI	Instituto Nacioncal de Estadística y Geografía
IPCC	Intergovernmental Panel on Climate Change
IT	information technology
IVEM	International Vehicle Emissions Model
kg	kilogram
km	kilometer
L	liter
LAC	Latin America and Caribbean (World Bank region)
LCA	life cycle analysis
LCSTR	Latin American and Caribbean Transport Unit, World Bank
LDV	light duty vehicle
LOS	level of service

LPG	liquefied petroleum gas
LR	light rail
M	million
MCMA	Mexico City Metropolitan Area
MJ	mega joule
mn	million
MOVES	Motor Vehicle Emissions Simulator
mpg	miles per gallon
MTOE	million tonnes of oil
Mtonnes	one million tonnes
NAS	National Academy of Sciences
NOx	nitrogen oxides
O-D	origin-destination
OECD	Organization for Economic Co-operation and Development
pass-km	passenger-kilometer
PITV	Plan Integral de Transporte y Vialidad
PPP	purchasing power parity
RTP	Red de Transporte de Pasajeros del Distrito Federal
SECTRA	Comisión de Planificación de Inversiones e Infrastructura de Transporte
SETRAVI	Sectretaría de Transportes y Vialidad
SMA	Secretaría de Medio Ambiente del Gobierno del Distrito Federal
STE	Servicio de Transportes Eléctricos
SUVs	sport utility vehicles
TAZs	travel analysis zones
TMIP	Travel Model Improvement Program
UC	University of California
UNAM	Universidad Autónoma de México
US	United States of America
USD	United States dollars
US EPA	United States Environmental Protection Agency
veh	vehicle
VKT	vehicle-kilometers of travel
VW	Volkswagen
WBCSD	World Business Council for Sustainable Development