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GHG Emissions, Urban Mobility and Efficiency of Urban Morphology: A Hypothesis

“Carbon based energy pricing could trigger demand shift toward transit in dominantly monocentric cities providing adequate zoning changes were made. Is the zoning approach currently used in Singapore and New York applicable to other cities?”

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“If restraining carbon emissions from fossil fuel use is important to sustainability, then it is important to know whether technologies actually work; whether raising fuel prices work; whether non-price policies work. It is very hard to say how these kinds of stimuli affect energy use or emissions.”
Lee Schipper, 1999

1. Introduction: The link between GHG emissions, transport cost, transport speed and city shape

Urban productivity is dependent on people’s mobility within a metropolitan area. GHG emissions, however, are only weakly linked to the number of kilometers traveled per person because there are such large variations between the emissions per km passenger between different transport mode and between the carbon content of the various energy sources used for transport. To reduce urban GHG emissions due to transport, it is therefore important to look at all the parameters that contribute to emissions. People’s mobility depending on the choice of an urban transport mode is based on criteria of speed, cost, comfort, convenience, and reliability. Transport mode shifts that could reduce GHG would be possible only if all the demand factors are taken onto account. A supply driven approach to GHG reductions will have little chance of success if consumers’ demand is ignored.

In the following sections, we will review the three concurrent strategies that could contribute to reducing GHG emissions due to urban transport: technology change within mode, mode shift, and land use strategy allowing the spatial concentration of jobs. However, none of these strategies are likely to succeed if not supported by an energy pricing policy directly linking energy price to carbon content.

1.1. GHG emissions and urban transport

Urban GHG emissions per person in large cities are a fraction of the national average (Figure 1). This difference appears as a paradox as cities have a higher GDP per person than the national average and it is usually assumed that higher GDP means higher GHG emissions. In fact, modern
cities with a large proportion of service jobs consume less energy per capita than smaller towns and rural areas. Energy intensive industries are also usually land intensive and for this reason are not found anymore in large cities. However, because GHG are emitted in urban areas by a very large number of small sources – cars, appliances, individual buildings – as opposed to concentrated sources like power plants or factories, it is difficult to develop an emission reduction strategy that would work for all emitters.

**Figure 1: CO2 emissions in cities compared to countries**

Reliable data on urban emissions in cities are difficult to collect as there is always an ambiguity over what source should be included as urban. Should urban GHG emissions be limited to sources located within metropolitan boundaries? Or should the emission be counted on the basis of the consumption by people living in urban areas? The data for cities shown on *Figure 1* correspond to the first definition, although emissions from electricity are accounted for on the basis of consumption and not on emission at the location of the power plant.

Some data sets solve the definition problem posed by emission location vs. location of consumption by including “Life cycle emissions”.
For instance, the emissions of a car are not limited to the fuel consumed but include also the energy used to manufacture it, to maintain it, and to scrap it after its useful life. While this type of definition makes a lot of sense, the resulting numbers are difficult to calculate and the method implies a number of assumptions – in particular, concerning the number of years and the number of kilometers traveled included in the useful life of a vehicle – that numbers should be considered as independent variables in any GHG reducing strategies. It is important to be aware of the limitations of the data set available when comparing cities’ performance in GHG emissions. Some apparent inconsistencies in the data presented below can be attributed to slightly different assumptions in the data collected about emissions’ attributions.

Figure 2: CO2 emissions in 5 high income cities

The sample of 5 large cities\(^1\) in high income countries shown on Figure 1 gives a range of emissions from 4 to 7 tons per person per year in 2005 (McKinsey, 2008). It is likely that GHG emissions in cities in low and middle income countries, for which no reliable data are available, are even higher than the OECD cities shown on Figure 1. The use of older cars and

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\(^1\) London, New York City, Stockholm, Rome and Tokyo.
buses, and the prevalence of 2 strokes engines for motorcycles and three wheelers might contribute to higher GHG emissions per capita.

The three main sources of GHG emissions in cities are buildings, transport and industries. In the sample of 5 high income cities included in Figure 1, the proportion of GHG emissions due to transport varies from 25% of total emissions in New York City to 38% in Rome. (Figure 2)

This paper will be limited to identifying the best strategies to reduce GHG emissions due to transport in a context of increasing urban productivity. The conclusions of this paper would be particularly relevant to cities that are above 1 million inhabitants. According to UN data and projections, the population of cities above 1 million people represented about 1.2 billion people or 18% of the world population in 2005. In 2025 it is expected that the population of cities above 1 million will increase to 1.85 billion and will then represent 23% of the world population.

Transport is a key driver of the economy. It is a significant and the fastest growing sector of greenhouse gas (GHG) emissions globally. Between 1990 and 2003, emissions from the transport sector grew 1412m tones (31%) worldwide. The sector’s share of CO2 emissions is also increasing. In 2005, the transport sector contributed 23% of CO2 emissions from fossil fuel combustion. It is also the sector where the least progress has been made in addressing cost-effective GHG reductions (Sperling and Cannon, 2006). As mentioned above, the fragmentations of emissions sources and the complexity of demand and supply issues in urban transport explain the lack of progress. Making transport activity more sustainable must be a top priority policy if climate change is to be addressed.

The transport sector is highly dependent (98%) on fossil oil. In most cities, a number of urban problems are transport-related such as congestion on urban roads, poor air quality, fragmented labor markets, and social fractioning due to poor access to economic and social activity, etc. Road transport accounts for by far the largest proportion of CO2 emissions from the transport sector, principally from automobile transport. Against the projected increase in car ownership worldwide (expected to triple between 2000 and 2050), road transport will continue to account for a significant share of CO2 emissions in the coming decades. Within cities, modal share and measures facilitating less GHG intensive modes such as public transport require closer examination. Modal shift policies are generally inadequately assessed in CO2 policy (OECD, 2007). They are an important part of the
policies to manage traffic growth without restricting the accessibility that mobility provides.

Because GHG emissions caused by urban transport have to be reduced while urban productivity has to increase it is important to establish the links between urban transport, labor mobility and city productivity.

1.2. Mobility within spatial concentrations is the lifeblood of cities’ economies

“[...] mobility, which I would argue is the centerpiece of our national productivity, is neither highly valued nor understood among public officials.” (Pizarski, 2006)

Improvements in labor and goods mobility provided by urban transport networks have been the cause of the growth of large cities during the last 150 years. The emergence of Mega-cities in the last 50 years has been driven by the increasing return to scale and agglomeration economies caused by the spatial concentration of people and fixed capital. This spatial concentration has been made possible by improvements in transport technology.

Economic literature, both theoretical and empirical, linking the wealth of cities to spatial concentration is quite abundant and not anymore controversial in academic circles. National accounts show that the output share of large cities is always much higher than their share of population. The 2009 World Bank Development Report (World Bank, 2009) “Reshaping Economic Geography” and the report of the Commission on Growth and Development “Urbanization and Growth” (Annez, 2009) exhaustively summarize and document the theoretical and empirical arguments justifying the economic advantage provided by the spatial concentration of economic activities in large cities.

