Transport Reviews, Vol. 25, No. 6, 691–717, November 2005

Climate Change Mitigation and Transport in Developing Nations

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(Received 15 March 2005; revised 17 June 2005; accepted 20 July 2005)

ABSTRACT *Emissions from the transport sector represent the fastest growing source of greenhouse gas emissions. There is little prospect that this situation will be resolved with a single technological fix. As developing nations quickly move to catch up with the motorization levels of developed nations, the sheer number of private vehicles may overwhelm any advances made by cleaner fuels. By 2030, there is projected to be more vehicles in the developing world than in developed nations. Despite the growth in developing-nation transport emissions, the sector has produced relatively few mitigation projects within the mechanisms of the Kyoto Protocol. However, a few developing cities, such as Bogota, Colombia, have demonstrated innovation in low-cost solutions to reducing emissions. This research employs scenario analysis to examine the size and cost of potential emission reduction options from the urban transport sector of developing nations. In particular, the analysis compares the cost of greenhouse gas emission reductions from fuel technology options to reductions from measures promoting mode shifting. This comparative analysis indicates that a diversified package of measures with an emphasis on mode shifting is likely to be the most cost-effective means to greenhouse gas emission reductions.*

Introduction

The spectre of rapidly growing private vehicle ownership and usage in developing nations casts a worrying shadow over the projected course of global greenhouse gas emissions. If such nations follow the same path of automobile dependence as developed nations, there is little that technological advances can offer to offset such a monumental increase in motorization and its subsequent emissions. The resulting emissions from millions of new vehicles will simply overwhelm the reductions achieved through improved fuel and propulsion technologies.

However, most developing-nation cities still possess the basis for a more sustainable future. Public transport and non-motorized transport (walking and cycling) still command a dominant share of travel in developing cities. Unfortunately, the quality of these modes is often quite poor with regard to security, comfort, convenience and prestige. The sum effect of inadequate public transport

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0144-1647 print/1464-5327 online/05/060691-27 © 2005 Taylor & Francis
DOI: 10.1080/01441640500360951

and difficult conditions for walking and cycling means that most developing-city citizens will move to private motorized vehicles as soon as it is economically viable to do so. Thus, a central principle behind a more efficient and sustainable transport future in developing cities must be the preservation of existing mode shares for public transport and non-motorized options.

This research provides a comparative analysis of the two different types of climate change mitigation options for developing cities. The research first conducts a risk analysis of strategies based solely on fuel technologies. Scenario analysis techniques are then used to compare the size and cost of potential benefits from fuel-based solutions and from mode-shifting solutions. The urban transformation of Bogota, Colombia, is used to illustrate the potential of low-cost, low-technology mechanisms to achieve dramatic improvements in urban mobility and emission reductions. Finally, the research reviews the international efforts to date to mitigate developing-nation emissions from the transport sector.

Transport policy decisions made today in developing nations will have profound ramifications on any possible attempt to control global greenhouse gas emissions. These policies will also in part determine the extent to which other key developmental objectives, such as health levels, economic efficiency and overall quality of life, are realized in developing cities. Once policies are orientated towards motorization, it will be difficult to return to more sustainable options. As the developed world has discovered, moving commuters away from cars to public transport and non-motorized options is quite difficult and costly.

Trends in Developing-nation Transport

The planet will soon reach a milestone of being resident to over 1 billion motorized vehicles. Virtually all trends related to motor vehicle usage remain on course for continued growth. The International Energy Agency (IEA) has compiled a comprehensive set of spreadsheet analyses projecting transport trends between 2000 and 2050 (IEA/SMP, 2004). This work has been undertaken in conjunction with 'Mobility 2030' report of the World Business Council for Sustainable Development (WBCSD), which has attempted to characterize transport trends and options over the coming decades (WBCSD, 2004).

Vehicle Ownership

The reference case from the IEA spreadsheet provides the expected business-as-usual scenario. Figure 1 shows the expected trends in vehicle ownership levels. It has two striking features. First, despite the existing saturation of vehicle ownership in countries such as the USA, growth in ownership in these countries is expected to continue through to 2050. Second, the rate of growth in developing countries is significant, resulting in the number of developing-nation vehicles surpassing the number of vehicles in the Organization for Economic Co-operation and Development (OECD) by 2030. Currently, there are approximately 982 million passenger vehicles worldwide; by 2050, this figure is projected to reach 2.6 billion.[1]

It may be argued that vehicle ownership is not an emissions issue. The focus of an emission reduction strategy should be vehicle usage and not ownership. However, ownership and emission levels are in fact closely correlated for several reasons. First, approximately one-third of a vehicle's lifetime emissions stem from the upstream manufacturing process of the vehicle.[2] Second, once a vehicle is

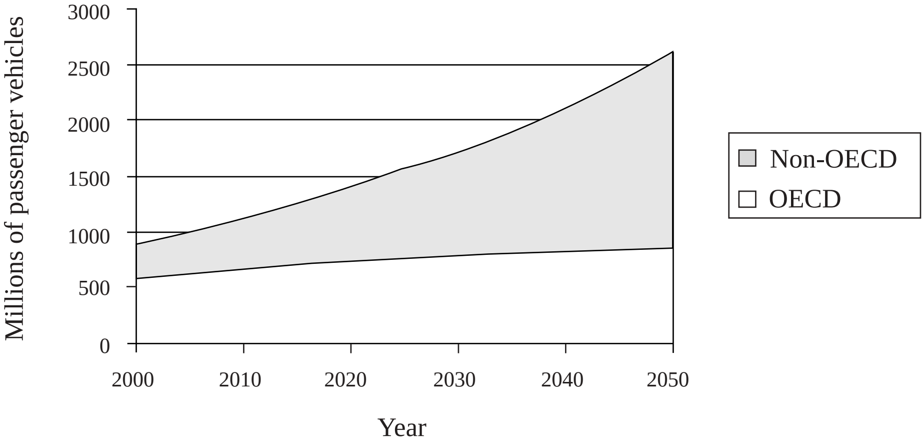

Figure 1. Vehicle ownership by region. *Source:* IEA/SMP (2004)

purchased, the convenience of use induces additional travel (Gilbert, 2000). Third, in the developing world, ownership has tended to arrive by way of highly polluting, used vehicles. In Peru, the lifting of used vehicle import restrictions resulted in a surge of vehicle ownership, with 70% of the annual growth being realized by older, used vehicles discarded from countries such as the USA (Zegras, 1998). An older vehicle fleet in conjunction with poor maintenance practices and limited vehicle testing can mean that the impacts of motorization on developing nations are many times worse than an equal level of motorization in a developed nation.

The growth in motorized vehicle ownership has largely followed trends in per-capita income. Dargay and Gately (1999) show that in the per-capita income range of US$2000–5000, vehicle purchases jump sharply. Other factors affecting vehicle ownership growth are population growth, urbanization levels, importation regulations and the quality of alternative transport services. The relative lower cost of suburban versus urban housing can also increase the demand for private vehicles. Several major developing nations are entering the income zone of rapid motorization.

Vehicle Usage

Figure 2 shows a projection of vehicle usage levels through to 2050 for both OECD and non-OECD nations. Like vehicle ownership, vehicle usage is expected to grow for both OECD and non-OECD countries, with the highest growth rates in the developing world.

