The limits of technology:
Achieving transport efficiency in developing nations

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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 motorisation levels of developed nations, the sheer number of private vehicles on the roadways will overwhelm any advances made by cleaner fuels. By the year 2030, there is projected to be more vehicles in the developing world than in developed nations. However, most developing cities today still have the basis for a more sustainable future. Public transport and non-motorised transport (walking and cycling) still command a dominant share of travel in developing cities. Thus, a key objective for local and international initiatives is to preserve existing mode shares. Unfortunately, most investment in reducing transport emissions relies exclusively upon achieving costly reductions only through fuel and propulsion system technologies.

Bogotá (Colombia) represents one of the best examples of a city that has developed a package of complementary measures to substantially reduce vehicle emissions and congestion. Bogotá's implementation of a high-quality bus rapid transit (BRT) system, bicycle infrastructure, pedestrian improvements, car-free events, and auto restriction measures all have contributed to an urban transformation in a period of just a few years. Initial projections of greenhouse gas reductions during the first 30 years of the BRT system's operation indicate reductions of approximately 14.6 million metric tons of CO2 equivalents.

This research presents a framework for evaluating the greenhouse gas emission reductions in the transport sector. This framework highlights three principal areas of emission reduction potential: 1.) Mode share (behaviour); 2.) Distance travelled (land-use/design); and 3.) Fuel efficiency (technology). Only by addressing all three components an optimum transport energy path can be achieved.

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1. Introduction

The specter 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 nations such as China and India 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 motorisation and its subsequent emissions. The resulting emissions from millions of new vehicles will overwhelm the reductions achieved through improved fuel and propulsion technologies.

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

This article outlines the relative emissions impacts of technological-based solutions versus options related to the preservation of mode share and improvements in land use. The urban transformation of Bogota (Colombia) is used to illustrate the potential of low-cost, low-technology mechanisms to achieve dramatic improvements in urban mobililty and emission reductions. Ideally, a more optimum transport energy path can be achieved if mode share, land use, and vehicle and fuel technology are developed as a sustainable package. Relying exclusively on only one of these elements is unlikely to stem the negative impacts associated with the projected growth of motor vehicle usage in developing cities.

2. Trends in developing-nation transport

2.1 Emissions and levels of motorisation

Despite international concerns over global climate change and energy security, few effective remedies have been developed to curb fuel consumption from the transport sector. Current estimates show that the transport sector represents from 22 per cent to 24 per cent of global greenhouse emissions from fossil fuel sources, second only to the industrial sector. By all accounts, though, the transport sector is the fastest growing sector with respect to emissions. Table 1 summarises sectoral contributions to greenhouse gas emissions.

Table 1 Global greenhouse gas emissions from fossil fuel combustion by sector (1995)

Sector	Mega-tonnes (Mt) of carbon	Percent of total emissions	Average growth rate (1990-1995)
Industry	2,370	43%	0.4
Transport	1,227	22%	2.4
Residential buildings	1,171	21%	1.0
Commercial buildings	584	10%	1.0
Agriculture	223	4%	0.8
Total	5,577	100%	1.0

Source: Price et al. (1998)

The planet will soon reach a milestone of being resident to over 1 billion motorised vehicles. From 1995 to 2030, worldwide vehicle ownership is expected to grow by 228% to over 1.6 billion vehicles (OECD and EMCT, 1995). As noted in table 2, the bulk of this growth will take place in the developing world. Growth in motorised vehicle ownership is due to several factors with per capita income explaining potentially 70 per cent to 80 per cent of the increase (IIEC, 1996). Dargaya and Gately (1999) show that in the income range of US$ 2,000 to US$ 5,000 vehicle purchases jump sharply. Other factors affecting vehicle ownership growth are population growth, urbanisation levels, importation regulations, and the quality of alternative transport services.

Table 2 Expected growth in world vehicle ownership

	1995		2030	
Region	**Cars (000)**	**Vehicles (000)**	**Cars (000)**	**Vehicles (000)**
OECD countries	383,329	536,174	621,091	842,257
Non-OECD (developing countries)	111,255	240,357	391,755	781,130
Global Totals	494,584	776,531	1,012,846	1,623,387

Source: OECD and EMCT, 1995

The amount each vehicle travels also seems to be growing as well. Based on data from Newman and Kenworthy (1999), the growth in annual car use (kilometres) and average journey-to-work distances was evident in most parts of the world. While some researchers had previously projected that market forces would encourage a levelling off of distances travelled due to a dispersal of jobs to the suburbs (Gordon and Richardson, 1989), little evidence to date suggests that this is the case (Newman and Kenworthy, 1999). Schafer and Victor (1997) project that global travel distance will more than double from 1990 to 2020, and then redouble by 2050.

Despite the advent of more efficient fuel and propulsion technologies, such as hybrid-electric vehicles, petrol consumption has largely followed the increase in motorised vehicle usage. Table 3 provides a summary of world petroleum consumption (Davis and Diegel, 2002). The transportation sector consumes approximately 67 percent of world petroleum use (Davis and Diegel, 2002).

