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Measuring the Carbon Dioxide Impacts of Urban Transport Projects in Developing Countries

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ABSTRACT

All over the world, transportation projects are changing how people and goods move, with direct and indirect impacts on greenhouse gases emissions. Transport and environment officials, investors, and other stakeholders want to know how transport interventions will affect traffic, energy demand, and emissions. Estimating the impacts of projects involving fuel or technology switch is conceptually straightforward but still with its challenges regarding the reliability of available data and the capacity for data collection. Projects affecting modal share, load factors, origin and destination, number of passenger-kilometers driven, driving cycle and other parameters are a more complex proposition. Without reasonable measurement of results, decision makers hamper their ability to design effective control strategies and to monitor progress. This paper aims to present an overview of the challenges frequently encountered when estimating the impact of transport projects on carbon dioxide emissions; describes key approaches and methods commonly used; and provides examples from cities in Asia and Latin America. This paper is based on literature review, consultation with experts in the transportation, energy and emissions fields and on experience in developing emissions estimations for projects interventions in developing country cities.

INTRODUCTION

The movement of goods and people is critical for economic growth and social well-being. Improvements in mobility not only provide people with access to a broad range of socio-economic opportunities, but also have strong income effects by lowering transport cost and hence the prices of consumer goods and services.

Mobility demand has been shown to be directly affected by growth in population and incomes. In the past decade, the average global per capita income has increased by 26% and the world population by 20% (World Resources Institute, 2007) which translated into an increase in passenger mobility demand. Driven by continued strong population and income growth in developing countries, transportation demand is forecast to continue rising by an average of 1.8% per year between 2003 and 2050 (IEA, 2006; Schaefer and Victor 1997; WBCSD 2004). The growth in travel demand has a number of implications for energy use and emissions of greenhouse gases. Transport is the dominant sector in terms of oil consumption - it has accounted for nearly all growth in oil use over the past 30 years, and this trend is expected to continue (L. Fulton, 2004). At the global level, the transport sector accounts for 20% of global carbon dioxide emissions (World Resources Institute, 2007) and is the fastest growing contributor to global warming.

Since the 1992 Rio Summit and the Kyoto Conference of the Parties in 1997, pledges for reduction of carbon emissions have taken a national and trans-national character. More recently with the entry into force of the Kyoto Protocol in 2005, the Clean Development Mechanism and other agreements have been created as market-based instruments to promote greenhouse gas (GHG) emission reductions. The need to be able to produce credible pledges has generated much investment and effort in the development of methodologies to estimate emissions changes from projects. Parallel to the rapid growth in volumes traded in the Kyoto-based compliance carbon markets, a wide range of corporate and private voluntary off - set buyers have developed the Voluntary Carbon Markets (VCMs). The growth in VCMs is primarily based on the use of project-based emission reductions by proactive corporations setting self-imposed carbon neutrality commitments or offering low-carbon products and services. Again, measuring the results of such pledges is important for public relations and investor confidence, even if the pledges themselves are not binding.

In the developing world, few nations have taken on commitments or have introduced programs to reduce or restrain GHG emissions. However, a number of authorities have viewed such controls as an important co-benefit of programs to reduce traffic congestion, fuel consumption, or local air pollution. As multilateral and bilateral agencies have created technical assistance programs and funds aimed at supporting developing countries to create air quality monitoring systems, cities and countries have adopted policies and have taken steps towards reducing vehicle emissions, such as improving fuel quality, implementing vehicle standards and inspection and maintenance regimes, and undertaking traffic management and urban transport planning.

Transport and environmental officials, investors and civil society want to know how specific projects or policies might affect traffic, fuel use, and emissions. The objectives commonly cited are the evaluation of existing air quality control strategies; assessment of effectiveness of alternative policy options; planning and design of transport and air quality policies; public relations; and international obligations. However, vehicle emissions in most countries are not well understood and there is a very limited ability to make accurate future emissions estimates.

This paper aims to present an overview of the challenges frequently encountered when estimating the impact of transport projects on carbon dioxide emissions; describes key approaches and methods commonly used; and provides examples from cities in Asia and Latin America. This paper is based on literature review, consultation with experts in the transportation, energy and emissions fields and on experience in developing emissions estimations for projects interventions in developing country cities.

DETECTING RESPONSES TO THE CARBON CHALLENGE

Top down versus bottom up approach

At a national level, tracking total carbon dioxide emissions from fossil fuel combustion can be straightforward. Assuming fuel sales reflect actual use and the allocation of fuel consumption by sector is correct, The Intergovernmental Panel on Climate Change (IPCC) procedures permit a relatively accurate calculation of GHG emissions. Uncertainty arises from difficulties in the accountability of fuel stocks and the tracking of emissions from fuels purchased or smuggled from a different jurisdiction, state or country. When these issues are resolved at the national level, the analysis shows strong rising trends in emissions from land and air transport in almost every country, either over time or as a function of GDP, as Figure 2 shows below.

Unfortunately, the level of aggregation presented in Figure 1 is too high to reveal all but the largest and most dramatic changes in total fuel use at the national level, and unless those fuels can be assigned accurately to each mode (e.g., car, motorcycle, bus, etc), little more can be said about the transportation-fuel use interaction (Schipper, Price, Figueroa and Espey, 1993). In contrast to many OECD countries, virtually no developing country disaggregates transport sector fuel use by mode, only by fuel (i.e., gasoline, diesel, liquid petroleum gas, compressed natural gas, etc.)