The necessity to manage urban growth rather than to try to slow it down is eventually reaching mayors, city managers and urban planners. The size of cities is not what matters; what matters is the connectivity insured by urban transport networks² between workers and firms and between providers of good and services and consumers, whether these consumers are other firms or individuals. This connectivity is difficult to achieve in large cities; it requires coordination between land use and investments in transport networks; difficult pricing decisions for road use, parking, and transit fares;

² We define urban transport network as including all public or private spaces and systems devoted to circulation of good and people, from sidewalks, elevators and cycle tracks to Bus Rapid Transit networks and underground rail.
and finally, local taxes and user fees that makes the maintenance and development of the transport network financially sustainable (Staley, 2008).

Congestion slowing down mobility represents a management failure on the part of city managers. Congestion has a double negative effect, it acts as a tax on productivity by tying down people and goods and it often increases GHG emissions even for vehicles that would otherwise be performing satisfactorily. It is conceivable that mismanaged large cities may reach a level of congestion whose negative effect may offset the economic advantage of spatial concentration. In this case, these cities would stop growing. However, the positive economic effect of agglomeration must be very powerful to offset the chronic congestions of cities like Bangkok and Jakarta that are still the economic engine of their region in spite of their chronic congestions.

Poor migrants moving to large cities have usually difficulties in participating in the urban economy either because their housing is located too far from the urban transport networks or because they cannot afford the cost of transit or motorized transport. It has been observed that some slums appear to be self sufficient and that many slum dwellers are able to just walk to work. Some have argued that slum dwellers’ lack of motorized mobility and inclination towards walking would constitute an advantage in terms of GHG emissions and should be emulated by higher income groups. This argument is a cruel joke on the poor as their lack of mobility condemns them to live in large cities with all its costs but none of its benefits. The lack of mobility in many slums and in some badly located government housing projects constitutes a poverty trap rather than an advantage to be emulated in the future. We will document below the issues raised by the lack of mobility of the poor in the case of Gauteng.

We are not implying that walking or cycling do not have their place as a mode of transport in large cities. To the contrary, they constitute an indispensable transport mode choice. However, people walking to work should do it by choice not because they are forced to do so by lack of access to other means of transport or because other means of transport are unaffordable. Because mobility is a necessity for economic survival in large cities, a reduction of GHG should not be made by reducing mobility and certainly not by preventing an increase in mobility for the poor. The reduction of the number of Passengers Kilometer Traveled (PKmT) should not be targeted for reduction in order to reduce GHG emissions. To the contrary, because of the lack of mobility of a large number of poor people living in large cities, PKmT should increase in the future. We will see below
that there are many alternative solutions to decrease GHG emissions while increasing PKmT.

1.3. **How to identify the key parameters in urban transport GHG Emission sources?**

GHG emissions from transport are produced by trips that can be divided into 3 broad categories:

1. commuting trips
2. non-commuting trips, and
3. Freight.

Commuting trips are the trips taken to go from residence to work and back. In most low income cities, commuting trips constitute the majority of trips using a motorized vehicle (with exceptions in some East Asian cities where non-motorized trips still constitute a large number of commuting trips). Non-commuting trips are trips whose purpose is other than going to work; for instance, trips to schools, to shops or to visit family or other personal reasons. In low income cities most of these trips involve short distances and are using non-motorized transport. Freight trips, including public vehicle travel and urban goods and services travel constitute a sizable portion of all trips but vary a lot between cities. Freight trips are always done by individual vehicle and cannot use transit. Road congestion affecting freight trips are extremely costly to the economy of cities.

In high-income countries, commuting trips constitute only a fraction of total trips. For instance in the US, commuting trips represented 40% of all motorized trips in 1956; in 2005 they represent only slightly less than 20% of all motorized trips (Pizarski, 2006). When non-commuting trips become more numerous and longer they tend to be done by individual cars or motorcycles as destinations are not spatially concentrated and transit networks cannot easily accommodate them. For instance, in New York in 2005 transit was used for 30.8% of all commuting trips but only for 9.6% of all commuting and non-commuting trips (O’Toole, 2008).

Will the trends observed in the US anticipate what will be happen in other parts of the world when more cities reach a level of income comparable to the US today? We do not think so. Most cities outside the US have a density far higher than American cities, often by 2 orders of
magnitude. While densities of large cities tend to decrease over time, the decrease is slow and is unlikely to ever reach the low density of US cities. It is probable that in high density cities non-commuting trips will use in large part non-motorized transportation, taxis or transit, as it is the case in high density Manhattan today.

We will therefore concentrate in analyzing emissions from commuting trips as it is the most common type of trips in low and middle income cities. In addition, commuting trips require the most capital investments because of the transport capacity required during peak hours. Commuting trips often define a transport network, the other type of trips, including freight, just piggy-back on the transport investments made initially for commuting trips. In East Asia, commuting trips using walking or bicycles constituted the majority of commuting trips in the 1980s and 1990s. During the last 20 years, because of the physical expansion of cities and the increase in floor space consumptions due to rising incomes, the share of non-motorized transport has unfortunately been shrinking. In 2006, for instance, the share of non-motorized commuting trips has been reduced to about 20% in Shanghai from about 75% in the early 1980s.

1.4. Disaggregating commuting trips by mode

Commuting trips could be disaggregated into three broad modes:

1. Non motorized mode (walking and cycling, and increasingly included in this category, people working at home and telecommuting)
3. Transit mode (minibuses, buses, bus rapid transit (BRT), light rail, subways and suburban rail).

The types of vehicles used in the last 2 modes vary enormously in emission performance. In addition, within each mode – SOV and transit – each city has a fleet of vehicles, which GHG emissions performance differs often by orders of magnitude depending on the technology, the maintenance, the age of the vehicle, the energy source, and the load (the average number of passengers per vehicle). In order to see more clearly the impact of different transport strategies on the reduction of GHG emissions, we have built a simple model linking the various vehicle fleet parameters to GHG emissions per commuter. The model is limited to analyzing CO2 emissions
from commuting trips, which are still the most common motorized trips in low and middle income cities.

For each mode, the inputs of the model are:

1. the % of commuters using the mode,
2. the average commuting distance,
3. the CO2 equivalent emission per Vehicle Kilometer Travelled (VKmT) , calculated for full life cycle when data available, and
4. the load factor per type of vehicle.