Table 3 World petroleum consumption (millions of barrels per day)

Year	United States	Total OECD	Total non-OECD	Total
1990	16.99	44.92	25.05	65.97
1995	17.73	44.96	24.92	69.88
2000	19.70	47.92	27.61	75.53

Source: Davis and Diegel, 2002

New technologies and new emission standards have allowed a stabilisation, and in some cases, a reduction in local air pollutants. Such pollutants as particulate matter, nitrogen oxides, and carbon monoxide are of particular importance to developing-city policy makers since the local health costs have significant ramifications on health care provision and economic development. The tightening progression of emission standards set by the European Union and the United States Environmental Protection Agency (USEPA) have led to cleaner air in the urban areas of developed nations. Table 4 gives the projected global trends in emissions of carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx). Interestingly, these figures illustrate an initial improvement based upon improved fuels and emission technologies, but such improvements are ultimately offset by the expected rise in vehicle ownership. Thus, even accounting for vast advances in vehicle technologies, the increasing number of vehicles will simply overwhelm these advances.

Table 4 Expected global trends in emissions of CO, HC, and NOx (million of tonnes)

Pollutant	1995	2000	2010	2020	2030
CO	201.6	178.4	121.6	123.1	154.2
HC	32.3	29.4	29.2	34.4	43.0
NOx	30.2	28.4	29.7	36.0	45.1

Source: OECD and EMCT, 1995

The extent to which developed-nation standards have contributed to lower emissions in developing nations is far from clear. In many nations, there are few controls on limiting the importation of older used vehicles. An older vehicle fleet in conjunction with poor maintenance practices and limited vehicle testing can mean that the impacts of motorisation on developing nations are many times worse than an equal level of motorisation in a developed nation.

There is one type of emission for which there is little doubt over its projected course. Greenhouse gas emissions, and particularly carbon dioxide (CO_2), are increasing at unprecedented levels. The emission control technologies that are somewhat stabilising local pollutants (CO, NOx, particulates, etc.) are doing little if anything to address rising CO_2 emissions. Further, as noted previously, the addition of rapid motorisation in developing nations has only exacerbated the trend set by the developed world:

> “In 1999, the last year for which data are available, the transport sector was the source of approximately 24 percent of global energy-related carbon dioxide emissions. This represents an absolute increase of 1017 million

tonnes of carbon dioxide and a share gain of 2.4 percent since 1990. Worldwide, emissions of carbon dioxide from the transport sector are projected to grow at the rate of 2.5 percent each year through 2020. The growth rates of transport sector carbon emissions in the developing world and in economies in transition are projected to be even higher – 4.0 percent per year and 3.3 percent per year, respectively" (OECD and IEA, 2001).

Table 5 shows the projected trends in carbon dioxide emissions for both developed and developing nations. The OECD and EMCT (1995) project that by 2030 carbon dioxide emissions will grow to be nearly 70 per cent above the 1990 baseline. By contrast, the Kyoto Protocol calls for "Annex B" countries (principally OECD countries) to actually reduce overall emissions from the 1990 baseline. Additionally, by 2030, CO_2 emissions from non-OECD countries are projected to overtake emissions from the OECD.

Table 5 Projected growth in carbon dioxide emissions from the transport sector (billion of tonnes)

Region	1990	2000	2010	2020	2030
OECD countries	2.834	3.056	3.403	3.405	3.301
Non-OECD countries	1.135	1.585	2.092	2.670	3.426
Global totals	3.969	4.641	5.495	6.075	6.727

Source: OECD and EMCT (1995)

2.2 Public transport

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 motorised modes and general dissatisfaction with the quality of transit services has contributed greatly to the steady mode share loss. Table 6 documents the loss of public transport mode share across several cities. In general, public transport is relinquishing a 0.2 to 1.4 mode share percentage annually (WBCSD, 2001).

Table 6 Trends in mode share of public transport in selected cities

City	Earlier year	Public transport as a percentage of motorised trips	Later year	Public transport as a percentage of motorised trips
Bangkok[1]	1970	53	1990	39
Buenos Aires[2]	1993	49	1999	33
Kuala Lumpur[3]	1985	34	1997	19
Mexico City[4]	1984	80	1994	72
Moscow[4]	1990	87	1997	83
Sao Paulo[4]	1977	46	1997	33
Seoul[4]	1970	67	1992	61
Tokyo[4]	1970	65	1990	48
Shanghai[4]	1986	24	1995	15
Warsaw[4]	1987	80	1998	53

Source: 1. Barter (1999); 2. Secretaría de Transporte (2001); 3. City Hall Kuala Lumpur (2001); 4. WBCSD (2001)

A visit to any number of developing cities can quickly reveal the source of customer dissatisfaction with public transport and non-motorised options (Figures 1 and 2). Poor transit services in the developing world push consumers to private vehicle options. Public transport customers typically give the following reasons for switching to private vehicles:

1. Inconvenience in terms of location of stations and frequency of service;

2. Failure to service key origins and destinations;

3. Fear of crime at stations and within buses;

4. Lack of safety in terms of driver ability and the road-worthiness of buses;

5. Service is much slower than private vehicles, especially when buses make frequent stops;

6. Overloading of vehicles makes ride uncomfortable;

7. Public transport can be relatively expensive for some developing-nation households;

8. Poor-quality or non-existent infrastructure (e.g., lack of shelters, unclean vehicles, etc.)

9. Lack of an organised system structure and accompanying maps and information make the systems difficult to use; and

10. Low status of public transit services.

Figures 1 and 2. *The poor quality of public transport in developing cities creates great hardship for the citizenry.*

However, all of these problems can be rectified within the modest budgets of developing-nation municipalities. Cities such as Bogotá (Colombia), Curitiba (Brazil), and Quito (Ecuador) have dramatically improved transit services with simple solutions. In each case, the city relied upon low-cost improvements in public transit and non-motorised infrastructure rather than expensive tailpipe technologies.

In reality, virtually all developing cities possess a significant advantage in terms of achieving a more sustainable urban form. Most developing cities already posses a high mode share for public transit and non-motorised modes as well as a fairly high-density, mixed use design pattern. The challenge for these cities is to improve and modernise their transport systems in order to preserve their inherent advantages. Table 7 provides mode share data from a sampling of different developing cities.

Table 7 Mode share of urban transport in selected developing cities

City	Mode share (percentage of daily trips)			
	Non-motorised transport	**Public transport**	**Private motorised 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
Bogotá, Colombia (2000)	15	71	12	2

Source: Vasconcellos (2001), WBCSD (2001)

The loss of mode share from public transport and non-motorised options towards private vehicles is not pre-ordained. Municipal leaders who wish to transform their cities and provide efficient mobility can do so with a relatively low-cost and low-technology approach. To make this happen, the challenge is typically more political than technical.

Unfortunately, in developing nations such as China, policy making has seemed to take a different direction. Official policy in China has worked towards promoting vehicle use at the expense of non-motorised options. In recent years, China's vehicle ownership level has been growing by as much as 40 per cent each year (Whitelegg and Haq, 2003). The Mayor of Beijing exuded pride in the fact that the city's construction of a fifth and sixth ring road "beats the number of ring networks in Paris and Tokyo" (Gittings, 2002). The automobile is officially touted as a symbol of progress and modernity for China.

In cities, such as Shanghai and Guangzhou, that are promoting automobile manufacturing, bicycle mode share has fallen dramatically. In Shangahi mode share has gone from 33 per cent in 1995 to 27 percent in 2000; in Guangzhou mode share has fallen from 33 per cent in 1995 to less than 20 per cent in 2002 (Hook, 2002). Most major Chinese cities are actively discouraging bicycle use through priority measures for automobiles and through the neglect of non-motorised infrastructure. In December 2003, Shanghai officials announced a new policy of effectively banning bicycles from central portions of the city.

If China manages to reach a vehicle ownership level equal to that of the United States, the global vehicle fleet would grow by approximately 1 billion. If India was to do the same, then another 740 million vehicles would be added to the global fleet.

Even at European ownership levels, China is still adding nearly 550 million vehicles. Clearly, decisions in developing cities today have profound global ramifications.

3. Framework for transport emissions

To understand the relative importance of behavioural (mode share) and land-use measures relative to technology measures in reducing greenhouse gas emissions, an appropriate analytical framework is needed. The International Energy Agency (IEA) and University College London (UCL) are currently working to development such a framework and to better understand contributions from each individual component.

As noted in Figure 3, all three elements (behaviour, land-use, and technology) have a basic role to play in determining overall emission levels.

Figure 3 Calculation of transport emissions for an individual mode

		Mode share (behaviour)		Distance travelled (land-use/design)		Fuel efficiency (technology)
Transport emissions per mode	=	Number of vehicles	x	Distance travelled	x	Emissions per vehicle distance travelled

These three broadly-defined variables each consist of several different components. For the case of public transport, the "mode share" is affected by at least two component categories:

1. Customer utility – This component includes system attributes such as cost, comfort, convenience, travel time, and security that encourage people to use a particular mode; and,
2. System capacity – The total capacity of the system effectively acts as the ceiling to the amount of mode share that is possible to achieve.

The "distance travelled" is affected by at least two component categories:

1. Land use changes – Transit-oriented-development (TOD) and complementary land-use policies can ultimately produce changes in travel distances by bringing destinations closer to trip origins and by allowing for a single trip to replace what was previously several separate journeys; and,
2. System design and management – The routing structure and the location of stations and terminals will directly affect the distance travelled; also, efficiently managing the number of vehicles operating at peak and non-peak times will produce savings.

The "fuel efficiency" is affected by at least two component categories:

1. Operational efficiency – The "smoothness" of the vehicle operations (number of stops, amount time idling, use of dedicated busways, etc.) will impact the fuel usage; and,
2. Vehicle efficiency – The type of propulsion technology, the type of fuel utilised, the materials and design of the vehicle, and the quality of the vehicle maintenance all directly impact the fuel usage rate.