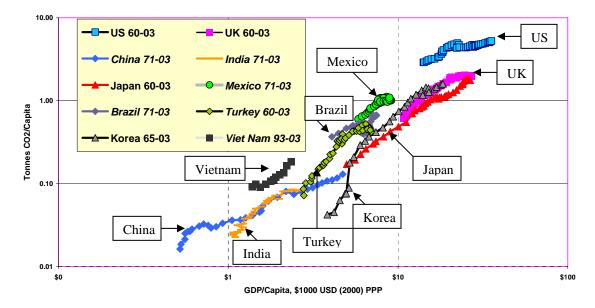


FIGURE 1 Fuel use per capita for road vehicles versus GDP per capita measured in Purchasing Power Parity for a variety of developing countries ((Source IEA and OECD national Accounts).

What happens if stakeholders wish to connect or attribute changes in GHG emissions to a particular project, technology, or policy? In the US, for example, there was a clear break in the relationship between transport fuel use and gross domestic product (GDP) at the national level after the imposition of CAFE standards (corporate average fuel economy standards) in 1978 and the big increase in fuel prices a year later. How much of this to attribute to the new standards, as opposed to the much higher fuel prices, is debatable (Greene, 1994). Unfortunately, most interventions are far smaller in scope and focused on a local scale, as more and more cities and states (like California) have made pledges to limit greenhouse gas emissions from transport and other sectors. In general, the kinds of interventions carried out at a local scale are invisible using national statistics or top-down fuel sales data.

One other point bears emphasis. In developing country cities, vehicle numbers are growing rapidly, and their patterns of usage are changing as cities sprawl outwardly and traffic grinds to a halt downtown and on major arteries. Hence, the "recent" data on vehicles, speeds, fuel, etc. may not reflect the real situation when an

intervention is imposed, and the interventions could succeed beyond the wildest goals yet not lead to an observed reduction in traffic or emissions, simply because the latter are growing so rapidly.

PARAMETERS THAT AFFECT TRANSPORT EMISSIONS

The transport sector encompasses of a diverse set of activities connected by the common purpose of moving people and goods. Broadly speaking emissions (G) in the transport sector are dependent on the level of travel activity (A) in passenger-kilometers (or ton-km for freight) across all modes; the modal structure (S); the fuel intensity of each mode (I), in liters per passenger-km; and a fuel's carbon content, which yields an emission factor (F), in grams of carbon per liter of fuel consumed. The relationship between these parameters is represented mathematically by the "ASIF" equation (Schipper and Marie 1999; Schipper, Gorham and Marie 2000) as illustrated in Figure 2.

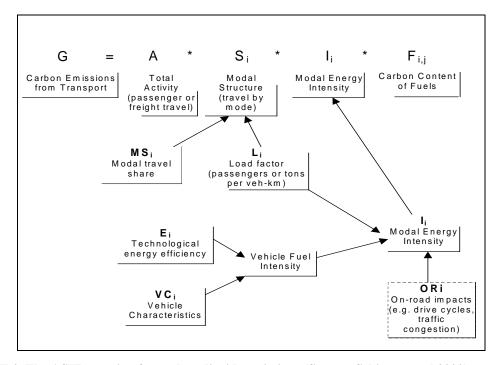


FIGURE 2 The ASIF equation for carbon dioxide emissions (Source: Schipper et al 2000).

The relative importance of each of the components to total changes in emissions varies with project type. The transportation system is highly interconnected and various policies, programs, and projects can directly and indirectly affect one or more of these components.

A - Passenger travel has increased in the past three decades and forecast economic and population growth will accelerate this trend. Freight haulage levels have increased substantially on a per capita basis. Land use and urban growth patterns also have a determining influence on travel distances. Most observers agree that without a substantial shift in vehicle-km per passenger, large cuts in emissions cannot be achieved from urban transport projects. Interventions that affect load or km run to satisfy a specific travel demand can have a very strong impact on emissions – moving more people in fewer vehicles reduces emissions. It is common to encounter inefficient public operation of urban transport systems where the ratio of supply and demand is not optimized. Great savings on emissions and km driven can be obtained with improvements in system operation and route design.

S - Modal structure represents the share of total travel by mode (in %). Because fuel and emissions per passenger-km (I) differ by more than a factor of ten between a large loaded bus or train with a modern engine

and an old, large car with only one occupant, shifts in travel or traffic from one mode to another have an important impact on overall emissions. Choices of mode are affected by the availability of transport modes, speed and travel time provided by each mode, prices of fuels and vehicles, income, legislative and fiscal policies in effect, personal security, and social/psychological dynamics. Care should be taken when designing public transportation systems, as the measures favoring modal shifts are not always as effective as planned in terms of fuel savings and emissions abatement, because of impacts on surrounding traffic, induced demand, modal shift from non-motorized to motorized transportation, and the development of new residential areas along transport routes. This last possibility can have ambiguous effect on overall traffic and emissions, however: it could reduce commuting distances and encourage less car use, or it could attract many new residents, leading to a population boom that overwhelms the system.