### GHG emissions for various vehicles with various passengers load assumptions

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Gr Co2 e. per passkm</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUV</td>
<td>258</td>
</tr>
<tr>
<td>Average US car</td>
<td>227</td>
</tr>
<tr>
<td>Motor buses</td>
<td>137</td>
</tr>
<tr>
<td>Light rail</td>
<td>111</td>
</tr>
<tr>
<td>Commuter rail</td>
<td>93</td>
</tr>
<tr>
<td>Hybrid gas</td>
<td>91</td>
</tr>
<tr>
<td>Toyota Prius</td>
<td>73</td>
</tr>
<tr>
<td>Hybrid Diesel</td>
<td>63</td>
</tr>
<tr>
<td>Metro</td>
<td>58</td>
</tr>
<tr>
<td>New York MTA</td>
<td>45</td>
</tr>
<tr>
<td>New York subway</td>
<td>36</td>
</tr>
</tbody>
</table>


**Figure 3: GHG emissions for various vehicles with various passengers load assumptions**

A number of publications provide GHG emissions expressed in grams of CO2 equivalent per Passenger Kilometer Traveled (PKmT) (*Figure 3*). However, the data assume a passenger load to calculate the CO2 per PKmT. As the load is a crucial parameter in the model, it has been necessary to calculate the CO2 emissions per Vehicle Kilometer Traveled (VKmT). However, fuel consumption may vary for the same vehicle, depending on the load, therefore, load and fuel consumption are not completely independent variables. We have therefore slightly adjusted the energy consumption values by VKmT to reflect this. A more sophisticated model would establish more accurately the relationship between load and fuel consumption for each type of vehicle. For demonstration purpose of the methodology, we propose we found that our results were robust enough to allow this simplification.

The equation used in the model showing the daily GHG emissions as a function of the number of passengers using different modes, with different
average commuting distances, load factor and engine fuel performance is presented on Figure 4.

\[
Q = T \sum_{i=1}^{N} \frac{2.D_i.P_i.E_i}{L_i.10^6}
\]

Where:
- \(Q\) is the total carbon equivalent emitted per day by passengers while commuting to work (does not include non commuting trips) in metric tons per day.
- \(T\) is the total Number of commuters per day
- \(N\) is the number of commuting transport modes types numbered from 1 to \(N\)
- \(D_i\) is the Average commuting distance one way per passenger in km per type \(i\) of commuting mode
- \(P_i\) is the percentage of commuters using transport mode type \(i\)
- \(E_i\) is the carbon emissions of vehicle used for mode \(i\) in gram carbon equivalent (full life cycle) per vehicle kilometer traveled
- \(L_i\) is the load factor expressed in average number of passengers per vehicle of type \(i\)

**Figure 4: Equation linking mode characteristics to daily GHG emissions**

We can see clearly from the equation shown on Figure 4 that trying to reduce the average commuting distance per day (variable \(D\)) – de facto reducing labor mobility – would not provide much effect on \(Q\) (GHG emissions per day) compared to a change in vehicle fleet performance (variable \(E\)), a mode shift (variable \(P\)) or an increase in the load factor (variable \(L\)). As seen on Figure 3, the possible values taken by \(E\) vary by a factor of 4 between an hybrid diesel and an SUV, and by a factor of 2 between New York Subway and a Toyota Prius! By contrast, land use changes might at best manage to reduce average commuting distance \(D\) within a period of at least 20 years by 5 or 10% at best.

This model, which could be used as a rough policy tool, was tested for parameters for New York and Mexico City. The inputs and outputs of the model using New York parameters in 2000 are shown on Figure 5.
The model shows the difference of performance in terms of GHG emissions between transit and cars in New York: emissions per car passenger per year are nearly 6 times more than the emissions per transit passengers. The model allows testing the impact of alternative strategies; for instance, what would be the impact of an increase of hybrid cars over the total number of cars, everything else staying constant. Or what would be the impact of an increase in transit passengers, or in the load factor of buses, etc. Figure 6 shows the impact of 2 alternatives in reducing GHG emissions.

The table shown on Figure 6 demonstrates the potential impact in New York of a change in the composition of the car fleet and alternatively, a mode shift from cars to transit. The changes concern only the value of variable P in the model’s equation. The current situation in 2005 is shown in column (A). In column (B) an increase from 0.5% to 19% in the number of commuters using hybrid cars representing about 1 out of 4 cars used by commuters bring a 28% reduction in GHG emissions. In column (C) a mode shift from car to transit, raising the share of transit from 36% of commuters to 46% decrease GHG emissions by 13%. Further reductions could be achieved by introducing hybrid buses or increasing loads of both cars and transit.
The use of the model allows a back-of-the-envelope calculation of the impact of potential changes in technology and transport mode on GHG emissions. The model does not have anything to say about the feasibility or the probability of such a change to occur. While the rough calculations shown above imply that the combined impact of technology change and mode shift could be large, how to achieve these changes remains the main problem to be solved. Most of the vehicle technology, such as hybrid engines, that reduce fuel consumption has been around for at least 10 years. Rail transit using electricity has been common in large cities for more than 100 years. The fact that in many cities the use of transit represents a minority mode raises important questions about consumer preferences for urban transport. The transport mode split for New York in 2005 shown on Figure 5 represents a state of equilibrium. It is important to know what factors could change this equilibrium to a new state that would be more favorable for GHG reductions.

1.5. Consumers’ demand for transport depends on price, speed and urban spatial structures

The loss of transit share over the last decades in most major cities of the world has to be acknowledged. Even in Singapore transit mode share...
declined from 55% of commuters in 1990 to 52.4% in 2000 \(^3\) (Singapore Census, 2000). This decrease is striking as Singapore has had the most consistent transport policy over 2 decades favoring transit, including strict limits on car ownership and has been a world pioneer for congestion pricing using advanced technology. In addition Singapore has always had an excellent coordination between land use and transport investments.

While the preceding section has shown that there is an overwhelming case for increasing transit mode in order to reduce GHG emissions, consumer choice seems to follow the opposite trends. It is therefore important to understand why transit is loosing ground in so many cities and what alternative strategies exist and in which type of cities the trend could possibly be reversed.

Consumers’ decision to use one mode of transport over others depends on 3 main factors:

1) Cost of transport
2) Speed of transport
3) Convenience: frequency, reliability of service and comfort.

For low income commuters the cost of transport is the major consideration. For very low income commuters walking is often the only affordable alternative significantly lowering their ability to take advantage of the large labor market offered by large cities. In Mumbai, for instance, about 4 millions people walk to work every day (about 45% of the active population). Middle income and low income users above extreme poverty are the prime customers for transit, as fare are often subsidized and buying and maintaining a car is beyond the means of a large number of households in low and middle income countries. However, in a number of middle and high income countries some cities retain a significant number of transit users who are middle or high income – for instance, London, Hong Kong, New York, Paris, Singapore, among others. How these cities have managed to maintain a high use of transit among affluent households will be described in the next section.

In an increasing number of low or middle income cities the dispersion of employment makes it inconvenient to use transit as no transit route goes directly to their location of employment. For these commuters, too poor to use individual cars or motorcycles, collective taxis or minibuses are the most

\(^3\) This figure from the 2000 census reflects resident working persons aged 15 years and over by mode of transport to work which includes public bus, MRT or taxi.
convenient mode of commuting. Commuting by microbuses at the expense of transit has become the dominant transport mode in Gauteng, Mexico City, and Tehran, for instance.