It is worth noting that "vehicle efficiency" is just one of many constituent parts in this emissions framework. However, too often this category is the only one pursued by both local and international groups seeking to reduce emissions and improve efficiency. Table 8 provides an overview of each of the component categories to public transport emissions.

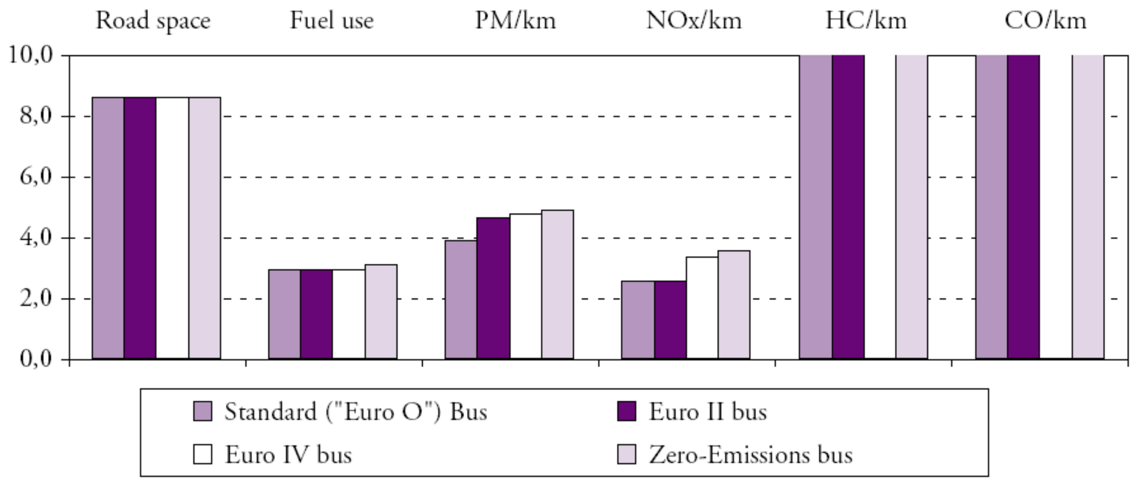
Table 8 Overview of components affecting public transport emissions

Equation variable	Component Category	Components
1. Mode Share	1.1 Customer utility	▪ Customer service attributes that affect customer satisfaction including: affordability, appearance, awareness, clarity, comfort, convenience, integration with other modes, reliability, safety and security, vehicle type ▪ Operational efficiencies that affect travel time (dedicated busways, route structure, service frequency, dwell times, station location)
	1.2 System capacity	▪ Vehicle capacity ▪ Infrastructure capacity (stations, terminals, fare collection systems)
2. Distance Travelled	2.1 Land use	▪ Transit-oriented development ▪ Reinforcing land-use policies
	2.2 System design and management	▪ Dedicated busways ▪ Route structure ▪ Terminal and depot locations ▪ Management of number of vehicles at peak and non-peak times

3. Fuel Efficiency	3.1 Operational efficiency	▪ Dedicated busways (impact on both transit vehicles and mixed traffic vehicles) ▪ Route structure ▪ Dwell times ▪ Distance between stops ▪ Driver behaviour ▪ Vehicle control systems
	3.2 Vehicle efficiency	▪ Carbon content of fuel ▪ Propulsion system efficiency ▪ Vehicle design and materials (weight, aerodynamics, etc.) ▪ Vehicle mechanical maintenance

The International Energy Agency (IEA) has conducted some initial analysis to determine the relative impacts of mode share in comparison to different fuel and propulsion options. The IEA 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 per cent load factor for the bus and only eight per cent of the passengers having switched from private vehicles, the resulting emission reductions were substantial. The projected reductions in hydrocarbon and carbon monoxide emissions per kilometre were over ten times the emissions of a single bus[1] (IEA, 2002). The reduction per kilometre of particulate matter, nitrogen oxides, and carbon dioxide (fuel use) ranged from two times to four times the emissions of a single bus (Figure 4).

Figure 4 Impacts of mode shifting to public transport



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 results. This result occurred because the relative impact of the tailpipe standard (and thus the fuel and

[1] The IEA study notes that this high level of emission reductions is achieved "because diesel buses emit very low levels of these pollutants compared to two and three-wheelers" (IEA, 2002, p. 47).

propulsion choice) was overwhelmed by the impact from mode switching. The IEA study notes that:

> "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, 2002, 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, 2002, p. 48)

The IEA results do not imply that fuel and propulsion technology should be ignored in achieving lower emissions. However, the results do suggest that these technologies alone only address a relatively small portion of the total emission reduction potential. Improving the efficiency of the transport sector and reducing emissions revolves around a full set of factors, including the many factors that are most important to customers such as cost, comfort, convenience, and security.

4. The tranformation of Bogotá, Colombia

4.1 Background

The IEA research indicates that perhaps the most effective emission strategy is a synergistic package of low-cost measures that encourage mode shifting, more efficient land use, and improved fuel and propulsion technology. The recent transformation of the transport sector in Bogotá (Colombia) provides perhaps the best world example of this premise in action.