Public Transport Usage

While private vehicle usage is reaching unprecedented heights, the same cannot be said of the state of public transport. In much of the world, public transit usage is decreasing at a fairly steady rate. In developing cities, continued penetration of motorized modes and general dissatisfaction with the quality of transit services has contributed greatly to the steady mode share loss. Table 1 shows the loss of public transport mode share across several cities. In

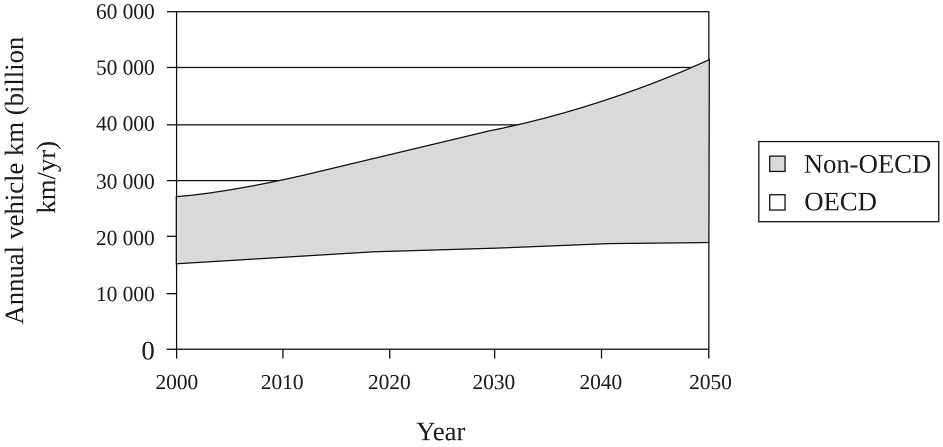

Figure 2. Vehicle use by region (vehicle-km travelled). *Source:* IEA/SMP (2004)

these surveyed cities, public transport is relinquishing a 0.2–1.4 mode share percentage annually.

A visit to any number of developing cities can quickly reveal the source of customer dissatisfaction with public transport and non-motorized options (Figures 3 and 4). Poor transport services in the developing world push consumers to private vehicle options. If public transport is too slow, uncomfortable, unsafe, insecure and lacking in status, then the loss of mode share is almost certain, even in seemingly captive markets. Likewise, if the pedestrian infrastructure is of poor quality, then motorization can be the mode of choice even for very short distances, as has been the case in some Asian cities (Hook, 2000).

Greenhouse Gas Emissions

While emission control technologies have to an extent limited health-related vehicle emissions (e.g. particulate matter, sulphur oxides, nitrogen oxides and carbon

Table 1. Trends in mode share of public transport in selected cities

City	Earlier year	Public transport as a percentage of motorized trips	Later year	Public transport as a percentage of motorized trips
Bangkok	1970	53	1990	39
Buenos Aires	1993	49	1999	33
Kuala Lumpur	1985	34	1997	19
Mexico City	1984	80	1994	72
Moscow	1990	87	1997	83
Sao Paulo	1977	46	1997	33
Seoul	1970	67	1992	61
Tokyo	1970	65	1990	48
Shanghai	1986	24	1995	15
Warsaw	1987	80	1998	53

Source: WBCSD (2001).

Figures 3 and 4. The poor quality of public transport in developing cities creates great hardship for the citizenry

monoxide), the same cannot be said of greenhouse gas emissions. Given the trends noted in vehicle ownership and usage (Figures 1 and 2), it is not surprising that transport greenhouse gas emissions are projected to follow a similar pattern of high growth. Figure 5 shows the projected trends for greenhouse gas emissions from the transport sector for both OECD and non-OECD countries.

Current estimates show that the transport sector represents approximately 24% of global greenhouse emissions from fossil fuel sources, second only to the generation of electricity and heat (39%) (IEA/OECD, 2003). By all accounts, though, transport is the fastest growing source of greenhouse gas emissions, with an annual growth rate of 2.1% worldwide and an annual growth rate of 3.5% for developing nations (IEA, 2002a).

'De-coupling' and 'Leap-frogging'

The rise of a service economy based upon information technologies holds the potential to decouple transport usage from economic growth. Less transport-intensive manufacturing should reduce the need for transport inputs into industrial processes. By extension, developing nations can potentially leap-frog past transport-intensive stages of economic growth and proceed directly into a new, less vehicle-dependent transport paradigm.

To an extent, some evidence exists of efficiency gains leading to a reduced relationship between economic growth and petroleum usage (Lovins, 2003), but the

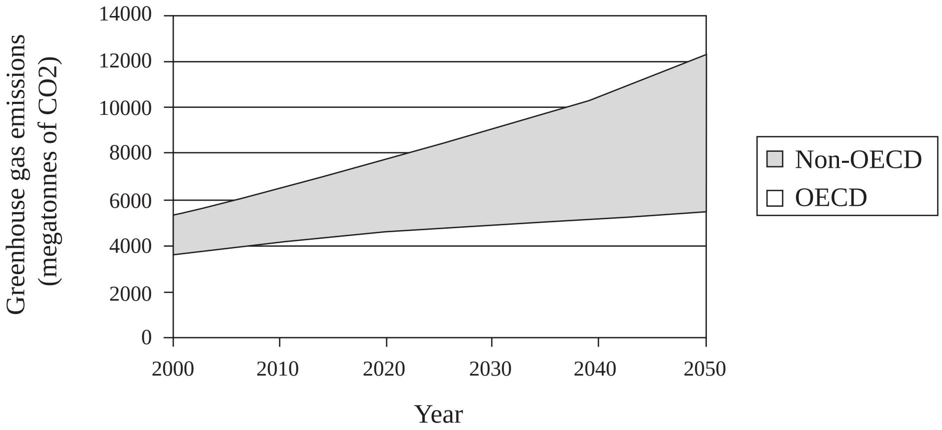

Figure 5. Transport carbon dioxide emissions by region. *Source:* IEA/SMP (2004)

growth of vehicle ownership and usage seems to continue irrespective of transport inputs to an economy (IEA/SMP, 2004). The United Nations Framework Convention on Climate Change (UNFCCC) conducted a survey of Member States in terms of quantifying the historical relationship between economic activity and transport-sector growth. Of all the Member States, only one nation indicated a discernible decoupling effect. During the 1990s, Finland's economy grew significantly while simultaneously curbing growth in its transport sector (Diaz-Bone, 2004). This divergence is in part credited to a 'Nokia' effect in which the economy's principal growth source was decidedly not transport-intensive.

However, other Scandinavian nations had similar economic characteristics without producing reduced transport emissions. The difference in the case of Finland was the simultaneous application of policies to curb vehicle ownership and usage. Otherwise, the wealth generated from Finland's non-transport-intensive economy would likely have produced increased motorized transport, as it has elsewhere in the world. Freight transport represents just 5.9% of worldwide vehicle-km travelled (IEA/SMP, 2004). Private individual travel still predominates in global terms. Thus, increased wealth, regardless of whether the wealth is generated by a less transport-intensive industry, seems to lead to increased use of private motorized vehicles.

As for the prospects of developing-nation leap-frogging, there is relatively little evidence in the projected trends for anything other than continued motorization. China's rapid adoption of the car is a prominent example. In 2004, annual growth in vehicle ownership reached 75% (*The Economist*, 2005). Bicycle use in China has fallen as national policy gives favour to its burgeoning automobile industry. Most major Chinese cities are actively discouraging bicycle use through priority measures for automobiles and through the neglect of non-motorized infrastructure (Hook, 2002). A few Chinese cities have actually even banned bicycles from sections of the urban area.

Preserving Mode Share in Developing-nation Cities

Despite the overwhelming movement towards motorization, virtually all developing cities possess a significant advantage in terms of achieving a more

Table 2. Mode share of urban transport in selected developing cities

City	Mode share (percentage of daily trips)			
	Non-motorized transport	Public transport	Private motorized vehicles	Other
Bamako, Mali (1984)	63	12	26	0
Havana, Cuba (1998)	57	27	6	11
Hanoi, Vietnam (1995)	54	4	42	0
Ouagadougou, Burkina Faso (1994)	52	3	45	0
Cairo, Egypt (1998)	36	47	17	0
Sao Paulo, Brazil (1997)	35	33	31	1
Santiago, Chile (1991)	20	56	16	9
Bogota, Colombia (2000)	15	71	12	2

Sources: Vasconcellos (2001) and WBCSD (2001).

sustainable urban form. Most developing cities already posses a high mode share for public transit and non-motorized modes as well as a fairly high-density, mixed-use design pattern. The challenge for these cities is to improve their transport systems in order to preserve the market share of low-emitting modes. Table 2 shows mode share data from a sampling of different developing cities.