As households’ income increases, the speed of transport and convenience become more important factors than cost, or rather, higher income commuters give a higher value to the time spent commuting than lower income ones. Speed of transport is limited in most transit system by frequent stops and the time required for transfers. In city structures where car is a feasible alternative mode of transport, commuters who can afford the cost would normally switch to individual cars.

Figure 7: Average travel time in US cities by transport mode

The exhaustive study conducted by Alan Pizarski (Pizarski, 2006) on commuting characteristics in US cities gives an order of magnitude of the speed difference between transit and individual cars in US cities (Figure 7). The average commuting distance is about the same between the different modes except for walking, cycling and railroad. One can see that in spite of the congestion prevalent in most US cities, commuting time by transit requires about double the time required by individual cars. Travel time for
car pooling when involving more than 4 people becomes similar to transit. This explains in great part the loss of transit share in US cities in the last 2 decades.

**Singapore - Travel time, distance per travel mode**

<table>
<thead>
<tr>
<th>Mode</th>
<th>Median Travel Time (minutes)</th>
<th>Distance (km)</th>
<th>Speed Km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car</td>
<td>27</td>
<td>29.2</td>
<td>65</td>
</tr>
<tr>
<td>Metro</td>
<td>41</td>
<td>11.5</td>
<td>17</td>
</tr>
<tr>
<td>Metro + Bus</td>
<td>51</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bus alone</td>
<td>38</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Figure 8: Singapore - Travel time by transport mode*

In Singapore, with one of the most efficient transit system in the world, the ratio between transit travel time over car driving time is lower than in US cities. However, the difference in travel time is significant enough to indicate that transit would not be a first choice transport mode for people who can afford an alternative. The high speed of car commuting is of course part of the success of Singapore transport strategy. Congestion pricing, constantly adjusted to facilitate fluid traffic, ensure high speed for all car commuters who can afford the high premium paid for car ownership and for congestions tolls.

The challenge is to propose urban transport strategies that would result in reducing GHG emissions while maintaining mobility as reflected by commuters’ mode preference. These different strategies would have to be adapted to different spatial forms of urban growth – monocentric, polycentric, high and low densities – and to a context of increasing urban income and a decreasing cost of car acquisition. These strategies will have to rely on the 3 tools available to urban managers: pricing, regulations and land use policy.

**1.6. Two hypothesis are tested in this paper:**

This paper seeks to address travel in urban areas, inquiring the link between GHG emissions, public transport, road transport and their travel cost and city shape. The central hypothesis is that carbon based energy pricing could trigger demand shift towards transit in dominantly
monocentric cities, providing adequate zoning changes were made. More specifically, it seeks to develop and determine the following:

**Hypothesis 1**: Price signals, including energy prices and carbon-market based incentives, road tolls, and transit fares, are the main drivers of technological change, transport modal shift and land use regulatory changes.

**Hypothesis 2**: Price signals could shift transport mode from individual cars to transit for trips from the periphery to the CBD only in cities that are dense (more than 50p/ha in built-up areas) and already dominantly monocentric.

2. Energy pricing, GHG emissions and market based incentives

We have seen that a significant reduction in GHG in urban transport could be achieved in 2 ways:

1. Technological change to reduce carbon content per VkmT;
2. Transport mode shift from private car to transit.

We believe that the pricing of energy based on its carbon content is an indispensable policy instrument to trigger these changes to reduce GHG in the long run. The pricing of energy based on carbon content could be achieved through a carbon tax or through “cap and trade”. We will discuss below the merit of each approach.

In each city the current use of low carbon technology and the ratio between transit and car commuting is reflecting an equilibrium state between supply and demand. Any change in technology or in transport mode share will require a move to a new state of equilibrium in the economy of transport. Significantly higher gasoline prices, as experienced in 2008, temporarily modified this state of equilibrium. Demand for transit increased and VKmT decreased. However, as long as renewable energy sources are not available at a competitive price, the high price of oil made it cheaper to generate electricity from coal or shale oil. Electricity is used mostly as a source of energy for rail transit but it will be used increasingly by electrical car that would recharge their batteries from the electricity grid. In cities
where electricity comes from coal or shale oil the carbon content of energy might be higher than the one used by a Toyota Prius. Electricity produced by coal burning power plants generates twice as much GHG per kilo Joule than power plants using natural gas. Without a system of pricing energy based on its carbon content higher oil and natural gas prices could increase GHG emissions rather than reducing it by shifting electricity generation to coal fueled power plants.

However, carbon pricing cannot be decided at the local level and is dependent on national policy and increasingly on international agreements. Since the audience for this paper is considered to be mostly local city managers, we discuss below the policy instruments currently used and their performance. We must acknowledge that these policy instruments will have a limited impact in the absence of carbon pricing.

A number of policy instruments are currently available to reduce GHG emissions due to urban transport. Their effectiveness is often limited by the quality of national and local governance, cities income distribution and spatial structure. Policy instruments can be divided among three principal categories:

1. Regulatory instruments, such as
   - limitations on the number of vehicles on the road a given day (e.g. Beijing, Bogota and Mexico City “pico y placa”),
   - Limitation on the number of cars registered in the city (e.g. Singapore car quota system)

2. Pricing instruments modifying relative prices between private car and transit modes, such as
   - road pricing: fixed tolls and congestion pricing (e.g. Singapore, London, Stockholm)
   - fuel tax which need to be compared with an increase in the price of a barrel of oil due to oil market evolution (e.g. Bogota, Singapore, Chicago, most US cities)
   - transit fares subsidies (e.g. Los Angeles, San Francisco)
   - pricing and taxing of parking (e.g. New York, Sheffield, Peterborough, Edinburgh)

3. Investment in transport infrastructure in order to increase and improve supply of transit modes (e.g. Singapore, Bogota, Jakarta)
2.1. Regulatory instruments

Regulatory instruments aiming at mode shift from car to transit are generally not effective because the choice of a transport mode must be demand driven. Regulatory instruments aiming to limit or reduce car ownership and car usage could seriously limit mobility in the absence of adequate investments in transit to replace the decrease in car trips. The example of Singapore in fixing a quota for car growth is rather unique. It could have been very disruptive to the economy if the government had not simultaneously been able to finance and develop a very effective transit system consistent with its land use policy. This important aspect will be developed in a subsequent section.

In countries with high economic inequality (e.g. Bogota, Mexico), policies such as “pico y placa” create an incentive for higher income households to buy a second car. This second car is often a second hand car with worse engine performance than most recent ones. As a result, “pico y placa” policy has often resulted in worse pollution and higher GHG emissions than the status quo ante. The availability of a new type of low-cost cars, the Tata Nano, for example, could make this policy even more ineffective.