Prior to 1997, Bogotá was not unlike most other large developing cities. The "public" transport sector was entirely in the hands of thousands of private operators. Fifeteen to thirty year old buses and mini-buses roamed the city in an uncoordinated fashion competing for passengers who were largely captive to an uncomfortable, insecure, and wholly unpleasant service.

In reality, Bogotá seems a rather unlikely place for creating a new standard in sustainable urban transport. As a large, densely-populated city with 7 million inhabitants and approximately 230 inhabitants per hectare, Bogotá has its own share of developmental issues, including high levels of unemployment and a history of violence. The violence in part stems from a nation that has been engaged in a virtual civil war for the past four decades.

Nevertheless, thanks to a series of dynamic mayors Bogotá has become a world leading example of sustainable transport. Mayor Enrique Peñalosa presided over a three-year term (1997-2000) that witnessed a dramatic transformation of the city (Figures 5 and 6). After decades of failed metro plans, the mayor led a process to build a high-quality "surface metro" system using bus-based technology.

This concept is known as “Bus Rapid Transit” (BRT). BRT gained its initial prominence with its application in Curitiba (Brazil) beginning in 1974. 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, 2003). 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:

Figures 5 and 6. *Bogotá went from this to...*

…this, in just three years.

- Exclusive right of way lanes
- Rapid boarding and alighting
- Free transfers between lines
- 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

The Bogotá BRT system, known as TransMilenio, included an initial phase with 40 kilometres of dedicated busways that was delivered at a cost of US$ 5.3 million per kilometre, considerably less than rail-based options. Most BRT systems today are being delivered in the range of US$ 500,000 to US$ 10 million per kilometre. By contrast, elevated rail systems and underground metro systems can cost from US$ 50 million per kilometre to over US$ 200 million per kilometre. The lower cost allowed Bogotá to finance the initial phase largely through existing local resources and not through international loans. A portion of the national petrol tax in Colombia is dedicated to financing local transit.

The system now features 58 kilometres of busways and 309 kilometres of feeder routes, moving over 800,000 passengers per day. Additionally, by achieving peak capacities of over 36,000 passengers per hour per direction, TransMilenio has changed how transport planners previously viewed the capacity potential of bus-based systems. TransMilenio is also making money, and does so while providing an affordable single fare of approximately US$ 0.37. Through a competitive bidding process, the system features multiple private sector operators. Oversight for the system is provided by a non-profit public company, TransMilenio SA, which employs a small team of approximately 80 persons to manage the BRT system for the entire city. A separate concession was also awarded to a private firm handling fare collection. Operators are compensated based upon the kilometres travelled, which is recorded by a geographical positioning satellite (GPS) system. The system functions with no operating subsidies, even with each private sector operator financing Euro II, articulated buses.

Of course, to optimise public transport's contribution to any city, it is best integrated with complementary measures. Bogotá thus also features nearly 300 kilometres of new, high-quality cycle ways. In a few short years, bicycle mode share has increased from approximately 0.4 per cent to over three per cent of all trips. Likewise, public space has been reclaimed to provide better pedestrian access.

Bogotá has also gained fame for its development of car-free events. Each Sunday 120 kilometres of arterial roadways are closed to private motorised vehicles (Figure 7). In their place, as many as two million inhabitants take to the streets as cyclists, skaters, and strolling families. The festive atmosphere of the Sunday "ciclovía" (bicycle street) is credited with creating a great sense of community and citizen culture in the city. Bogotá is also holds the world's largest car-free weekday event, covering the entire expanse of the city's 28,153 hectares. The first car-free day during a weekday was held in February 2000. The day has become institutionalised through a public referendum. On 29 October 2000, 63 per cent of the voters in Bogotá approved a referendum to make the February car-free day event permanent. Additionally, Bogotá is also home to what is called the world's longest pedestrian corridor, "Alameda Porvenir". This 17-kilometre stretch of pedestrian and bicycle paths connects several lower-income communities to shops, employment, and public services.

Figure 7. *As many as two million of the city's inhabitants take to the streets during Bogotá's weekly car-free Sundays.*

Bogotá's success with non-motorised and public transport modes is also due to a highly synergistic implementation of transportation demand management (TDM) techniques, which have acted to discourage private vehicle usage. Each week day the city restricts 40 per cent of all autos entering the city during the morning (06:00 to 09:00) and evening (16:30 and 17:30) peak periods. The reduction is achieved by not allowing autos with license plates that end in certain numbers to enter on a particular day (Table 9). Emergency vehicles, diplomatic and presidential vehicles, and public utility vehicles are exempted.

Table 9 License plate restrictions in Bogotá

Day of week	License plates ending with these numbers are restricted from use
Monday	1, 2, 3, 4
Tuesday	5, 6, 7, 8
Wednesday	9, 0, 1, 2
Thursday	3, 4, 5, 6
Friday	7, 8, 9, 0

The city has also dramatically reformed its control on parking. On-street parking has been eliminated from most streets, with privately contracted firms providing off-street parking services. In many cases, the previous parking bays have been converted into more attractive public space (Figure 8).