Thus, finding a mechanism merely to preserve existing mode shares in developing nations could be one means towards greenhouse gas stabilization.

Bogota, Colombia, and Curitiba, Brazil, are perhaps the two most notable examples of cities that have shown the erosion of public transport mode share is not preordained. Both cities have demonstrated innovation with high-quality bus systems and a complementary package of supporting measures, including infrastructure for non-motorized transport and car-restriction measures.

In both Bogota and Curitiba, Bus Rapid Transit (BRT) has played a prominent role. The general idea of BRT is to create "a mass transit system using exclusive right of way lanes that mimic the rapidity and performance of metro systems but utilises bus technology rather than rail vehicle technology" (Wright, 2004, p. 1). BRT essentially emulates the performance and amenity characteristics of a modern rail-based transit system but at a fraction of the cost. To achieve this level of quality, BRT systems tend to focus on an array of features that enable a city to transform a standard bus service into a mass transit system. These features include the following (Wright, 2004):

- Exclusive right of way lanes.
- Reformed business and institutional structures.
- Rapid boarding and alighting.
- Free transfers between routes.
- Pre-board fare collection and fare verification.
- Enclosed stations that are safe and comfortable.
- Clear route maps, signage and real-time information displays.
- Modal integration at stations and terminals.
- Clean vehicle technologies.
- Excellence in marketing and customer service.

Most BRT systems today are being delivered in the range of US$1–15 million/km, depending upon the capacity requirements and complexity of the project. By contrast, elevated rail systems and underground metro systems can cost from US$50 million to over US$200 million/km (Wright, 2004).

BRT gained its initial prominence with its application in Curitiba in 1974. The system helped Curitiba gain an average annual ridership gain of 2.3% over two decades (Rabinovitch and Hoehn, 1995). Likewise, under the administration of Mayor Enrique Peñalosa, Bogota launched its BRT system in December 2000. It subsequently experienced a gain in public transport ridership (Figures 6 and 7). The Bogota system, known as TransMilenio, included a 41-km Phase I at a cost of US$5.3 million/km.

As of March 2005, the system features 58 km of busways and 309 km of feeder routes, moving over 800 000 passengers/day. The system functions with no operating subsidies, even with each private sector operator financing Euro II or Euro III articulated buses.

Bogota's BRT is also complemented by new cycleways, pedestrian upgrades and car-free events. The addition of nearly 300 km of high-quality cycle ways has helped increase bicycle mode share from 0.4 to over 3.0% in a few years. Bogota has also gained fame for its development of car-free events. Each Sunday, 120 km of arterial roadways are closed to private motorized vehicles (Figure 8). Bogota

Figures 6 and 7. Bogota went from this to this in just 3 years

Figure 8. As many as 2 million of the city's inhabitants take to the streets during Bogota's weekly car-free Sundays

also holds the world's largest car-free weekday event, covering the entire expanse of the city.

Bogota's success with non-motorized and public transport modes is also due to a highly synergistic implementation of car-restriction measures. Each weekday the city restricts 40% of all vehicles entering the city in the morning (06.00–09.00 hours) and evening (16.30–17.30 hours) peak periods. The city has also dramatically reformed its control on parking. On-street parking has been eliminated from many streets. In many cases, the previous parking bays have been converted into attractive public space. Likewise, Curitiba dramatically improved its allocation of public space to pedestrians with major car-free areas in the city centre. The pedestrian zones also act as feeder services to the BRT system by easing pedestrian movements towards stations.

The degree to which the success of both Curitiba and Bogota can be replicated is uncertain. Both cities benefited from highly charismatic mayors who made public space and transport a priority. Over 1000 city officials from approximately 50 countries have visited Bogota in the past few years. In part due to the influence of Bogota and Curitiba, new BRT systems are already in operation in Beijing in China, Jakarta in Indonesia, Leon in Mexico, and Seoul in South Korea. Other cities such as Cape Town in South Africa, Dar es Salaam in Tanzania, Hanoi in Vietnam, Lima in Peru, Mexico City in Mexico, and Santiago in Chile, have projects underway. Visits to Curitiba by US officials have even helped to catalyse a national BRT programme in the USA. However, none of these subsequent projects has reached the same level of quality or ambition as Bogota or Curitiba. Without the high degree of political will exhibited in Bogota and Curitiba, full implementation is often lacking. Further, both Bogota and Curitiba have enjoyed a continuity of transport policy across several political administrations.

Framework for Transport Emissions

The source components of transport emissions represent a myriad of opportunities for reduction. Figure 9 shows a framework for identifying and evaluating these different components. Much of the emphasis of national and international emission reduction efforts has focused on just one of the over 20 subcomponents in this equation, namely the 'type of fuel'.

This research paper attempts to quantify the relative emission benefits of addressing different emission components individually as well as through a package of measures. To an extent, investments in greenhouse gas reductions in the transport sector are a zero-sum game. Investment priorities on one component (such as fuels) can mean less investment is available to address other components. Likewise, political and institutional attention on one component can be to the detriment of others.

The first category shown in Figure 9 relates to the relative market share of a particular mode (private vehicles, public transport, non-motorized options, etc.) and the number of passengers carried in each vehicle (load factor). Most of the subcomponents in this category are aimed at affecting the behaviour or personal modal choice of the consumer. Attributes such as cost, travel time, security and convenience all play a pivotal role in the consumer's modal choice.

The second category relates to the distance travelled and is affected by land-use and transport network design. Transit-oriented development has become a popular tool for focusing residential and commercial development around public transport nodes, thus reducing the distances travelled. Additionally, the rise of new information and communications technologies (ICT) holds the possibility of reducing the number of trips through substitution effects. Whether or not ICT is actually achieving such reductions is debatable, as telecommuters may simply replace work commutes with other motorized trips (Tayyaran and Khan, 2003).

The final category in Figure 9 relates to technological attributes that affect vehicle emissions per distance travelled. The carbon content of the particular fuel used receives a great deal of attention in emission reduction efforts. However, other system characteristics such as vehicle weight, driver behaviour and maintenance practices are also of importance to overall vehicle emissions. For public transport systems, the provision of priority infrastructure such as busways will also significantly improve fuel efficiency by allowing smoother, uninhibited operations.

Risk Analysis of Fuel-based Approaches

This section briefly reviews the risks associated with emission reduction strategies that are solely focused on fuels. These risks include: (1) uncertainty over the timing of technology commercialization; (2) uncertainty over the size of the mitigation effects; (3) risk due to lack of diversification; (4) risks of transport sector growth outpacing fuel-based emission reductions; and (5) risks of secondary effects from fuel-based solutions.