I- Modal energy intensity (in fuel and emissions per passenger-km) is linked to vehicle technology and driving cycles. Vehicle technology is in turn influenced by vehicle emission standards, income levels and fuel and vehicle costs. Income growth may affect energy intensity of vehicles as older units are replaced by newer, more efficient ones. Countries with relatively high fuel prices tend to have more fuel-efficient automobiles, which are also driven less (Schipper et al. 1993). In the 1970s and 1980s, fuel intensity of cars in North America plummeted, but then remained constant since the early 1990s. By contrast, fuel intensity of cars in Europe initially declined slowly, but that pace picked up after the Voluntary Agreement on carbon dioxide emissions per km of the late 1990s (IEA 2004). A new EU agreement mandating even lower emissions - 120 gm/km – is now in final negotiations. On-road fuel economy is affected by road conditions and congestion levels – worse congestion means worse fuel economy. This may in turn affect activity (A) due to induced demand: a substantial reduction in congestion, as observed in Mexico City's *Insurgentes* BRT Corridor (Rogers, 2006), could lead to *more* car trips if speeds increase sufficiently.

Finally, \mathbf{F} , the carbon content of fuels has changed very little in most regions, except in Brazil where sugar-cane based alcohol now accounts for 40 % of automobile fuels. Many so-called biomass fuels are associated with considerable releases of carbon dioxide during harvesting and preparation that may offset most or all of the GHG emissions from the fuels replaced. Other alternative fuels from coal or gas also have the potential to increase the carbon intensity of transport fuels, giving impetus to European Union and Californian initiatives to create performance-based GHG emissions standards.

DATA SOURCES

Vehicle Numbers and Distances Traveled

Most developing countries have records of the number of motor vehicles usually taxed and registered at the national level and aggregated by state or city. However, registration happens only once, such as when the vehicle is purchased or imported legally. Because few countries or jurisdictions levy yearly taxes, there is almost no way to distinguish between vehicles registered and actually in-use. Consumer or household surveys give some indication of the ownership of cars or two-wheelers, but in low income countries a large fraction of "cars" are not owned by households.

Whereas the utilization of vehicles in fleets (buses, delivery vehicles, taxis) is usually recorded carefully by owners or managers through fuel receipts, direct measurement, financial records on fuel expenditures; the usage of the vast majority of cars, two wheelers, and three wheelers (in Asia) are simply not recorded. Police, insurance, and manufacture warranty records could provide enough information to reconstruct patterns of overall use; but to our knowledge no one has attempted this yet. The only regions of the developing world where data on vehicle use is available are where yearly inspections are required and odometer settings carefully recorded, such as in Mexico City (Rogers 2006).

One import tool developed to deal with this problem is the vehicle activity survey carried out by the International Sustainable Systems Research Center in Diamond Bar, California (ISSRC). The International Vehicle Emissions Model was built using surveys of vehicle stocks, utilization, and driving cycles in over a dozen cities around the world, and measurements of fuel use and emissions in half of them (ISSRC, 2007). A key feature of the ISSRC approach is that it can observe vehicles and traffic in the zone of influence of a project

and compare activity with other places in a city, to measure changes in speed, acceleration, and other traffic characteristics before and after an intervention has taken place. By observing the license plates and odometer readings of hundreds if not thousands of vehicles, the exact age and distance driven of each vehicle can be determined by authorities. The results give a general curve of utilization as a function of the age of the vehicle, which can be extrapolated to represent the entire fleet.

Fuel Consumption and Sales Data

Except for well defined, centrally operated vehicle fleets, transport sector fuel consumption is physically difficult to collect due to the highly decentralized decision making process for transport activity. Because transport is closely linked to practically all other economic activities, it is extremely complex to forecast the trajectory of transport-related carbon dioxide emissions for a given situation. In fact, almost all official fuel "use" data are from reported fuel sales. Unfortunately fuel sales data, usually inferred from fuel tax receipts, are often underestimated due to tax evasion. In addition, it is not always easy to know what amount is used for transportation or to define the regional boundary for fuel use. Regional differences in fuel tax policies and vehicle registration requirements can cause distortions in the regional data on fuel use and vehicle ownership as well.

Even if fuel sales in a region were known, inaccuracies could be larger than expected results from projects, masking the project's impact. This is because some fuel sold in a given region may not be consumed there due to regional price differences, traffic transiting a region, or even fuel smuggling or adulteration with unknown fuels. The most infamous example is Luxembourg, a city-state whose low fuel taxes attract drivers from surrounding countries, giving Luxembourg one of the highest per capita sales of road fuels in the world yet no signs of abnormally high consumption by residents. Singapore has imposed sanction to combat this evasion – cars may not leave with nearly empty tanks and fill up on cheaper fuel in Malaysia. But in much of the United States and Europe, fuel prices across state lines differ modestly just as between expensive downtown areas and more distant suburbs. Even if price differences do not generally drive cross border sales as much as noted above, they still mean that fuel is frequently not consumed where it is purchased, introducing potentially large errors in measuring carbon dioxide emissions from road transport.

Above all, projects affect only a small amount of overall fuel sales in a region, often within the limits of the uncertainties and distortions noted above. Thus, we must rule out changes in region-wide fuel sales as any kind of reliable guide to measuring changes in vehicle use unless a region has been subject to such radical transport projects that a large reduction in automobile use has occurred.