Figure 8. *Bogotá has converted much of its previous parking space to public space.*

4.2 Bogotá's emission impacts

Bogotá's broad package of sustainable transport options allows a relative comparison of the emission impacts from different mechanisms. In turn, this type of comparative analysis can be used in other cities to prioritise investments towards the most effective solutions. The results of a Bogotá emissions analysis will also help international agencies target the most cost-effective mechanisms to reduce greenhouse gas emissions. In fact, a current proposal to the Global Environment Facility (GEF) calls for a detailed emissions analysis of Bogotá's BRT system. The TransMilenio system is also the subject of the first transport initiative being brought forward as a project of the Clean Development Mechanism (CDM) under the "ERUPT" programme of the government of The Netherlands. If the CDM proposal is successful, Bogotá would be the first site of a transport project receiving credits as Certified Emission Reductions (CERs).

As a system-based approach to public transport, the TransMilenio system is able to address virtually all the possible components in an emissions reduction effort, as outlined earlier in Table 8. Specifically, TransMilenio is achieving emission reductions through the following mechanisms:

- Increasing the share of public transport ridership by dramatically improving the quality of service (in terms of travel time, comfort, security, cleanliness, etc.);
- Replacing 4 to 5 smaller buses with a larger articulated vehicle;
- Requiring the destruction of 4 to 8 older buses for every new articulated vehicle introduced into the system;
- GPS controlled management of the fleet allowing the optimisation of demand and supply during peak and non-peak periods;
- Encouraging transit-oriented development around stations and along corridors; and,
- Emission standards currently requiring a minimum of Euro II emission levels with a future schedule requiring eventual Euro III and Euro IV compliance.

Bogotá is one of the few cities in the world that is registering a significant increase in public transport ridership. According to a study by Steer Davies Gleave (2003), ten per cent of ridership on Bogotá's BRT system comes from persons who previously drove a private vehicle to work. The quality of TransMilenio is such that even middle- and higher-income travellers are utilising the system. The older mini-buses that dominated Bogotá prior to TransMilenio were largely not an option that discretionary transit users would frequent.

Figure 9. *In phase 2 of TransMilenio, for every new articulated vehicle introduced into the system, 7.0 to 8.9 older vehicles are destroyed.*

Like much of Latin America and elsewhere in the developing world, Bogotá's public transport sector has historically not been highly regulated. The result has been a large proliferation of small private sector operators who compete aggressively with one another for a relatively captive transit market. Such market conditions can create relative inefficiencies in which an oversupply of small vehicles translates into congestion and high levels of contamination. Prior to TransMilenio, over 22,000 public transport vehicles of various shapes and sizes plied the streets of Bogotá. In order to rationalise the system, companies bidding to participate in TransMilenio were required to scrap older transit vehicles. During the first phase of TransMilenio, the winning bids agreed to scrap approximately four older vehicles for each articulated vehicle introduced (Figure 9). In the second phase, the successful bids committed to scrapping between 7.0 and 8.9 older buses for each new articulated vehicle. The destruction of older vehicles prevents the "leakage" of these vehicles to other cities.

Each articulated vehicle in TransMilenio has a capacity of 160 passengers. The vehicles are currently achieving a load factor of approximately 80 to 90 per cent. The older public transport vehicles in Bogotá come in a variety of sizes, from microbuses to full-sized conventional buses. Table 10 summarises recent data collected on characteristics of public transit vehicles in Bogotá.

Table 10 Characteristics of public transit vehicles in Bogotá

Vehicle type	Passenger capacity	Fuel consumption (km / litre)	Passengers per vehicle-kilometre travelled (IPK)
TransMilenio articulated bus, Euro II diesel	160	1.56	5.20
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: Martínez, 2004

The differences in "passengers per vehicle-kilometre 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 efficiencies associated with congestion and an oversupply of vehicles.

The CDM proposal developed for the TransMilenio system provides an estimate of emission reductions achieved due to mode shifting and energy efficiency gains. The study does not include any emission reduction projections emanating from land-use changes. The proposal develops a baseline scenario (Bogotá without the TransMilenio system) and a project scenario (Bogotá with the TransMilenio system). In the project scenario the analysis also accounts for expected emission increases due to industrial emissions from the construction of concrete busways and the added energy process emissions from the scrapping of older transit vehicles. The emission reductions are principally achieved through carbon dioxide (CO_2) reductions, but the impacts of methane (CH_4) and nitrous oxide (N_2O) are also included. Table 11 summarises the study's results for the period of 2001 through 2016. The annual reductions increase significantly over the period due to the continued expansion of the TransMilenio system.