2.2. Pricing instruments

Pricing instruments normally aimed at pricing transport at its real economic price. When this can be achieved it removes the distortions that hidden subsidies introduce in resource allocation. Congestion pricing and parking pricing, for instance, aim at adjusting the price of using a highway or of a parking space to reflect its real economic value, including externalities due to congestion. The aim of economic pricing is not to be punitive but to seek a more efficient allocation of resources.

Pricing instruments also include subsidies. Their aim is different from economic pricing. Subsidies aim at being redistributive. For instance, most transit fares are heavily subsidized. Transit fare subsidies are aiming at increasing the mobility of low income households, allowing them to fully participate in a unified metropolitan labor market.

It is tempting also to use transit fare subsidies as a financial incentive to convince car commuters to switch to transit. This is not a very effective manner to increase transit mode share in the long run. The subvention for

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4 “Pico y placa” consists in limiting the number of vehicles on the road on a given day by allowing on alternative days only vehicles with a license plate ending with an odd or even number.

5 Hong Kong metro is an exception; neither capital cost nor operation and maintenance are subsidized.
transit operation and maintenance often comes from local government budget allocation. The larger the number of users, the larger the subsidies required. This works as a reverse incentive for the transit operator to improve services. In the long run, the subsidies paid by the government to the transit authority usually fall short of the real cost of operation and maintenance, resulting in a deterioration of service.

We saw an example of this problem during the latest financial crisis in the US. Local governments, because of increasing deficits, were obliged to scale down transit services, including frequency, right at the moment when the high price of fuel and declining households’ income were forcing some commuters to switch from car to transit commuting.

Transit fare subsidies when they exist should be targeted to low income households or to the unemployed. Transit fare subsidies directed to the affluent are in fact a transfer payment made by government to commuters for not polluting instead of charging car commuters for the externalities they cause.

2.3. Congestion pricing of highways, bridges and parking.

Pricing instruments reflecting real economic costs have a value in themselves as they contribute to better allocating resources. However, they do not necessarily change consumer behaviour, when this is the objective that is thought. For instance, a toll charge on a highway may not reduce congestion if it is set too low. Congestion pricing, as practiced in Singapore, consist in increasing tolls until the desired decrease in congestion is achieved. Congestion pricing consists in increasing or decreasing prices until reaching equilibrium between supply and demand is reached. Congestion pricing does not aim at recovering the cost of a highway, but at limiting traffic volume to obtain a desired speed.

Pricing parking at market price is equivalent to congestion pricing: the operator will increase the price of parking until all the parking spaces are filled. In New York, the municipality taxes private parking space at 18% of the daily rate paid (in addition to the property tax and business tax). This way, the municipality recovers a share of the private market rate, without having to set a municipal parking rate. The transaction cost of recovering the rate from consumers and adjusting it to market price is paid by the private operator, while the municipality recovers a share of it. Taxed privately operated parking garages might be a more effective way of recovering an area wide congestion fee than the way it is currently recovered in London.
2.4. When congestion pricing is not possible, the effectiveness of pricing instruments depends on price elasticity.

However, congestion pricing is not always possible. It requires technology investment that may be expensive to install and operate and the high transaction cost may greatly reduce the income of the operator.

In some cases, congestion pricing is not politically acceptable. For instance, it would be difficult to increase or decrease transit fare every hour depending on the number of commuters boarding at the moment. In the case where congestion pricing is not feasible the effectiveness of increasing or decreasing prices, i.e. by how much a given price change will increase or decrease demand, depends on the price elasticity of demand.

The price elasticity of demand depends on a number of factors and can be measured from empirical experience and cannot be calculated in advance without empirical data.

Various factors affect how much a change in prices impacts travel demand for a given travel mode:

(1) Type of price change
(2) Type of trip
(3) Type of traveler
(4) Quantity and price of alternative options
(5) Time period: Short term (1 year); Long term (5–10 years)

Nearly all the studies assume that the effects of a reduction are equal and opposite to the effects of an increase or in other words, that elasticity is “symmetrical”. There is some empirical evidence that this assumption might not be true. On the other hand, because of the number of factors affecting elasticity it is often difficult to extrapolate with certainty results from one city to another in the absence of an empirical local database. With this caveat, we review below the data from the literature available on the price elasticity of demand in urban transport.

2.5. Transportation elasticity estimations from the literature

The current literature on price elasticity in transports could be summarized as follows:
(1) **Long run elasticities are greater than short run ones**, mostly by factors of 2 to 3. (Goodwin, Dargay, Hanly, 2004)

(2) **Fuel consumption elasticities to fuel price are greater than traffic elasticities**, mostly by factors of 1.5 to 2. (Goodwin, Dargay, Hanly, 2004)

<table>
<thead>
<tr>
<th>Dependent variable to fuel price</th>
<th>Short term</th>
<th>Long term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Km</td>
<td>-0.1</td>
<td>-0.3</td>
</tr>
<tr>
<td>Fuel consumption</td>
<td>-0.25</td>
<td>-0.6</td>
</tr>
<tr>
<td>Efficiency of the use of fuel</td>
<td>-0.15</td>
<td>-0.4</td>
</tr>
<tr>
<td>Car ownership</td>
<td>-0.1</td>
<td>-0.25</td>
</tr>
<tr>
<td>Transit ridership (UE)</td>
<td>+0.16</td>
<td>+0.12</td>
</tr>
</tbody>
</table>

Source: Goodwin, Dargay, Hanly, 2004

(3) **Motorists appear to be particularly sensitive to parking prices.** Compared with other out-of-pocket expenses, parking fees are found to have a greater effect on vehicle trips, typically by a factor of 1.5 to 2.0 (USEPA, 1998): a $1.00 per trip parking charge is likely to cause the same reduction in vehicle travel as a fuel price increase that averages $1.50 to $2.00 per trip.

(4) **Shopping and leisure trips elasticities are greater than commuting trips elasticities.** While we can reduce or avoid travel or the need to travel in the former, we are less likely not to travel in the latter.

Vehicle operating expenses (i.e. monetary costs), including fuel, parking fees and road tolls.

<table>
<thead>
<tr>
<th>Trip Type</th>
<th>Elasticity of Road Travel with Respect to Out of Pocket Expenses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban shopping</td>
<td>-2.7 to -3.2</td>
</tr>
<tr>
<td>Urban commuting</td>
<td>-0.3 to -2.9</td>
</tr>
</tbody>
</table>

(5) **Road pricing and tolls effects depend on the pricing mechanism design.** Luk (1999) estimates that toll elasticities in Singapore are –0.19 to –0.58, with an average of –0.34. Singapore may be unique; the high cost of car ownership constitutes a very high sunk cost which may tend to make travel less sensitive to price.

(6) **Transit prices effects are significant:** TRL (2004) calculates that bus fare elasticities average around –0.4 in the short-run, -0.56 in the medium run, and 1.0 over the long run, while metro rail fare elasticities are –0.3 in the short run and –0.6 in the long run. Bus fare elasticities are lower (-0.24) during peak than off-peak (-0.51).