The most reliable fuel use data are developed by surveying large numbers of vehicle users (Schipper, Price, Figueroa, and Espey 1993; IEA 1997). By tracking fuel purchases and distances driven over a period of time, reflecting both the typical vehicle use and several fillings of the tank, an accurate picture can be extrapolated to the entire vehicle stock (if known), yielding both utilization profiles and fuel consumption of the vehicles. The two broadest of these are carried out at the national level every few years by the Australian Bureau of Statistics and yearly by the Dutch Central Bureau of Statistics. Unfortunately these are exceptions; few other developed countries survey motor vehicle fuel use to derive the energy intensity for each class of vehicle. Given the many kinds of vehicles and even greater number of makes and models, the most one can hope to estimate is the average fuel consumption per km for all vehicles of a given kind, based on a stratified sample of cars by vintage, make, model, engine size etc. Canada's National Private Vehicle Use Survey (NRCAN 2006) represents a typical survey where drivers record their distances and fuel consumption during a number of weeks, often during a warm part of the year and again during a cold part of the year.

Surveys in some OECD countries have measured average fuel consumption by asking drivers to fill out diaries recording both fuel use and distances driven, and so obtain yearly averages (Schipper, Price, Figueroa and Espey 1993). But that average has significant variation due to the "driving conditions". Tests of vehicles usually give different results from those obtained by ordinary drivers in day-to-day traffic; this is the so called "mileage gap" that appears in averages listed for new vehicles (Schipper and Tax 1994). Needless to say, the instantaneous consumption varies even more, hence without detailed measurements it is hard to say how much fuel is consumed by a group of cars driving on a given stretch of road or even within the zone of influence. In addition, the actual condition of the car's engine affects fuel intensity. Because of these problems,

it is virtually impossible to estimate on-road fuel intensity for cars (or two wheelers) in developing countries where the mix of cars, their test fuel economy, actual driving conditions, and the condition of the vehicles is so poorly known.

Alternatively, individual cars could be metered continuously in real traffic or on a dynamometer to measure actual fuel consumption second by second under tightly specified driving conditions. Either way, there is significant variance in the results for fuel economy for virtually identical cars, not to mention an entire sample of cars metered or surveyed. In the final analysis, the only way to arrive at some kind of average fuel economy is through on-board tests of different kinds of vehicles under average operating conditions, coupled with a large survey of vehicle users and fleets to get recorded distances and fuel purchases. A modest number of on-board tests coupled with a large survey ought to pin down the key fuel intensities of typical vehicles and yield information on average driving distance.

Emission factors

A carbon dioxide emission factor can be calculated using the standard IPCC coefficients to convert fuel (or electricity) consumption to carbon emissions. Emission factors can also be produced by emissions models if specific fuel characteristics are known, based on the carbon content and heat rate of the fuel. Emissions models can also provide emissions estimations once activity data is provided as an input. Further information is provided below.

EMISSIONS IMPACTS FROM TRANSPORT INTERVENTIONS

Let us assume we are satisfied with the data and set of estimation procedures as giving a good enough picture of the link between transport activity and emissions. What do we need to do to measure how a transport intervention would change carbon dioxide emissions?

Definition of project boundary

The project boundary can be defined by the scope of influence of the developer; or by the area within which secondary traffic effects have a significant impact on emissions. If the impact of a project on the surrounding traffic is considered negligible, or within the margin of error of the measurement method, this can be dismissed, or a conservative assumption of its magnitude can be made. However, upstream and downstream emission leakages must be explicitly acknowledged.

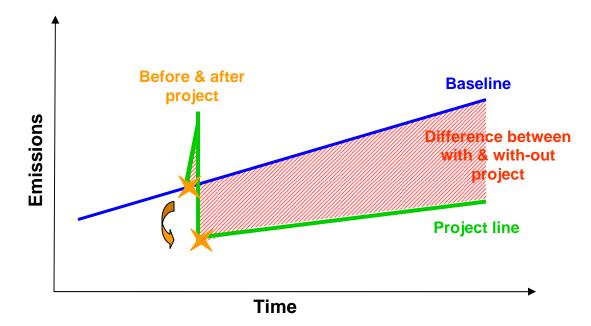
The impact on non-project vehicles and people can be difficult and expensive to calculate. Emission changes may occur "Upstream", related to how different vehicle are manufactured, different fuels are produced, or the emissions inbuilt on construction materials. For instance, the substitution of petroleum based fuels per CNG brings different greenhouse gas upstream emissions. The need to build infrastructure also has an emissions cost. A number of life cycle models have been developed to model these effects (Wang 1999; Delucchi 2002). These models can be used to gain an understanding of their relative importance but would need local data to estimate the size of any particular effect in a specific country. For lack of space we do not consider them here, but note where they could be important. Another component of leakage may be the unanticipated changes in traffic or travel outside the project boundary, such as traffic that could be induced by the reduction in congestion from a project like BRT or changes in travel pattern of the surrounding traffic.

One may decide to ignore the secondary effects, but experience in some cities indicates that the impact on emissions can be significant and constitute an increase or a decrease in overall emissions, as illustrated in the estimation of the impact of Metrobus BRT in Mexico City (see case study below). This suggests that even a rough estimation can help assess the magnitude and significance of secondary impacts before big investments in measurements are made.

Definition and comparison of baseline and post project emissions

Once the project boundary is defined, snapshot emission estimates can be calculated for before and after the project. Emissions five or ten years after the project implementation may be higher than before the project was undertaken, yet less than if the project had not been undertaken, i.e., the without project scenario. Needless to say, the with/without project estimation offers a more comprehensive understanding of the short, medium and long term impacts of the project, but adds to the complexity of the estimation due to forecasting uncertainties. To paraphrase Niels Bohr, predictions are risky, especially those about the future.