Table 11 Projections for greenhouse gas emission reductions from Bogotá's TransMilenio system (tons of CO_2-equivalents)

Year	Baseline scenario (tons of CO_2-eq.)	Project scenario (tons of CO_2-equivalents)					Total annual reductions (tons of CO_2-eq.)
		Private buses	Trans-Milenio	Cement produc-tion	Vehicle scrap-ping	Project scenario total	
2001	1,580,925	1,450,471	74,510	27,355	12,646	1,564,982	15,943
2002	1,567,044	1,440,392	85,256	0	11,476	1,537,124	29,920
2003	1,557,493	1,387,571	95,236	7,339	15,587	1,505,733	51,760
2004	1,558,716	1,357,836	99,840	20,683	17,792	1,496,150	62,566
2005	1,562,152	1,212,356	145,198	0	29,732	1,387,286	174,866
2006	1,556,963	1,199,327	147,550	0	30,864	1,377,741	179,222
2007	1,551,663	1,184,314	149,898	0	31,902	1,366,113	185,550
2008	1,552,519	1,173,484	152,260	0	33,060	1,358,804	193,715
2009	1,556,270	1,165,207	154,597	13,010	34,300	1,367,115	189,155
2010	1,586,795	1,034,346	177,373	12,543	45,606	1,269,868	316,927
2011	1,616,032	854,166	210,317	5,671	57,902	1,128,056	487,976
2012	1,612,589	823,534	217,029	0	63,387	1,103,950	508,639
2013	1,608,863	815,339	217,048	7,072	65,309	1,104,768	504,095
2014	1,662,188	713,824	249,013	0	76,639	1,039,476	622,712
2015	1,661,548	688,882	252,482	0	78,240	1,019,604	641,944
2016	1,666,696	639,111	253,477	0	76,203	968,791	697,905
Totals	25,458,456	17,140,160	2,681,084	93,673	680,645	20,595,562	4,862,894

Source: CAF, 2004

Thus, for just the period of 2001 through 2016, the TransMilenio system is expected to reduce greenhouse gas emissions by a total of 4.86 million metric tons of CO_2 equivalents. The period of 2001 through 2016 represents the period over which the construction of the entire system will take place. By 2016, there will be 388 kilometres of exclusive busways constructed in Bogotá. These projections are most likely to be conservative values given that the impacts from land-use changes are not included. Further, the life of the project can be extended significantly as much of the infrastructure will have a duration of 20 to 30 years before requiring complete renovation and/or reconstruction. Thus, the relative amount of emission reductions realised in the year 2016 can be expected to continue for many additional years. Based on this assumption, an extrapolation of the project through the year 2030 yields a total emission reduction of 14.6 million metric tons of CO_2 equivalents.

Although land-use impacts have yet to be quantified on the TransMilenio system, there is already evidence to suggest that the effect could be quite significant. Large commercial centres are being constructed along the corridors, especially near terminals and stations. Forthcoming research indicates increases in residential property values are directly proportional to proximity to TransMilenio stations (Rodriguez and Targa, forthcoming, 2004). The densification of commerce, employment, and residences along the TransMilenio corridors will likely yield reductions in both the number of trips undertaken as well as the average distance of each trip.

The results from TransMilenio are likely to be influential in justifying similar initiatives elsewhere. The project confirms the significant synergies that can be realised by following an emissions reduction strategy based on a "systems" approach. If the city had only upgraded the vehicle technology without the development of higher-quality transit service, priority busways, enclosed stations, and a new business model for transit operations, then the emission reductions would likely have been significantly less impressive.

4.3 The potential for replication

The extent to which other cities will be able to realise similar amounts of emission reductions will depend upon many local factors including the relative efficiency of existing bus operations and the percentage of commuters likely to switch to a higher-quality service. However, given that Bogotá has achieved a dramatic transformation of its transit services at a relatively economic cost and with largely local financial resources, there would appear to be much potential for replication elsewhere. Already, in conjunction with the National Department of Planning and the World Bank, the Colombian government is preceding with bus rapid transit projects in six additional cities, including Barranquilla, Bucaramanga, Cali, Cartagena, Medellin, and Perreira.

Bogotá has also captured attention from city officials in other nations as well. Over one thousand city officials from over 50 countries have visited the new Bogotá in the past few years. New BRT systems are already in operation in Jakarta (Indonesia) and Leon (Mexico). Cities as diverse as Accra (Ghana), Cape Town (South Africa), Dakar (Senegal), Dar es Salaam (Tanzania), Delhi (India), Dhaka (Bangladesh), Guatemala City (Guatemala), Lima (Peru), Mexico City (Mexico), and Santiago (Chile) are now either constructing or are planning a BRT system, in part due to the Bogotá experience.

The experience of Bogotá as well as that of Curitiba (Brazil) has also been influential in the developed world. Bus rapid transit systems may be one of the best examples of technology transfer from the developing south to the developed north. Already basic systems have been developed in cities such as Brisbane (Australia), Nagoya (Japan), Ottawa (Canada), and Rouen (France).

5. The international response

Transport policy decisions made today in developing nations will have profound ramifications on any possible attempt to control global greenhouse gas emissions. Additionally, 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 realised in developing cities. Once policies are orientated exclusively towards motorisation and techonological control strategies, then it will be extremely difficult to later shape more sustainable alternatives. As the developed world has discovered, moving commuters away from private vehicles to public transport and non-motorised options is quite difficult and costly.