### 2.6. Carbon-based Investment in transport infrastructure face three main barriers

Carbon priced based investments in transport infrastructure face three main barriers:

1. financial,
2. institutional,
3. political.

Carbon markets have been positioned as an economically efficient market based incentive for answering these three barriers. But, today, their usage for cities, and even more for urban transportation is limited:

1. Cities’ participation to carbon market is limited to flexibility mechanisms (offset project, voluntary or CDM / JI).
2. There has been little use of these markets for promoting a more energy and carbon efficient urban transportation pattern: to date, 1224 CDM projects have been registered by the UNFCC Executive Board, and only two have been transportation projects, representing less than 0.13% of the total CDM projects (The Bogotá bus rapid transit (BRT) TransMilenio, and the Delhi subway regenerative breaking system)
3. Carbon markets favor low-hanging fruit projects, which do not have the greatest potential to reduce GHG emissions: the majority of the CDM transportation projects accepted or proposed claim their emission reduction through fuel switch. Some entail improvements of vehicle efficiency through motor switch or a better vehicle utilization. Few deal with modal shift. None of
these projects involve a reduction of the total transportation activities.

Therefore, two questions have to be answered:

(1) **How and why carbon markets are biased against projects targeting urban transportation?**

Three are several reasons explaining why carbon markets are biased against projects targeting urban transportation:

i. CDM and transport projects differ widely in terms of challenges and opportunities. There is a scale gap between the two realities in which the main leaders of each project evolve.
   1. (Local) transport projects aim to change the city, make it economically attractive. Challenges include involving all stakeholders in the decision-making process.
   2. (International) challenges for CDM projects is technical (convincing CDM EB and international experts) and financial.

ii. Diffuse emissions, such as in the transportation sector, are costly to aggregate, thus CDM “act and gain money” incentive has rather limited effects.

iii. Classic CDM challenges are particularly vexing for transport sector
   1. Defining project boundaries, because of complex up & down-stream leakages
   2. Establishing reliable baseline, when behavioral parameters are key
   3. Implementing reliable monitoring methodology, as data generation is costly

Consequences of this bias are that:

i. Transport and CDM projects are conducted in parallel, without interaction

ii. Cities outsource CDM project to international experts & organizations without much involvement.

iii. CDM project-based design is missing main GHG reduction opportunities

Thus, within its existing framework, carbon markets can be used
i. as source of funding significant only at the local level;
ii. to subsidized (and reduce) transit fares;
iii. To finance intermodality infrastructures and thus facilitate modal shift.
iv. For well-bounded technology-oriented CDM projects, such as fuel switch, technology switch, optimization of the balance between bus supply and demand, traffic light system, and more generally, New Information Technologies (NIT) for vehicle or system operations. These well-bounded technology-oriented CDM projects could be levered by bundling them through the newly existing programmatic CDM.

(2) How the design of carbon markets could evolve in order to be more “urban transportation friendly”.
In the perspective of post-2012, regarding transportation sector, there is a unanimous call for changes in the carbon markets’ design. Many important opportunities for transportation emission reductions would not easily fit into an individual CDM project. Various propositions are under discussion:

a. Sectoral policy-based approach crediting new green policy or standards’ enforcement. A sectoral approach would not reduce methodological difficulties. Its advantages would rather be to scale activities up to a level that is equal to the scale of the challenges faced in redirecting transport into a more sustainable direction.

b. Cities commitment to reduce GHG emissions and “No Loose Target” approach

c. Register including NAMAs (National Appropriate Mitigation Actions) for cities and/or urban transportation sector

d. Integrate GEF & ODA in CDM funding, notably to finance transaction costs, to fund capacity-building activities, and data generation.

In brief, the idea is that a broader and flexible (based on a bottom-up mechanism definition) approach would

1) foster cities to take the lead on GHG emissions reduction strategies (financial and electoral motivations)
2) give them incentives to act for the short term (low-hanging fruits) but also for the long term, and thus change the urban development trajectory,

3) and at the same time, leave intact their ability to create and implement solutions that are relevant and palatable with local specificities. (For example, to implement land use policies that increase FAR in the CBD, or transport policies that modify relative prices of different transport modes)

3. Linkages between urban spatial structures and transport mode: monocentric vs. polycentric structure

Price and speed are not the only determinant of consumers’ choice for transport mode; urban spatial structures play a major role in determining the type of transport that is likely to be the most convenient. Urban structures are defined by the spatial distribution of population densities within a metropolitan area and by the pattern of daily trips. Depending on a city spatial structure, commuters may be able to switch from car to transit or their choice may be limited between individual cars and minibuses and collective taxis. In high density cities sidewalks and cycle lanes could be designed is such a way as not to discourage walking and cycling. While urban structures do evolve with time, their evolution is slow and can seldom be shaped by design. The larger the city, the less it is amenable to change its structure. However, it is important for urban managers to identify the opportunities present in their city and to take full advantage of it to reduce GHG emissions with transport strategies consistent with their spatial structures. We will identify below the most common types of spatial structures and the transport strategies that would have the most chances of success for each type of spatial structure.

3.1. The type of urban spatial structures limits the choice of transport modes

The distribution of densities

Urban economists have studied the spatial distribution of population densities intensively since the pioneering work of Alonso (1964), Muth (1969) and Mills (1972) that developed the classical monocentric urban density model. Empirical evidence shows that in most cities, whether they are polycentric or monocentric, the spatial distribution of densities follow the classical model predicted by Alonso, Muth, and Mills (Bertaud and Malpezzi, 2003).
The profile of densities of most large cities shows that the traditional monocentric city model is still a good predictor of density patterns. It also demonstrates that markets remain the most important force in allocating land, in spite of many distortions to prices due to direct and indirect subsidies and ill conceived land use regulations. The profile of population densities of 12 cities on 4 continents (Figure 9) shows that in spite of their economic and cultural differences, markets play an important role in shaping the distribution of population around their centers. All the cities shown on Figure 9 follow closely the negative sloped gradient predicted by the classical monocentric urban model although a number of cities in the samples are definitely polycentric (Atlanta, Portland, Rio de Janeiro, Mexico City). The profile of densities shows already some incompatibility with
transit in some part of metropolitan areas. In areas where residential densities fall below 50 people per hectare, the operation of transit is ineffective.

**Trips pattern**

Land use and the transport network determine the pattern of daily trips taken by workers to commute to work. As income increases, non-commuting trips – trips to shopping centers, to bring children to school, to visit relatives or leisure trips – become more important. The proportion of commuting trips over other types of trips is constantly decreasing.

**Figure 10: Urban trip patterns in monocentric and polycentric cities**

*Figure 10* illustrates in a schematic manner the most usual trip patterns in metropolitan areas.