The parties making traffic and emissions predictions must agree to the time frame and treatment of unforeseen, exogenous events. These exogenous variables include major demographic shift; changes in the national rate of economic growth; unforeseen rapid development raising traffic in one mode or another; and unforeseen political events that severely perturb traffic in the zone of influence. The results should be presented relative to an appropriate index to ensure that the emissions are not underestimated or inflated by variables such as population and economic growth which are influenced by exogenous events and trends.



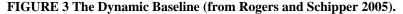


Figure 3 shows the "without project" scenario, frequently called the dynamic baseline, which is based on a forecast accounting for some or all of the exogenous factors mentioned above. The discontinuity in the "project line" represents the possibility that, during the actual project, construction work could severely perturb traffic, leading to delays and detours and temporarily increasing overall emissions. The emissions in the project line grow slower than the projected "without project" emissions, which indicates that the impact of a project is compounded over time, though actual emissions after the project may eventually *surpass* initial pre-project emissions. This illustrates the importance of using the with/without approach instead of the simpler before/after approach for estimating the impact of a project on emissions. The complex nature of transport activity forecasts and the likelihood of unforeseen perturbations makes it difficult to estimate what would have happened, with what emissions, had no project been implemented.

The calculations can be done ex-ante or ex-post depending on whether the goal is to estimate or monitor the impact of emissions. With the ex-post analysis, it is necessary to predict what the emissions would be if the policy had not been introduced (see Bogota case study below). Over a short period of time, it is possible to make this prediction by extrapolating trends rather than with doing detailed regional modeling. However, many policies will take a number of years to take full effect so it may not be possible to keep the time frame of the analysis very short.

Transport models

Traditionally, transport planners use models to estimate emission-producing activities like the number of trips, vehicle miles traveled, and speeds, as well as the spatial distribution of the resulting traffic over the transportation network (See Singapore and Hanoi case studies below).

Classical transport demand models include four main steps: generation, distribution, modal choice and assignment. Once these steps have been executed, the resulting traffic can be simulated on a transportation network. The 4-step travel demand modeling approach that has been used worldwide since the 1960s has been helpful for transport and land use planning at a regional level, typically an area that includes a large city and the surrounding suburbs and satellite cities. The 4-step demand modeling approach addresses some short term behavioral changes such as car or vanpooling versus driving alone and modal choice but does not address behavioral changes such as driving characteristics; route choice; peak spreading; rescheduling; trip chaining; induced and suppressed demand; changes in types of vehicle owned and used; and changes in household and business location. In addition, due to its high aggregation level, this approach can cause significant bias. Model disaggregation involves reducing the size of spatial, temporal and demographic categories used in the models, enabling them to more realistically represent transport user behavior.

Macroscopic models are the dominant type of assignment model and have been used for decades to estimate travel demand. Macroscopic models do not take into consideration the behavior of individual travelers during their journey, cannot deal with localized capacity constraints, are not sensitive to delay and queuing patters, acceleration or deceleration events, etc. As a result, macroscopic models cannot be used for congestion management and facility design. Mesoscopic models consider traveler behavior while microscopic modeling enable detailed analysis of almost all aspects of an individual trip. Activity-based models create a simulated population and create individual activity tours for each member of the simulated population. The modeling research community has been moving towards disaggregation while practitioners pursue a diversity of modeling approaches, depending on their application. Microscopic level modeling is not suitable for large regions as it would be prohibitively data intensive and it would increase calibration challenges. Microscopic level modeling has been applied at the interchange and corridor level.

Most transport projects lead to small changes in traffic patterns, speeds, load factors and other determinants of changes in fuel use and emissions. While these may be important within the project itself, they tend to be small compared to overall emissions and traffic region wide. Moreover, for many kinds of projects (BRT, one way streets or signal timing, etc) there is an impact on the vehicles outside the project boundary. While city-wide transport models might predict the changes such projects cause, the uncertainties in the model results for the entire city are large compared with the expected results from the project alone. This indicates that it is important to use more advanced modeling methods when policies of interest become larger in scope and/or effect; the geographical area of interest becomes larger; the time horizon becomes longer; policies become less focused on simple supply changes and more on pricing, demand management, or economic incentives/penalties; and when the future is anticipated to bring large exogenous changes (e.g. fuel prices, technologies, economic growth/decline, etc.).

It should be noted that more advanced models typically cost more to create and implement. Cities and practitioners may resist the introduction of a new model as this often requires additional time, human resources and financial investment. The network model requires detailed data on road capacities, travel speeds, and traffic count data, while travel demand modeling requires detailed data on the locations and characteristics of households, employment, and schools in the region. The local availability, quality, and cost of collecting these types of data is clearly an important consideration when having to choose a simple or more advanced model. When similar models have been estimated in fairly similar regions, it may not be necessary to collect detailed household survey data and develop new models from scratch. One can start with the parameters of models estimated elsewhere and calibrate them to match local aggregate data such as traffic counts and transit passenger counts at specific locations. As models become more disaggregated the transferability should be even greater. It is questionable, however, whether model parameters can be transferred across cultures. It is always best to have some local behavioral data, even if that is from a limited survey focused on a particular policy context.