National research and development budgets have heavily invested in fuel technologies. By far the largest financial investment is being made in the area of hydrogen fuel cells. In 2003, the USA launched its 5-year Hydrogen Fuel Cell Initiative with a commitment of US$1.7 billion in research funding. Likewise, the European Union is supporting a €2.8 billion (US$3.7 billion) public–private partnership in a 10-year fuel cell development programme. In 2003, Japan

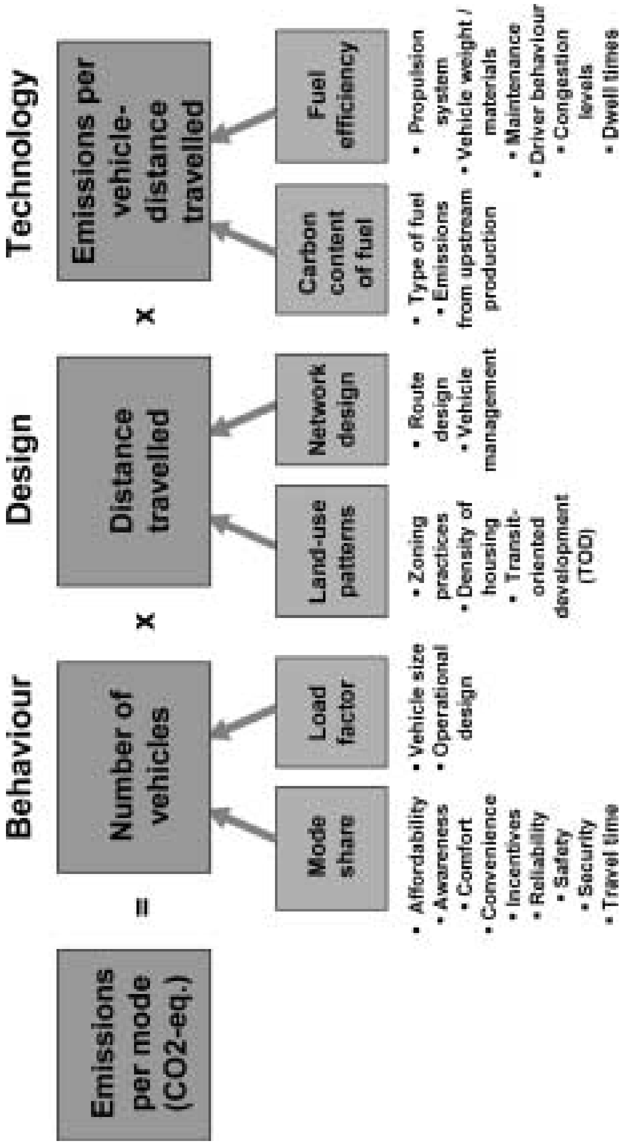

Figure 9. Factors affecting greenhouse gas emissions from the transport sector

dedicated US$268 million of its government research budget to fuel cells. Likewise, other governments such as Canada and China also have their own fuel cell programmes (*Science*, 2004). International forums for developing-nation transport options, such as The World Bank-led 'Clean Air Initiative', have placed considerable emphasis on alternative fuels. The WBCSD's '2030 Report' likewise focused upon fuel-based solutions.

Despite the optimism brought with these investments, the timing of the emission benefits is still uncertain. The IEA (2004a) notes that there are no certainties when technologies such as hydrogen fuel cells will become commercially viable. Hydrogen storage capabilities, the dependence on expensive rare-metal catalysts (e.g. platinum) and the development of appropriate infrastructure all represent formidable uncertainties in the timely delivery of a commercial product. By depending on a technology without a known delivery date, action on transport-sector emissions can be significantly delayed:

> by skewing research toward costly large-scale demonstrations of technology well before it's ready for market, governments risk repeating a pattern that has sunk previous technologies such as synfuels in the 1980s. By focusing research on technologies that aren't likely to have a measurable impact until the second half of the century, the current hydrogen push fails to address the growing threat from greenhouse gas emissions from fossil fuels. (*Science*, 2004, p. 958)

The timing and technological risks of a fuels-based approach are perhaps best exemplified by the climate change policy of the USA, as presented at the 10th Conference of the Parties to the UNFCCC. Specifically, this strategy contains three key components (US Department of State, 2004):

- Commercialization of hydrogen vehicles and development of a hydrogen fuelling infrastructure.
- Development of clean-coal electricity generation with carbon sequestration.
- Further development of nuclear-based electricity generation with increased research investment in nuclear fusion.

Thus, the strategy depends upon the commercial delivery of three technologies with major developmental issues remaining. The failure of one component to materialize can undermine the entire package. For example, if carbon sequestration techniques prove to be technically infeasible or commercially non-viable, the hydrogen produced from coal-based electricity may well increase greenhouse gas emissions relative to today's energy mix. A lack of diversity in an emissions strategy portfolio puts much pressure on the timeliness and effectiveness of speculative technologies.

Further, the expected size of the emission reduction benefits can also be quite uncertain. When full life-cycle emissions are considered, other fuel processes such as refining and delivery ('well-to-tank') can negate the 'tank-to-wheel' emission benefits of these fuels. For example, compressed natural gas (CNG) provides little to no benefit in terms of greenhouse gas emissions, especially when upstream methane losses along pipelines are considered. Some studies estimate that with the inclusion of methane leakage, CNG will actually produce significantly more total greenhouse gas emissions (CVTF, 2000).

Biofuels hold the potential to deliver a product with net zero greenhouse gas emissions. The CO_2 emitted by biofuels can be balanced by the CO_2 absorbed during plant growth, potentially resulting in a fixed carbon cycle. However, the reality is more complicated. Total greenhouse emissions from biofuel production are still quite poorly understood including certain factors that could increase net greenhouse gas emissions considerably. These factors include: (1) energy inputs into the cultivation of crops; (2) secondary emissions that have climate change impacts (e.g. black soot); (3) the amount of fertilizer used and resultant emissions of nitrous oxide (N_2O); (4) the amount of pesticide used; and (5) the type of biomass being displaced by energy crops. In some instances, such as soy-based fuels, the resulting greenhouse gas emissions from nitrogen releases may overwhelm other benefits (Deluchi, 2003). Additionally, it is unclear if the amount of agricultural land is sufficient to produce biofuels in a quantity sufficient to offset petroleum fuels dramatically (IEA, 2004b).

Hybrid-electric vehicles have gained particular attention due to the present availability of the technology as a commercially viable option. Both private and public vehicles with hybrid-electric technology are currently available at relatively modest cost premiums. However, even with this technology, the greenhouse gas benefits can vary depending on the driving duty cycle. The city of Seattle, WA, USA, has made one of the largest investments in hybrid-electric technology within its bus system. However, despite manufacturer claims of fuel efficiency gains of 25% or more, the initial results in Seattle were significantly less due to the route choice (Hadley, 2004). If the bus duty cycle does not involve sufficient stop and go travel, then the efficiency gains from regenerative braking are not realized. The additional weight of the hybrid-electric vehicle offsets the gains from the on-board electricity generation. Further, like all new technologies, a certain period of adjustments and experimentation are required before optimum results being achieved.

While hydrogen is touted as the ultimate fuel for ‘zero emissions’, much depends on how the hydrogen is processed. If hydrogen is derived from the electrolysis of water, powered by fossil-fired plants, upstream CO_2 emissions could be similar to or even higher than for conventional diesel buses (CFCP, 2001, cited in IEA, 2002b). Hydrogen production from entirely renewably generated sources is far from economic viability.

Each fuel shows promise in one aspect or another. CNG and liquid petroleum gas (LPG) may well be justified in terms of reductions in other types of pollutants (particulate matter, sulphur oxides, etc.), despite the lack of greenhouse gas emission benefits. Hybrid-electric vehicles show promise for improved fuel economy, but there remains a learning curve. However, no fuels are currently providing near-zero emissions from a well-to-wheel standpoint at anywhere near a competitive price level.

The chief advantage offered by fuel-based solutions is often in terms of political expediency. Fuel-based solutions allow current mode and travel practices to continue while avoiding seemingly difficult political and personal decisions:

> While its emissions are growing very quickly, transport is perhaps the most difficult sector to regulate because of the sheer size of the vehicle fleet and its relatively slow turnover, and the complex web of institutional interactions among personal attitudes relating to vehicles and land use, local politics and the marketing power of the auto-oil industry. (Rajan, 2005, pp. 4–5)

Fuel-based solutions bring with them the allure of continued growth in private vehicle usage without the necessity of lifestyle or behavioural changes. However, this attribute may also be the very weakness of a fuels-dependent path. A business-as-usual scenario in terms of motorization levels in the developing world will severely undermine the emission reductions from fuel-based strategies. Even if more advanced fuels are introduced in developing cities on a wide scale during this period (which is unlikely), the net increase in vehicle-km travelled can easily eclipse emission gains per vehicle.