In monocentric cities (*Figure 10 A*) where most jobs and amenities are concentrated in the CBD, transit is the most convenient transport mode, as most commuters travel from the suburbs to the CBD. The origin of trips
might be dispersed but the CBD is the main common trip destination. Small collector buses can bring commuters to the radials where Bus Rapid Transit or an underground metro can bring them at high speed to the CBD. Monocentric cities are usually dense (density above 100 people per hectare).

In polycentric cities (Figure 10 B) few jobs and amenities are located in the center and most trips are from suburbs to suburbs. There is a very large number of possible travel routes but with few passengers per route. The trips have dispersed origins and dispersed destinations. In this type of city structure individual means of transportation or collective taxis are more convenient for users. Mass transit is difficult and expensive to operate because of the multiplicity of destinations and the few passengers per route. Polycentric cities have usually low densities as the use of individual cars does not allow nor require much concentration in any specific location.

Figure 10 C shows the so called “urban village model” that is often shown in urban master plans but does not exist in the real world. In this model, there are many centers but commuters travel only to the center which is the closest to their residence. This is a very attractive model for urban planners as it doesn’t require much transportation or roads and it dramatically reduces VKmT and PKmT and as a consequence GHG emission. According to this model, everybody could walk or bicycle to work even in a very large metropolis. The hypothesis behind this model is that urban planners are able to perfectly match work places and residences! This model does not exist in reality because it contradicts the economic justification of large cities. Employers do not select their employees on the basis of their place of residence and specialized workers in large cities do not select jobs either on the basis of their proximity from their residence (with the exception of the very poor who walk to work and are limited to work within a radius of about 5 km from their home). The “urban village model” implies a systematic fragmentation of labor markets which would be economically unsustainable in the real world.

The 5 satellite towns built around Seoul are an example of the urban village conceit. When the towns were built, the number of jobs in each town was carefully balanced with the number of inhabitants, with the assumptions that these satellite towns would be self-contained in terms of housing and employment. Subsequent surveys are showing that most people living in the new satellite towns commute to work to the main city, while most jobs in the satellite towns are taken by people living in the main city.
The “composite model” shown on Figure 10 D is the most common type of urban spatial structure. It contains a dominant center but a large number of jobs are also located in the suburbs. In this type of cities most trips from the suburbs to the CBD will be made by mass transit while trips from suburb to suburb will use individual cars, motorcycles, collective taxis or minibuses.

The composite model is in fact an intermediary stage in the progressive transformation of a monocentric city into a polycentric one. As a city population grows and the built-up area expands, the city center becomes more congested and progressively looses its main attraction. The original raison d’être of the CBD was based on its easy accessibility by all the workers and the easy communication within the center itself because of its spatial concentration.

As a city grows, the progressive decay of the center because of congestion is not unavoidable. Good traffic management, timely transit investment, strict parking regulations and market price of off-street parking, investments in urban environment (pedestrian streets), and changes in land use regulations allowing vertical expansion would contribute to reinforce the center, make it attractive to new business and keep it as a major trip destination.

These measures have been taken with success in New York, Singapore, and Shanghai, for instance. However, the policy coordination between investments and regulations is often difficult to implement. This coordination has to be carried consistently for a long period of time to have an impact on the viability of urban centers.

Failure to expand the role of traditional city centers through infrastructure and amenities investments weaken in the long run transit systems, as the number of jobs in the center becomes stagnant or even decreases while all additional jobs are created in suburban areas.
The comparison between the distributions of population in Jakarta (Jabotabek) and Gauteng (Figure 11) explains why Jakarta is able to implement successfully a network of BRT in addition to the existing suburban rail network while in Gauteng suburban rail is carrying barely 8% of commuters and the great majority of low income commuters rely on microbuses. The dispersion of population in Gauteng is due in part to its history of apartheid. In the last 10 years a very successful subsidized housing program has contributed to further disperse low income people in distant suburbs while significantly attenuating the extreme poverty created by apartheid. The comparison as seen on the 3 D representation of population densities between the resulting city structure of Gauteng and that of Jakarta is striking. A BRT is being planned for the municipality of Johannesburg (one of the municipality in the Gauteng metropolitan region) but the current urban structure will make it difficult to operate for a long time. In addition, the violent opposition of microbus operators is making the project politically difficult. A change in transit mode involve passing to a new equilibrium and
create losers and winners and is not an easy thing to do; even when the final long range outcome seems desirable for all.

The structure of cities is path dependent. Once a city is dominantly polycentric it is nearly impossible to return to a monocentric structure. Monocentric cities by contrast can become polycentric through the decay of their traditional center. The inability to adapt land use regulations, to manage traffic and to operate an efficient transit system are the three main factors that explain the decay of traditional CBDs.

3.2. Transport strategies need to be consistent with cities’ spatial structures

We could summarize our finding concerning the relationship between urban spatial structures and transit in the following way:

(1) transit is efficient when trips’ origins are dispersed but destinations are concentrated
(2) individual transport and microbuses are more efficient when origin and destinations of trips are both dispersed, and for linked trips if amenities are dispersed
(3) Mode shift toward transit will happen only if price and speed is competitive with other modes, therefore for trips from suburbs to concentrated areas of jobs and amenities
(4) Trips toward dense downtown areas (above 150 people/ha) should be prevalently done by transit. Failure to provide efficient transit service to the CBD and to regulate traffic and parking would result in a dispersion of jobs in suburban areas, making transit inefficient as a main mean of transport in the long term.

The question to be answered is then: is it possible to have a land use and traffic policy to reinforce commuting destination concentration so that transit might become competitive with car trips?

Two cities are maintaining a high ratio of transit trips: Singapore with 52.4% of total commuting trips (Singapore census 2000)) and New York with 36 %. Their performance is particularly intriguing because these two cities have a high income population. Higher income households are less likely to use transit than lower income ones. By contrast Mexico City, with a density more than twice that of New York has only 24% of commuters using transit. It means that both Singapore and New York have had for many years a successful policy to keep such a large number of commuters using
transit. Are their experiences replicable in lower income cities with less performing governance? We are going to review their policy together with the counter example of Mumbai where transit is the dominant commuting mode but where city managers try to disperse jobs and housing.

4. The experience and performance of Singapore and New York and the counter experience of Mumbai

4.1. New York

The high ratio of transit trips in New York is the result of a deliberate policy of spatial concentration and diversification of land use.

The extremely high concentration of jobs is the most striking feature of the spatial structure of New York metropolitan area; 35% of the total numbers of jobs are concentrated in Manhattan, which represents only 0.9% of the total metropolitan area (53Km2) has. Within Manhattan, 4 districts (19 km2) have 27% of the jobs in the entire metropolitan area (population 15 millions). This concentration did not happen by chance, it was the result of a deliberate regulatory policy which was responding to the high market demand for floor space in Manhattan.