Emissions Models

After the vehicle activities that cause emissions have been estimated the next stage is to determine a set of activity-specific emission factors that specify the rate at which the emissions are generated for each of the emission-producing activities and the emissions levels. As described previously the IPCC provides default emission factors. When the characteristics of the fuel are known this can be input into an emissions model.

The U.S. Environmental Protection Agency (US EPA) has developed a series of emission factor models called MOBILE that are the only EPA-approved models. They are required for preparing state implementation plans (SIPs) and for conformity analysis, and have been used in the past three decades to produce emissions factors used in air quality analysis. The MOBILE model series offer highly aggregate fleet estimates and average emission rates that are not specific to the fleet in operation, mode of operation or grade of the highway facility. These emission factor models are not suitable for interface with transportation meso and micro-simulation models and have some limitations when assessing the impact of traffic flow strategies that affect speed, idling, or acceleration characteristics of vehicles. New vehicle technologies and fuel alternatives cannot be readily incorporated.

The US EPA's Office of Transportation and Air Quality (OTAQ) is developing a modeling system termed Motor Vehicle Emission Simulator (MOVES). This new system will estimate emissions for on-road and non-road sources; cover a broad range of pollutants and GHG emissions; and allow multiple scale analysis. MOVES was developed to address the National Research Council recommendations and the evolving needs of users, and uses a model binning approach to allow better resolution of emission implications of transport changes. Energy consumption and GHGs will be modeled within this framework. However, sources of GHG are still less reliable especially at a regional or city level. When fully implemented, MOVES will serve as the replacement for MOBILE6 and NONROAD. It should be noted, however, that currently the default databases do not have specifications for driving cycles from non-US vehicles.

Other examples of emissions models developed in the US are Mobile Emissions Assessment System for Urban and Regional Evaluation (MEASURE); Comprehensive Model emissions Model (CMEM). Examples of emissions models developed in Europe are: the European Environment Agency COPERT series, developed to estimate on-road emissions to be included in the official national inventories for the EU Member States; and the German-Swiss model.

Measurement approach

A measurement approach can also be coupled with passenger surveys (See Mexico City case study below). The measurement approach is only likely to be valid over a fairly short time frame, however - perhaps up to five years – as it does not take into consideration exogenous changes that may occur in the region that will affect emissions resultant from the project; and it assumes that the project does not affect land use development patterns within its area of influence. In addition, one concern raised is that it has no provisions to discern the impact of traffic displacement, and corresponding emissions, beyond the project boundary. Even if measurements are performed in a control route this route may be affected over time by exogenous changes, that are not accounted for with this approach.

A Tale of Four Cities – Singapore, Hanoi, Mexico City, Bogota,

Singapore

Singapore's Land Transport Authority (LTA) is a statutory board under the Ministry of Transport that manages land transport development in Singapore (LTA, 2007). Transport management policies have been implemented as early as 1973 to address the two major challenges faced in Singapore: land scarcity and the high aspiration to own private motor vehicles. Numerous vehicle and transport management measures have been implemented such as the Vehicle Quota System, Electronic Road Pricing, Off-peak Car Scheme, Classic Car Scheme, Private Car Rental Scheme, and Vehicle Entry Permit Fees and Tolls. These include prevention, enforcement, monitoring, and education strategies, all with the same goals of controlling vehicle population growth in order to prevent serious traffic congestion and deterioration in ambient air quality.

Effective transport management models and tools, heavily dependent upon Intelligent Transport Systems (ITS), are used to monitor and control traffic flow and to measure transport activities. Surveys are also used as a data source, in addition to the Expressway Monitoring Advisory System (EMAS), loop detectors, and surveillance and detection cameras. The LTA's models are designed for economic evaluation, using multi criteria. One parameter considered is time efficiency, which implies a cost-benefit analysis that takes travel time saving, value of time (wage rate), vehicle operating cost savings, and accident cost savings into account. Other aspects of the models are emissions, opportunity cost of land development and visual intrusion. Transport models are mainly used to estimate impacts, benefits, and drawbacks of transport projects. They are used for both ante and post project implementation review and are regarded as a type of evaluation technique. Transport emissions are often assigned the lowest priority in the cost-benefit analysis based on such models.

Since good traffic data are available, the models are used to estimate total daily distance traveled based on modal splits. Travel demand forecast is another application of the transport models used in Singapore. Additionally, OD household surveys are conducted once in every 5 years, and focus on transport behavior, speed, distance, and transport mode. Data are used to manage existing traffic conditions on a day-to-day basis. Transport models are used to forecast the impact of changes in demand and supply, such as of road improvements, e.g. when changing one-way streets to two. Since there are few diesel cars, and since fuel tanks of cars crossing the border to Malaysia are routinely checked, Singapore can relate gasoline fuel sales to its stock of gasoline two- and four-wheelers and estimate fuel intensity of key vehicles relatively easily.

Hanoi Transportation Master Plan Methodology, Vietnam

There are a number of cities in the world with transportation Master Plans. While this is a very good starting point, most of these master plans still omit environmental impacts. Hanoi requested the support of *EMBARQ* to provide an estimation of the impact on emissions of alternative transport strategies proposed in the City's Master Plan. Hanoi's Transportation Master Plan covers total road transport including walking; bicycle; motorcycle; car; truck; bus; and urban rail; and lays out two stark alternatives for Hanoi's transportation system, one based predominantly on motorcycles and cars and only 14.5% of trips provided by public transportation - the 2020 Business as Usual Scenario (BAU) -, and another with a 30% trip share – the 2020 High Mass Transit Scenario.