Finally, a fuel-based strategy may also represent a missed opportunity in terms of potential co-benefits. A scenario with a sole reliance on advanced fuels will not appreciably stem the other negative impacts of motorization, such as accident levels and congestion. Globally, an estimated 1.2 million deaths occur annually due to automobile accidents, making transport one of the leading causes of death worldwide. A disproportionate percentage of these deaths, approximately 90%, occur in developing nations. Of the road deaths in developing nations, approximately one-half of the victims are non-motorists, but rather pedestrians or bicycle users, thus raising serious equity questions (World Health Organisation, 2003). The number of persons injured from such accidents is estimated to be at least 15 times the mortality rate (Vasconcellos, 2001), or approximately 18 million persons in 2001. Congestion is also a growing issue in developing-nation cities. The road infrastructure in such cities is often unable to cope with the increases in vehicle ownership and usage. Strategies that reduce private motorized travel, such as mode shifting or trip reduction, simultaneously address greenhouse gas emissions, other types of emissions, noise, accidents and congestion. Litman (2005) developed a comparative framework for evaluating the effectiveness of particular strategies across a range of co-benefits. Fuel-based approaches may only singly address a few pollutants without any further complementary benefits.

Comparative Scenario Analyses

Emissions Reduction Comparison

The IEA has conducted some initial analysis to determine the relative impacts of mode share in comparison with different fuel and propulsion options. It examined the emission impacts of shifting mode share by the capacity equivalent of one bus with a total capacity of 120 passengers. Even with the rather modest assumption of only a 50% load factor for the bus and only 8% of the passengers having switched from private vehicles, the resulting emission reductions were substantial.[3] The projected reductions in hydrocarbon and carbon monoxide emissions/km were over ten times the emissions of a single bus (IEA, 2002b). The reduction/km of particulate matter, nitrogen oxides and carbon dioxide (CO_2) (fuel use) ranged from two to four times the emissions of a single bus (Figure 10).

Remarkably, the level of emissions reduced did not change significantly with buses of strikingly different emission standards. Buses with Euro 0, Euro II, Euro IV and fuel-cell technology all produced roughly the same reductions. This result occurred because the relative impact of the tailpipe standard (and thus the fuel and propulsion choice) was overwhelmed by the impact from mode switching. The IEA study notes that:

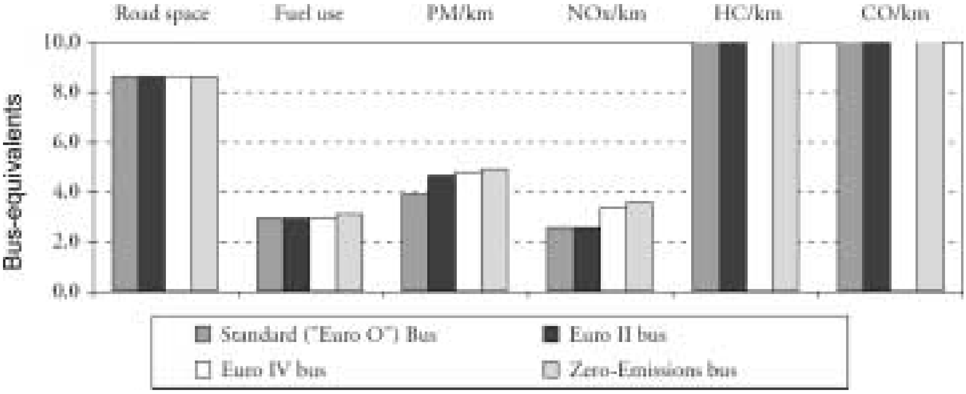

Figure 10. Impacts of mode shifting to public transport. *Source:* IEA (2002b)

> Regardless of whether a bus is 'clean' or 'dirty', if it is reasonably full it can displace anywhere from 5 to 50 other motorised vehicles …. (IEA, 2002b, p. 12)
>
> Certainly, a cleaner bus will yield lower emissions, but in this scenario, the emission reductions from technology choice are overshadowed by reductions from mode switching (and the resulting 'subtraction' of other vehicles). … Dramatic reductions in road space, fuel use, and most emissions can be achieved through displacing other vehicles with any bus, even the 'Euro 0' buses typically sold in the developing world. (IEA, 2002b, p. 48)

The results suggest that advanced fuels alone only address a relatively small portion of the total emission reduction potential.

Emission Reduction Costs

The potential size of the emission reduction is just one factor in mitigation investments. The cost/tonne of the potential CO_2 offset is also of primary importance to attracting investment. With the absence of the USA from the Kyoto Protocol, the demand for Certified Emission Reductions (CERs) is likely to be somewhat limited. Nevertheless, emission prices may well be in the range US$5–15/tonne of CO_2 offset. While many energy-related projects will exceed this price range, the potential for emission credits at least partially to cover project costs may be feasible. This research seeks to develop a few indicative cost figures for different emission reduction scenarios.

Fuel-based scenarios. The first set of scenarios analysed focuses upon advanced fuel technologies and their potential for greenhouse gas emission reductions. To an extent, early efforts in developing 'Clean Development Mechanism' (CDM) projects have already afforded a view of some emission reduction costs. In Yogyakarta, Indonesia, a cost analysis of greenhouse gas emissions reductions was conducted based on the conversion of a bus fleet from diesel fuel to LPG. The conversion of the 200-bus fleet would generate an estimated emissions savings of

3000 tonnes of CO_2 over a decade. With an assumed value of US$10/tonne of CO_2, the project would thus net US$30 000. However, the analysts calculated the transaction costs for the emission credits to be US$40 000, producing a net US$10 000 loss (Maulidia, 2004). Thus, based on these results, the project was abandoned as a CDM initiative.

Using IEA cost estimates of advanced vehicle technologies (IEA, 2002b) along with projections for potential fuel efficiency gains, a set of estimated emission reduction costs has been prepared for three different fuel technologies: CNG, hybrid-electric and fuel cells. For each fuel technology, a current realistic scenario is presented along with an optimistic future scenario. In each instance, the baseline emission comparison is with a EURO II diesel bus with an assumed operational life of 10 years.[4] Table 3 summarizes the results.

The pessimistic case for CNG assumes that no net greenhouse gas emission reductions are achieved due to upstream methane losses. For hybrid-electric vehicles, the pessimistic case assumes only a marginal emissions benefit due to an insufficient amount of stop-and-go travel. For fuel cell vehicles, the pessimistic case represents the standard performance and cost figures from today's vehicles, while the optimistic case represents one possible future scenario if technological barriers are overcome and scale-economies can be reached in vehicle manufacturing.

Based on these results, hybrid-electric technology represents the only technology in which a somewhat cost-competitive case could be achieved. At least from a greenhouse gas standpoint, CNG and fuel cells do not appear to be cost justified. In fact, these results in general are about an order of magnitude greater than the expected market value of emission reduction credits. Based upon these results, it appears somewhat challenging for vehicle/fuel-based solutions by themselves to become competitive greenhouse gas emission reduction options.

Mode shifting scenarios. The next set of scenarios analysed focuses upon projects that stimulate a shift in mode share from high-emitting modes (e.g. private motorized vehicles) to lower-emitting modes (e.g. public transport and non-motorized vehicles).

Existing Research

Some initial analytic work has also been conducted in this area. Project teams in both Bogota and Santiago have developed methodologies to calculate greenhouse gas emission reductions from BRT projects. If such methodologies are approved by the UNFCCC, the project developers can subsequently pursue the validation of CERs. The initial methodology put forward by Bogota was rejected, and thus it indicates some of the difficulties in establishing rigorous baselines and projections when the complexities of mode shifting are involved.

As a full BRT system, TransMilenio of Bogota provides several different sources of emission reductions, including the following:

- Increasing the share of public transport ridership by dramatically improving the quality of service (in terms of travel time, comfort, security, cleanliness, etc.).
- Constructing segregated busways that permit uninhibited bus movements without delays from mixed traffic.
- Using pre-board fare-collection systems that reduce dwell times.