Thus, given the potential impact of short-term decisions on the long-term future of developing-city transport, it would be expected that the international community would be strongly backing the sort of low-cost solutions that have shown such promise in cities like Bogotá. To an extent, international recognition of lower-cost and lower-technology providing significant impacts is beginning to occur. The German Overseas Technical Assistance Agency (GTZ) has developed a sustainable transport sourcebook covering a range of practical options for developing-nation cities.[2] Likewise, the United States Agency for International Development (USAID) is supporting BRT initiatives in such cities as Accra (Ghana), Cape Town (South Africa), Dakar (Senegal), Delhi (India), and Jakarta (Indonesia).

However, compared to other sectors, the transport sector has received relatively scant attention as an effective means towards emission reductions and greater energy efficiency. Further, when local governments and international organisations have invested in transport initiatives, the overwhelming tendency has been toward fuel and propulsion systems. It is thus worth asking if we have been looking for transport CO_2 reductions in all the wrong places.

To date, two major international agreements have been brought forward to curb greenhouse gas emissions. At the 1992 United Nations Conference on Environment and Development (UNCED), member nations developed the United Nations Framework Convention on Climate Change (UNFCCC). By 1994, 186 countries had ratified the convention, putting 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 (JIQ, 2002).

Subsequently, in 1997, the Kyoto Protocol was drafted. The protocol calls for developed nations to reduce emissions by an average of 5.2 per cent from a 1990 baseline. While ratification of the agreement remains stalled, several nations and organisations are proceeding with mechanisms that involve projects in developing nations as well as economies in transition. The initiatives inspired by the Kyoto mechanisms are being developed under the framework of the “Clean Development Mechanism” (CDM) and “Joint Implementation” (JI). These new mechanisms permit investors to gain Certified Emission Reductions (CERs) by investing in emission reducing projects in developing nations and economies in transition.

However, once again the transport sector has largely been ignored. CDM and JI projects are being supported by the government of Finland, the government of The Netherlands, and a World Bank programme called the Prototype Carbon Fund (PCF). Of the seven CDM projects and five JI projects sponsored by the Finnish government, none are in the transport sector. Likewise, within the ERUPT programme of The Netherlands there are 18 CDM projects and 8 JI projects, none of which are transport related. The World Bank created the Prototype Carbon Fund (PCF) to help stimulate the growth of a more robust market for emissions trading. To date, the PCF has funded nine CDM projects and four JI projects, none of which are transport related (JIQ, 2004). The recent proposal submitted to the Dutch government on the Bogotá TransMilenio system would be the first such project in the transport sector.

[2] For more information on the GTZ Sourcebook, see www.sutp.org.

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, United Nations Development Programme (UNDP), the United Nations 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).

One of these initial projects included a US$ 60 million investment by UNEP to finance 46 fuel-cell buses in developing cities such as Beijing, Cairo, Mexico City, Sao Paulo, and Shanghai. 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 utilised. If instead the US$ 120 million investment was applied towards bus rapid transit systems, then anywhere from 23 to 240 kilometres of a BRT system could have been financed. In fairness, though, 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, and Santiago.

The list of world-wide technology-focused initiatives is extensive. The US government has committed to funding fuel-cell research at a level of US$ 1.3 billion. By contrast, projects focused on mode switching to public transport or supporting non-motorised infrastructure are typically small in both number and size. It is possible that simply improving the state of developing-nation sidewalks could be one of the most effective long-term measures, both from the perspectives of cost and overall development. However, it is unlikely that any global sidewalks initiative is on the horizon anytime soon. The reasons for the apparent bias towards higher-technology solutions is likely due to a complex set of reasons:

- Establishing baselines in the transport sector can be quite difficult as mode shares, particularly with regard to motorisation, are fairly dynamic in nature.
- Private sector opportunities largely reside in fuels and vehicles; system type upgrades such as improved customer service either do not have large commercial opportunities or such opportunities tend to be local in nature.
- Public transport and infrastructure for sidewalks and cycleways tend to be largely "public" goods with less perceived opportunity for private firms to gain emission credits.
- 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 are perceived as being "sexier" and more "modern" by many political officials.

Most of these perceptional issues can be overcome. Bogota has demonstrated that a systems-based approach is not only significantly more effective in reducing emissions but can also be quite profitable as well. The transport sector should become a more viable option for local and international organisations seeking to achieve core economic, environmental, and social objectives.

6. Conclusions

Emissions from the transport sector represent the fastest growing source of global 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 motorisation levels of developed nations, the sheer number of private vehicles on the roadways will overwhelm any advances made by cleaner fuels.

Given such circumstances, it is surprising that relatively little action has been taken in this area. To the extent that transport emissions are being addressed at all, local and international attention is still mostly focussed on fuel and propulsion system solutions. However, a more promising alternative is a systems-based approach as achieved in Bogota. Low-cost, low-technology solutions that focus on providing higher-quality public transport and viable non-motorised options will help preserve sustainable transport mode shares in developing cities. Technology is still part of an optimised approach but within a package that includes attention to mode share and land use as well.

Access and mobility are basic to modern life and play a significant role in realising development and an improved quality of life. The promotion of exchange and movement does not need to conflict with our economic, environmental, and social goals. However, the road to transport efficiency will necesitate a multi-faceted approach that is not solely technology dependent.

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