EMBARQ applied the ASIF approach to estimate direct emissions resultant from combustion processes, using the transport activity data provided by the Hanoi Transportation Master Plan, making assumptions on fuel use per km based on local knowledge and used a carbon balance to determine the carbon dioxide emissions factors. Figure 5 shows the results for carbon dioxide emissions with the underlying fuel use by transport mode for 1995, 2005, and 2020. The BAU and High Mass Transit scenarios are split into variants representing differing (and progressively improved) vehicle emission standards.

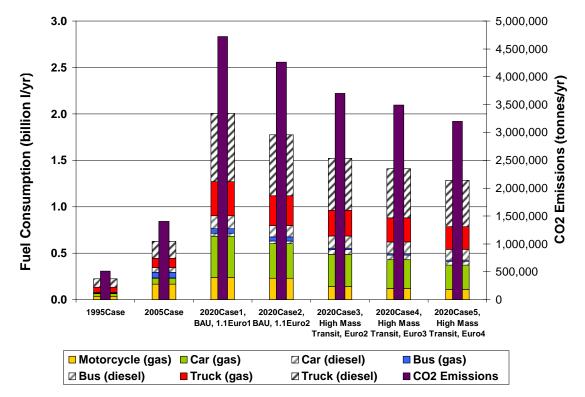


FIGURE 5 Fuel use by vehicle mode and total carbon dioxide emissions.

The total fuel consumption triples from 2005 to 2020, both because of the growth in truck traffic and the increasing presence of cars, which use considerably more fuel per passenger-km than motorcycles or today's buses in Hanoi. Fuel consumption for cars and motorcycles is lower in the High Mass Transit scenarios both because of the introduction of more fuel efficient cars and higher levels of fluidity when compared to BAU thanks to a higher percentage of the people traveling by public transportation reducing congestion.

It should not be any surprise that fuel consumption in the High Mass Transit scenario, even coupled with the stringent vehicle emissions standard, is still higher than fuel consumption in 2005. The huge increase in car and truck traffic is the chief culprit behind the rise in carbon dioxide emissions from 2005 to 2020. Indeed, motorcycle use is already so widespread that the increases in their emissions are modest. Although we do expect all vehicles to become more fuel efficient in the cleaner scenarios, the disproportionately large increase in car use outweighs the expected gains in fuel economy and drives total emissions up. Bus emissions increase, mainly because of the great increase in the level of bus activity. Note that emissions are lower in the High-Mass Transit scenario because we have assumed buses are well organized into a BRT system with fewer emissions per passenger-km, and slightly fewer total bus-km, in spite of considerably more pass-km on buses.

Carbon dioxide emissions depend on fuel type. While diesel vehicles tend to be more efficient than their gasoline counterparts, diesel fuel is denser than gasoline and each unit of energy contains more carbon, meaning that burning diesel instead of gasoline in small vehicles produces only a small net reduction in carbon dioxide emissions. In the same vein, diesel vehicles are more efficient than gasoline/spark congestion at pulling large loads, which gives them a great advantage over gasoline or compressed natural gas for heavy vehicles.

Emissions inventory and impact of Metrobus BRT on emissions, Mexico City

Mexico City lies in an isolated basin, at high altitude, surrounded by mountains. This coupled with a large population and high amounts of traffic leads to serious air pollution problems. Mexico City's most recent vehicle emissions and fuel use inventory of 2004 used the models MOBILE5-MEX and MOBILE 6.2-MEX for particulate matter and toxics measurement, and derived SO₂ and carbon dioxide levels from fuel sales. Data required for the vehicle emissions inventory included fuel sales to estimate fuel consumption; fleet size, age and

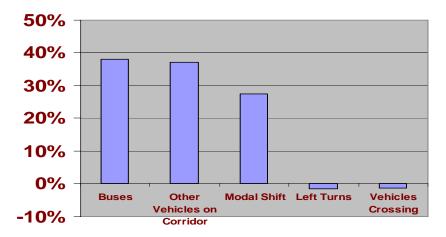
technology derived from vehicle inspection and maintenance programs (I/M), vehicle activity, and emissions factors. Private car activity data were obtained from odometer readings in I/M programs.

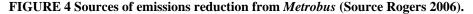
These data require extensive filtering due to mechanical problems. As for emissions factors, the Instituto Mexicano de Petroleo (IMP) calculated HC, CO and NOx emissions factors and only straight averages were used. Emissions factors were not weighted by fleet composition and no adjustments by total kilometers or test date were performed. Unfortunately the 1994 Origin-Destination survey did not contain useful information on vehicle use, and the more recent survey is not yet available.

All the data collected was analyzed and used as MOBILE input data, which also included average speed, ambient temperature and altitude, humidity and solar load, air conditioning, automatic transmission, mileage accrual, evaporation factors, cold start, and anti-tampering. US default factors were used for humidity and solar load, evaporation factors/cold start and anti-tampering input data. While the bottom-up totals for fuel consumption do not match sales exactly, the agreement is good enough to give a fair ASIF breakdown for all components of emissions (Schipper and Golub 2003).