Table 3. Emission reduction costs for fuel technology scenarios

Scenario type	Fuel/technical type	Carbon dioxide (CO_2) reduction (%)	Incremental vehicle cost (US$)	Incremental operating costs (US$/km)	Refuelling infrastructure investment (US$/ vehicle)	Incremental fuel costs	Estimated cost (US$/tonne CO_2)
Pessimistic	compressed natural gas	0	30 000	0.02	20 000	equal	n.a.
Optimistic	compressed natural gas	10	20 000	0.02	10 000	equal	442
Pessimistic	hybrid-electric	5	100 000	0.02	0	5% less	1912
Optimistic	hybrid-electric	20	65 000	0.02	0	20% less	148
Pessimistic	fuel cell	30	1 000 000	0.05	50 000	100% higher	3570
Optimistic	fuel cell	75	250 000	0.03	20 000	50% higher	463

n.a., Not applicable.

Figure 11. In phase 2 of TransMilenio, for every new articulated vehicle introduced into the system, 7.0–8.9 older vehicles are destroyed. Photo: courtesy TransMilenio SA

- Replacing four to five smaller buses with a larger articulated vehicle.
- Requiring the destruction of four to eight older buses for every new articulated vehicle introduced into the system (Figure 11).
- Managing the fleet through global positioning satellite (GPS) technology and thus allowing the optimization of demand and supply during peak and non-peak periods.
- Encouraging transit-oriented development around stations and along corridors.
- Requiring minimum-emission standards for vehicles (currently Euro II vehicles are employed with a future schedule requiring eventual Euro III/IV compliance).

According to a study by Steer Davies Gleave (2003), 10% of the ridership on Bogota's BRT system derives from persons who previously drove a private vehicle to work. Thus, the quality of the TransMilenio system would appear to be sufficient to discourage and even reduce private vehicle usage. Much of TransMilenio's ridership previously used conventional buses and mini-buses. The efficiency of these older and smaller vehicles is relatively poor due to the manner of fleet management and the age of the vehicles. Table 4 summarizes recent data collected on vehicle efficiencies in Bogota.

The differences in the number of 'passengers per vehicle-km travelled' are quite telling. The relative efficiency of operating a coordinated system in larger vehicles translates into economic advantages for the operators. By closely controlling the supply of vehicles during peak and non-peak periods, TransMilenio avoids wasteful trips. By contrast, the existing informal operators drive as much as 16 hours each day regardless of passenger flows. As long as the operator's marginal costs (mostly fuel costs) are covered, it makes sense to continue operating. However, this approach leads to the inefficiencies associated with congestion and an oversupply of vehicles.

Scenario Analysis

To test the emission impact of different mode shifting scenarios, a reference case has been created for a large, developing-nation city. In this reference case, 10 million passenger trips are assumed to take place each day, roughly equal to the

Table 4. Comparison of vehicle efficiencies in Bogota

Vehicle type	Passenger capacity (*n*)	Fuel consumption (km/litre)	Passengers/vehicle-km travelled
TransMilenio articulated bus, Euro II diesel	160	1.56	5.20
Private automobile	1.5	9.26	0.15
Conventional bus, diesel	70–80	2.14	1.00–2.27
Conventional bus, gasoline	70–80	1.53	1.00–2.27
Medium-sized bus, diesel, models 1995–2004	27–45	5.02	0.90–2.24
Medium-sized bus, diesel, 1980 model	27–45	3.96	0.90–2.24
Medium-sized bus, gasoline, 1980 model	27–45	2.64	0.90–2.24
Micro-bus, diesel	13–19	5.54	0.60–1.44
Micro-bus, gasoline	13–19	3.43	0.60–1.44

Source: A. Martínez, personal communication with Aleida Martínez Palacio, Manager, Sí 99, a private operating company within the Bogota TransMilenio system, 2004.

case of Bogota (7.2 million inhabitants). The average distance per non-walk trip is assumed to be 10 km. Fuel efficiency figures for private vehicles and motorcycles are based on the IEA spreadsheet model (IEA/SMP, 2004). The fuel efficiency figure for BRT vehicles is based upon the TransMilenio value shown in Table 4. The fuel efficiency for conventional buses is a weighted average of the fuel efficiency for buses, mini-buses and micro-buses shown in Table 4. Table 5 is a summary of the reference case. The baseline calculations have been developed in a simplified manner with no assumed growth in private motorized vehicles over 20 years of the analysis. Clearly, based on the IEA growth projections, this static baseline will not be the case. However, this assumption makes the results more conservative since any baseline growth in private vehicle emissions will make the reductions from mode shifting even greater.

The reference case was then compared with several scenarios with different mode shares. The cost of the mode shift was assumed to be the infrastructure cost of BRT, improved footpaths and/or cycle ways. Since BRT systems, such as TransMilenio, function with no operational subsidy, no operational costs are included in the subsequent cost/tonne of emissions reduced. The emission calculations for each scenario used the same emission factors and fuel efficiency values as in the reference case. The amount of the scenario's emission reduction is simply the scenario emission total subtracted from the emission total for the reference case. The cost of infrastructure is based on actual values from developing-city projects. The following infrastructure costs were used: (1) US$2.5 million/km of BRT; (2) US$150 000/km of pedestrian improvements; and (3) US$100 000/km of cycleways.

A single infrastructure value has been used for clarity when presenting the results. However, a more representative result can be achieved by using a range of infrastructure costs, especially for the case of BRT, which can range from US$1 million to US$15 million/km depending on local circumstances. Table 6 summarizes the results from the different mode shifting scenarios.

Each mode-shifting scenario resulted in relatively cost-competitive emission reductions with no costs higher than US$70/tonne of CO_2 reduced. By contrast, the lowest cost fuel-based strategy was US$148/tonne of CO_2 reduced.

Ideally, an emission reduction scenario would produce both large emission reductions as well as low-cost reductions. Each non-motorized option produced

Table 5. Reference case

Mode	Mode share (%)	Trips/ day (000s)[a]	Passengers/ vehicle-km	Distance travelled/ day (km, 000s)	Fuel consumption (litres/ 100 km)[b]	CO_2 (kg)/ litre[c]	CO_2/ day (tonnes, 000s)	CO_2 over 20 years[d] (tonnes, 000s)
Automobile	20	2000	0.150	13 333	10.80	2.42	1087.2	21 744
Motorcycle	4	400	0.105	3809	2.20	2.42	63.2	1266
Taxi	5	500	0.150	3333	10.80	2.42	271.8	5436
Mini-bus	50	5000	1.300	3846	30.30	2.87	1043.5	20 870
BRT	0	0	5.200	0	64.10	2.87	0	0
Walking	20	2000	1.000	150	0	0	0	0
Bicycle	1	100	1.000	100	0	0	0	0
							2465.8	49 315

[a] Based on 10 million total trips/day.

[b] Fuel efficiency figures for private vehicles and motorcycles are based on the IEA spreadsheet model (IEA/SMP, 2004). The fuel efficiency figure for BRT vehicles is based upon the TransMilenio value in Table 5. The fuel efficiency for conventional buses is a weighted average of the fuel efficiency for buses, mini-buses and micro-buses given in Table 5.

[c] The fuel for all private vehicles is assumed to be gasoline. The fuel for mini-buses and BRT vehicles is assumed to be diesel. Emissions/litre of fuel are taken from IEA spreadsheet model (IEA/SMP, 2004).

[d] Vehicle-km travelled during weekends is assumed to be one-half of weekday travel.

results under US$20/tonne of CO_2 reduced. A US$60 million investment in bicycle infrastructure produces a projected emission reduction of 4.1 million tonnes of CO_2 over 20 years at a cost of approximately US$14/tonne.