A recent project in Mexico City called *Metrobus* installed a BRT corridor along Mexico City's central *Insurgentes* avenue. This system replaced 262 microbuses and 90 buses with 97 larger buses (160 passenger capacity). The new buses use 60% less fuel than the smaller ones without sacrificing passenger carrying capacity. Rogers (Rogers 2006) estimated that *Metrobus* saves 46,500 metric tons of carbon dioxide per year. This analysis was done based on ex-ante and ex-post measurement of traffic activity levels in the project corridor, obviating the need for modeling. The velocity of the vehicles along *Insurgentes* was measured using cameras to record their passage between two points. Changes in idling time could be inferred from changes in velocity and in this way account for fuel losses from increased congestion or vice versa.

As figure 4 illustrates, Rogers found that nearly 40% of the emissions reduction came from changes in bus size and technology. The fact that traffic in the corridor improved despite the loss of a lane in each direction to the BRT might be surprising. Rogers attributes this improvement to the elimination of hundreds of minibuses that constantly blocked traffic, resulting in less congestion. Rogers found that another 40% of the emissions reduction came from changes in the private vehicles in the affected corridor; and nearly 30% of the reduction was due to modal shift. The introduction of the BRT corridor increased emissions by 3% due to the imposition of left-turn restrictions that forces traffic onto somewhat circuitous right turns, and due to some hindrance of traffic crossing *Insurgentes*.





When possible, such an approach is clearly preferable in terms of simplicity and verifiability. This measurement approach is only likely to be valid over a fairly short time frame, however - perhaps up to five years – as it does not take into consideration exogenous changes that may occur in the region that will affect emissions resultant from the BRT corridor; and it assumes that the BRT corridor does not affect land use

Transmilenio BRT Methodology, Colombia

Gruetter Consulting (2006) applied an ex post approach to estimating the impact of *Transmilenio*, the Bogotá BRT system on carbon dioxide emissions. Gruetter defined the unit of saving by trip, and compared the number of trips taken by travelers on the BRT System with trips they would have taken in the pre-BRT era either in smaller minibuses or cars. Passenger surveys supplied information about prior transport modes and an indication of the fuel type and fuel efficiency of the cars they left behind. Gruetter considers secondary traffic effects (e.g. interference with other traffic, induced use, etc) to be a minor consideration, but includes conservative default values to represent them anyway. Gruetter advocates estimating changes in load factors of buses and taxis that might lose passengers to the new BRT. Gruetter's method is the first and only methodology approved for certifying carbon dioxide savings in BRT projects under the Clean Development Mechanism, to date.

CONCLUSIONS AND RECOMMENDATIONS

The transport sector is the fastest growing contributor to global carbon dioxide emissions. Government authorities, investors and civil society worldwide are aware of the urgency to devise policies and implement measures that mitigate the rate of emissions while still providing the much needed transport accessibility to the population. In order to compare options and monitor progress it is important to quantify the impact of transport interventions, and this has proved to be challenging.

Our analysis shows that to detect the impact of transport interventions on emissions we need the granularity offered by a bottom up approach. The methods and data used to estimate emissions and fuel consumption at the national level are generally not sensitive to the implementation of a transport intervention at the municipal level. Transport activity, fuel efficiency and emission factors need to be tracked within the project boundaries. It should be noted that currently most developing countries lack reliable data and this is a major barrier to accurate emissions estimation. To ensure completeness and transparency in the calculations it is vital to explicitly acknowledge upstream and downstream emission leakages.

The impact of a project is felt across time and therefore there is a need to analyze future emissions with and without a transport project instead of simply providing a before and after snapshot. This is particularly important in developing country cities experiencing rapid changes in vehicle numbers and modal share. The comparison of the with and without project emissions should be presented relative to an appropriate index such as emissions per passenger. This ensures that the emissions are not underestimated or inflated by variables such as population and economic growth, which are influenced by events and trends exogenous to the transport project.

The calculations can be done ex-ante or ex-post depending on whether the goal is to estimate or monitor the impact of emissions. Over a short period of time, it is possible to make this prediction with a trend extrapolation rather than with detailed regional modeling. However, many policies will take a number of years to take full effect so it may not be possible to keep the time frame of the analysis very short.

Traditionally, transport planners use models to estimate emission-producing activities as well as the resulting spatial distribution of traffic across the transportation network. It is important to use advanced modeling methods when policies of interest become larger in scope and/or effect; the geographical area of interest becomes larger; the time horizon becomes longer; policies become less focused on simple supply changes and more on pricing, demand management, or economic incentives/penalties; and when the future is anticipated to bring large exogenous changes.

Cities and practitioners may resist the introduction of a new model that may require additional investment of financing, time, and human resources. As cities elevate the importance of the impact of transport on emissions and air quality, we may see a push for the requirement to use more sophisticated technology.

Cities that have not adopted a specific set of tools for transport planning may be particularly interested in opting for the more advanced technologies and in this way leap frog to more accurate emissions estimation.

A measurement approach coupled with passenger surveys can also be used to measure the with and without project emissions. The measurement approach is only likely to be valid over a fairly short time frame as it does not take into consideration the impact of changes exogenous to the project. In addition it has no provisions to discern the impact of traffic displacement beyond the project boundary. Even if measurements are performed in a control route this route may also be affected by exogenous changes, over time.

This paper shows that there are no wrong methods to estimate emissions from transport interventions. It is possible to have wrong applications, since each method carries with it different data requirements, accuracy levels, time frames, and costs. A city should choose its method based on its unique needs and resources. Some decisions may need high-confidence, complete modeling results, while an application for Clean Development Mechanism credits may require a verifiable and more conservative measure of emissions.

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