However, the package of measures bundled together (BRT with pedestrian upgrades and cycleway investment) was the most effective combination of large and relatively low-cost reductions. The scenario with the package of measures produced over 12 million tonnes of CO_2 reductions at a cost of approximately US$30/tonne. As an individual measure, BRT was more costly than the other scenarios at US$66/tonne, while the non-motorized options alone did not produce the largest reductions. This result is due to modal assignment between the different options. In the case of BRT or non-motorized options working individually, each will tend to suppress the mode share of the other. For example, improved public transport (e.g. BRT) will tend to attract previously non-motorized users in addition to targeted trips by private vehicles. The net emission reductions will not be as great as compared with a scenario in which public transport and non-motorized transport increase together. In the bundled scenario, trips by BRT, walking and cycling are all promoted and supported, and thus the loss of market share between these modes is minimized.

Finally, another interesting finding from this research has been the relative sensitivity of emission reductions from small changes in motorized mode share. A single percentage point reduction in motorized mode share and a subsequent gain by either non-motorized options or public transport is substantial in terms of greenhouse gas impacts. In the context of the stated reference case, a 1% reduction in mode share of private automobiles represents over 1 million tonnes of CO_2 through the 20-year project period. This finding implies that even shifting relatively small percentages of mode share to more sustainable options can be worthwhile.

It should be noted that the cost estimates generated in Tables 5 and 6 are approximations based upon generic conditions and assumptions within project

Table 6. Impact of mode shifts on carbon dioxide emission reductions

Scenario name	Mode shares	Carbon dioxide (CO_2) over 20 years (tonnes, 000s)	CO_2 reduced from the baseline (tonnes, 000s)	Cost of infrastructure	Cost (US$)/ tonne of CO_2
BRT mode share increases from 0 to 5%	automobile 19% motorcycle 4% taxi 4% mini-bus 48% BRT 5% walking 19% bicycle 1%	47 409.7	1905.5	US$125 million (50 km of BRT at US$2.5 million/km)	66
BRT mode share increases from 0 to 10%	automobile 18% motorcycle 4% taxi 3% mini-bus 45% BRT 10% walking 19% bicycle 1%	45 086.8	4228.5	US$250 million (100 km of BRT at US$2.5 million/km)	59
Walking mode share increases from 20 to 25%	automobile 19% motorcycle 4% taxi 4% mini-bus 47% BRT 0% walking 25% bicycle 1%	45 888.7	3426.6	US$60 million (400 km of pedestrian upgrades at US$150 000/ km)	17
Bicycle mode share increases from 1 to 5%	automobile 19% motorcycle 4% taxi 5% mini-bus 48% BRT 0% walking 19% bicycle 5%	47 393.3	1922.0	US$30 million (300 km of cycle ways at US$100 000/ km)	15
Bicycle mode share increases from 1 to 10%	automobile 18% motorcycle 3% taxi 5% mini-bus 46% BRT 0% walking 18% bicycle 10%	45 154.9	4160.4	US$60 million (500 km of cycle ways at US$100 000/ km, plus US$10 million promotional campaign)	14
Package: BRT, pedestrian upgrades, cycleways	automobile 15% motorcycle 3% taxi 3% mini-bus 34% BRT 10% walking 25% bicycle 10%	36 917.5	12 397.8	US$370 million (BRT US$250 million; footpaths US$60 million; cycleways US$60 million)	30

BRT, Bus Rapid Transit.

and baseline scenarios. The actual values will vary greatly depending on local circumstances and a range of factors, including baseline mode shares, local infrastructure costs and cultural preferences for particular modes. The scenarios presented here also did not account for any induced travel that may occur due to the availability of road space following a shift to lower-emitting options. Further, the final total cost of attempting to convert such reductions into tradable 'CERs' will also involve additional transaction costs as well as measurement and monitoring costs. Nevertheless, the results of these initial scenarios for mode shifting do appear promising from the standpoint of cost competitiveness.

Land-use measures. The land-use impacts from the BRT systems in Bogota and Curitiba are yet to be fully quantified. In the case of Bogota, there is some initial evidence to suggest that densification around BRT stations may be occurring. Large commercial centres are being constructed along the corridors, especially near terminals and stations. Rodriguez and Targa (2004) determined that residential property values along TransMilenio corridors are directly proportional to station proximity. In Curitiba, zoning laws only permitted high-rise development along the BRT corridors. The densification of commerce, employment and residences along BRT corridors likely yields reductions in both the number of trips undertaken as well as the average distance of each trip.

However, the challenges of projecting emissions from land-use changes are significant. The complex array of possible factors affecting land-use decisions creates considerable difficulty in establishing a credible baseline. The modelling of projected land-use changes and emission reductions in Santiago has produced some promising results in terms of cost-effective emission reductions (under US$10/tonne of CO_2) (Browne *et al.*, 2005). However, the complexity of this modelling process would unlikely meet the stringent requirements of the CDM.

Policy Measures

This paper has largely addressed the comparison of technology-based solutions with behavioural (mode-shifting) solutions. Policy measures represent another potential means for achieving greenhouse gas emission reductions from the transport sector. Increasing vehicle performance and efficiency through mandatory inspection and maintenance programmes as well as fuel economy standards are a few examples. Policies, particularly car-restriction policies, are quite important as complementary measures in supporting public transport and non-motorized options. As was the case in Bogota, the scenarios summarized in Table 6 may well necessitate complementary car-restriction measures to encourage the intended mode shifts. Thus, the right policy environment will ideally form another part of a packaged approach to emission reductions.

International Response

Given the potential global impact of developing-nation motorization, the international community would be expected to be investing in mode preservation strategies for developing cities. To an extent, international support of effective, lower-cost options has occurred. For example, the German Overseas Technical Agency (GTZ) has recently produced a sustainable transport sourcebook covering a range of practical options, including BRT.[5] Likewise, the US Agency for International Development (USAID), through the Institute for Transportation & Development Policy (ITDP), has supported BRT initiatives in such cities as Accra in Ghana, Cape Town, Dakar in Senegal, Delhi in India, and Jakarta. However, compared with other sectors, the transport sector has received less investment as a means towards reductions in greenhouse gas emissions. Further, when local governments and international organizations have invested in transport initiatives, the tendency has been toward fuel technologies.

International Funding Mechanisms

To date, two major international agreements have been brought forward to curb greenhouse gas emissions. At the 1992 UN Conference on Environment and Development (UNCED), member nations developed the UNFCCC. By 1994, a sufficient number of countries had ratified the convention to put the document into force. Although the convention was essentially a non-binding agreement, the UNFCCC did include a mechanism allowing participation by developing nations in emission-reducing projects. The mechanism, known as 'Activities Implemented Jointly' (AIJ), encouraged investment towards developing nation projects as a means to stimulate a future emissions trading market. Remarkably, though, of the 186 AIJ projects put forward, none addressed emissions in the transport sector (*Joint Implementation Quarterly*, 2002).

Subsequently, in 1997, the Kyoto Protocol was drafted. The protocol calls for developed nations to reduce emissions by an average of 5.2% from a 1990 baseline. Despite the absence of two major emitting nations, the USA and Australia, the agreement came into force on 16 February 2005. The Kyoto Protocol offers a mechanism, known at the CDM, that allows mitigation projects in developing nations to earn CERs, which will have a monetary value. The Protocol also includes a mechanism known as 'Joint Implementation' (JI) to promote emission reducing projects in 'economies-in-transition' (i.e. Eastern Europe). Thus, although developing nations and economies-in-transition do have not reduction requirements under the Protocol, these nations can sell credits gained through CDM and JI to other nations that do have Kyoto emission reduction requirements.

However, early indications from project proposals indicate that transport will not be a major area of investment. CDM and JI projects are being supported by many institutions, including the governments of Finland, Japan and the Netherlands, as well as The World Bank through its Prototype Carbon Fund. Through May 2005, a total of 126 CDM projects and 79 JI projects had been registered with the UNFCCC. No project is transport related (Fenhann, 2005).

Apart from the UNFCCC mechanisms, the Global Environment Facility (GEF) is amongst the world's largest grant-making facilities to fund projects alleviating global environmental problems. The GEF's resources of over US$2 billion are intended to catalyse demonstration initiatives that eventually lead to replication globally. The fund is managed by a central secretariat along with its implementing agencies, which include The World Bank, the UN Development Programme (UNDP), the UN Environment Programme (UNEP) and regional development banks. However, the transport sector was one of the last sectors that the GEF climate change programme has addressed. Further, the GEF's operational strategy for transport was largely prepared by special interests from the fuel cell industry, and thus has focused much of the early investments towards fuel and propulsion system solutions (GEF, 2001).

Through February 2005, of the 566 registered GEF projects related to climate change, only 13 were in the transport sector. Of these, six are focused on fuel cell technology. The fuel cell initiatives involve a US$60 million investment by UNDP to finance 46 fuel-cell buses in developing cities such as Beijing, Cairo in Egypt, Mexico City, Sao Paulo in Brazil and Shanghai in China. The actual project cost totals US$120 million when matching funds from private sector fuel and vehicle firms are included. Thus, the end result is 46 buses at a cost of approximately US$2.6 million per bus. However, given that in nations such as China the hydrogen for the fuel-cell buses will likely be derived from largely coal-based electricity, the overall greenhouse gas emissions will actually be higher than if a standard diesel vehicle was used. If instead the US$120 million investment was applied towards BRT systems, then anywhere from 23 to 120 km of BRT could have been financed. In response, the GEF is now moving towards a more systems-based approach to transport initiatives. The World Bank is currently leading GEF-financed BRT projects in Lima, Mexico City, Santiago and Hanoi, with additional projects being planned for cities in China and Colombia.

Explaining the Investment Deficit

The most frequently cited reasons behind the lack of greenhouse gas mitigation projects in the transport sector are the complexity of transport baselines and the cost-effectiveness of the projects. Projects encouraging shifts to lower-emitting modes depend upon modelling projections that are possibly not sufficiently rigorous to meet the standards of CERs (Sandvik, 2005). Further, the duration and timing of transport emissions may also be at odds with the CDM process. Busways and infrastructure for bicycles and pedestrians will have a lifetime of 25 years or longer, and thus the initial capital costs are amortized through the emissions reduced over this period. CDM project periods only cover 7 or 10 years, and thus do not permit the full emission reduction in a single reporting period.[6] Additionally, the nature of the CDM implies the presence of a motivated investor with a discrete product. Private sector opportunities largely reside in fuels and vehicles, while upgrades such as improved customer service either do not have well-defined commercial opportunities or such opportunities are local in nature.

By contrast, fuel-switching projects do not suffer such difficulties. The average 10-year life of buses coincides with permitted CDM project periods. Additionally, an emissions baseline for a fuel-switching project is far simpler without the inherent need of including changes in mode shares. However, as this research has indicated, fuel-switching projects do not appear to be cost competitive in terms of investment per emission quantity reduced.

In summary, system-based approaches that promote mode shifting are cost competitive but do not meet CDM methodological requirements. Fuel-based solutions meet methodological requirements but do not appear to be cost competitive. Thus, given the requirements of the CDM process, it would seem that transport will probably not play a significant role.

However, the CDM is just one form of potential investment in emission reductions. For example, GEF and bilateral agency investments do not involve emission credits and thus do not require the same level of baseline scrutiny, and yet transport has lagged as a sector here as well. To the extent transport is being addressed by either international agencies or local governments, it is often focused solely on fuel-based solutions. Although difficult to demonstrate quantitatively, there could well be a host of informational and political barriers that account for this predilection:

- Technological solutions (tailpipe technologies, fuels, propulsion systems) can appear to be simple black-box solutions that are intrinsically easier for public officials to understand than a broader systems approach.
- Higher-technology options may be perceived as being 'modern' by many political officials, while non-motorized transport may be perceived as counter to national aspirations.
- It may be far more politically expedient to promote increased motorization rather than public transport and non-motorized transport.
- BRT is a relatively new concept and there may be informational barriers to its wider application.

It is possible that simply improving the state of developing-nation footpaths could be one of the most effective long-term measures, from the perspectives of both cost and overall development. However, it is unlikely that any global footpaths initiative is on the horizon anytime soon. Future research on political perceptions of transport modes (at the level of both international agencies and local governments) and the subsequent impact on investment could be helpful in understanding this phenomenon.

Conclusions

Emissions from the transport sector represent the fastest growing source of global greenhouse gas emissions. The reference case from the IEA model indicates uninterrupted growth in motorized vehicle ownership and usage as well as greenhouse gas emissions. The sheer number of private vehicles being added to roadways will likely overwhelm any technological advances.

This research has produced a framework for understanding the various greenhouse gas emission components from the transport sector. The research has also conducted various scenario analyses to determine the relative size and cost-effectiveness of different emission reduction options. The scenario analyses indicated that the cost of fuel-based solutions ranged from approximately US$148 to over US$3500/tonne of CO_2. By contrast, shifting mode share from high-emitting sources (private vehicles) to lower-emitting sources (public transport and non-motorized options) produced emission reduction costs between US$14 and US$66/tonne of CO_2.

This research has thus indicated that fuel-based solutions alone will not likely achieve cost-effective reductions in greenhouse gas emissions. The most cost-effective means to emission reductions appears to be a diverse and integrated package of measures that promote shifts to lower-emitting modes. By extension, these measures also produce an array of co-benefits across a range of economic, environmental and social objectives. Ideally, mode share, land use, policy and technology are developed as a complementary package. Additional research is required to understand the potential contribution from land-use changes for emission reductions.

Despite the transport sector representing the fastest growing source of greenhouse gas emissions worldwide, there has been relatively little project activity to address emissions from the sector. The number of transport projects under the mechanisms of the Kyoto Protocol and under the GEF is relatively small in comparison with other sectors.

The Kyoto process and, specifically, the CDM may not be well suited to stimulate investment in improved transport for developing nations. Cost-competitive options such as the promotion of mode shifting to public transport and non-motorized transport are not likely to meet baseline methodological requirements. Further, in the absence of the USA from the Kyoto Protocol, there are likely to be limited prospects for a highly active carbon trading market. Thus, the CDM, along with its issues of baseline calculations and additional requirements, may be more of a distraction than a lucrative opportunity for transport investments.

While the GEF has been slow to address the transport sector, it represents perhaps the best future source of catalyst funding for mode-shifting initiatives. The World Bank's support of BRT and non-motorized initiatives through the GEF has already produced projects in Mexico City, Lima, Santiago and Hanoi, with other future initiatives also likely.

While the projections of increased motorization indicated in the IEA reference case are a cause for concern, these trends are not preordained. An alternative is still achievable for most developing nation cities. The low-cost solutions that have emphasized public transport, bicycling and walking, and land-use changes in Bogota and Curitiba are certainly possible elsewhere. Whether the political will exists elsewhere is a question to be answered.

Notes

1. 'Passenger vehicles' include cars, motorcycles, three-wheelers, mini-buses and buses. This value does not include freight vehicles, train carriages, water transport or air transport.
2. This value is based upon vehicles in Western Europe. It is slightly less in North America, where life-time km travelled per vehicle are higher (Gilbert, 2000).
3. The scenario assumes that 60 new passengers switch from other modes to an articulated bus with a passenger capacity of 120. The previous modes used by the new passengers are as follows: private car ($n = 5$), taxi (5), paratransit (10), small diesel bus (10), three-wheeler (5), two-wheeler (10), bicycle (5) and pedestrian (10).
4. A vehicle is assumed to travel 750 000 km over a 10-year life. The baseline emission factor for a EURO II diesel bus is assumed to be 2.87 kg of CO_2/litre of fuel.
5. For more information on the GTZ Sourcebook, see http://www.sutp.org
6. However, the 7-year option does offer the possibility of two subsequent renewals for a total of 21 years.

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