The map shown on Figure 12 shows the job density in the central area of the metropolitan region. The Midtown district reaches the astonishing density of 2,160 jobs per hectare! This extreme spatial concentration of people and jobs is extremely intellectually fertile, innovative and productive, in spite of the management problems it poses for providing services in such a dense area.
The zoning regulations controlling floor area ratio FAR is one of the main factors that made possible this concentration. The map of Manhattan regulatory FAR (Figure 13) shows the high FAR in Midtown and Wall street area (FAR values ranging from 11 to 15). The pattern of high FAR shows that the regulations have been adjusted to demand as the 2 main business centers in Manhattan expanded over time.

![New York Metro Area - Job Density (2000)](image)

**Figure 12: New York Metro area - Job Density**

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6 The limits imposed on Floor Area Ratio (FAR) is a common regulation linked with zoning. An FAR of 2, for instance, allows building an area of floor equal to twice the area of the plot on which it is built. An FAR of 2 therefore would allow 2000 m² of floor space to be built on a 1000 m² plot. If half of the land is built upon, the building would have 4 floors to fully use the allowed FAR. A regulatory limit put on FAR is therefore not the equivalent of a limit on height or number of floor as most building have to leave some of their lot open for light ventilation, circulation or often to follow regulations on set backs.
Figure 13: Map of FAR regulations in Manhattan's zoning

Note: in some zones the FAR might be increased up to 2 additional units because of bonuses due to plaza, arcades etc.
In some area the permitted FAR might not be reached because of set backs and plot geometry.
The zoning of Manhattan allows also a mix zoning for office space, commerce, theaters and housing. The mixed land use favors transit because it generates trips outside the traditional rush hours. Because of the theater districts, buses and subway run late at night making transit convenient also for workers who work different shifts. These workers with schedule outside normal hours in a different setting of homogenous land use would have to commute with individual cars. The land use in Manhattan make it possible for New York transit to have a high passenger load, significantly reducing GHG emissions we have seen in section 1 above.

We could summarize the urban management initiatives taken in New York that contribute to a high share of transit use and as a consequence to a lower GHG emission per capita:

1. High Floor Area ratio responding to market demand
2. Mixed land use in the CBD
3. Encouraging amenities in or close to the CBD (museums, theaters, universities)
4. Great majority of parking space provided off street, privately operated, charging market price but specially taxed by municipality. Progressive removal of most on street parking except for loading and unloading;
5. Constant improvements in the transit system, radio-concentric pattern of routes

4.2. Singapore

In Singapore, the transport sector is the second largest contributor to CO2 emission in 2005. Efforts to mitigate GHG emissions have mainly concentrated on buildings. The transport sector has received lesser attention. Unlike USA and OECD countries where transport data is readily available, statistics on Singapore’s transport sector and CO2 emissions by mode is extremely difficult to locate.

Like New York, Singapore is a highly dense, compact city. It has a land area of 700 sq km, accommodating a population of 5 million. The average density in the built-up area was about 110 p/ha in 2000. Through comprehensive planning, Singapore has expanded its downtown and
redistributed population throughout the city-state. Key infrastructure such as the airport, port and the network of expressways and mass rapid transit is planned and safeguarded in its long-term development plan to support a good living environment. The long term planning frame gives the assurance that projected needs can be met within the city’s limited land area. To keep Singapore economically vibrant, its transport planning is access and mobility-focused with emphasis on a transit-oriented and compact urban structure, vigorous restraint of private car ownership and usage and a strong commitment to public transport. Urban development has been increasingly planned in such a way as to reduce the need to travel and dependence on motorized vehicles.

Figure 14: Singapore CBD and the subway network

At the neighborhood level, neighborhoods and their new towns are structured with a host of amenities and services that could be readily reached within 5 minutes’ walk. Smart infrastructure design reduces the need for transportation. Public housing towns where 80% of the population lives are connected to each other and to the city by public transport, principally the mass rapid transit. At the city level, with the redistribution and growth of population in new towns in the suburbs, new growth centers have been planned in these regions in immediate proximity of the transit network to provide employment to the local population in concentrated areas easily
accessible by transit. Decentralizing some economic activities to the dense regional centers helps bring a number of jobs closer to homes and facilitate linked trips using public transport. It also reduces the usual peak hour traffic congestion to and from the CBD. At the same time, these centers provide lower cost for businesses that do not require a central area address, supporting a competitive economy. Over the next 10 to 15 years, more regional centers will be developed. Transport infrastructure is closely integrated with land use. To keep its individual vehicle population growth manageable, much focus is given to travel demand management, including a choice of transport mode and making public motorized transport more efficient.

Singapore is one city that has actively promoted the use of public transport as a more sustainable way to travel. There are strong policy measures to discourage private car usage, including high vehicle and fuel taxation measures and implementation of parking management, vehicle quota system and congestion pricing. These deterrents are complemented by mode-shift strategies aimed at improving the public transport system and new solutions such as car sharing. Improvement to public transport involves expanding the system or service such as extending the geographical coverage of the bus and rail networks, and improving the operation of the system and service such as mode transfer improvements, better coordination of schedules, through ticketing, increased frequency, vehicle comfort and bus shelter/rail station improvements. Extensive rail network has been planned to serve high population areas. The government continues to invest in the mass rapid transit network to improve its accessibility to the population as the city grows. It has announced an additional US$14 billion investment to double the rail network from the present 138 km to 278 km by 2020, thus achieving a transit density of 51km per million people comparable to that of New York. To allow more rail usage, land use is intensified around the mass rapid transit stations. Mixed-use developments are encouraged.

One of the most crucial land use decisions has been to develop a new downtown area adjacent to the existing CBD. To increase the accessibility of the new and current downtown floor area ratios have been kept high (some lots have an FAR of 25 but the majority of FAR values are around 12). This new downtown when built will reinforce the effectiveness of the radial concentric metro system.
Figure 15: Singapore - FAR values in the downtown area

4.3. Mumbai

Mumbai with a metropolitan population of 18 million people in 2001 and a density of about 390 p/ha in the municipal built up area is both much denser and larger than Singapore and New York. The transit mode share is evaluated at 71% of commuters using motorized travel (the number of people walking to work might be around 4 millions). The main mode of transit consists in buses and 2 main lines of suburban train. Private cars, taxis and rickshaws account for about 12% of commuting trips and motorcycles 17% (Baker, World Bank 2004).
Since 1964 Mumbai urban managers have tried to reduce congestion by reducing the number of people living in the city and by trying to disperse jobs and people in far away suburbs or satellite towns like Navi Mumbai. A strict control of the floor area ratio that was progressively reduced from an
initial 4.5 in the CBD (Nariman Point) to the current 1.33 has been the main
tool used to reach their dispersion objective. The objective was to promote a
dedensification of the central areas of the city and a dispersion of jobs. In a
certain way, Mumbai urban managers were trying to transform a dense
monocentric Asian city into a “Los Angeles” model where jobs and
population are dispersed randomly within the metropolitan area.

However, the suburban railways lines carrying 6.4 millions
commuters a day, converge on the traditional CBD. The policy consisting in
reducing FAR to promote dispersion did not succeed as it contradicted the
pattern of accessibility established by the transit network. The highest
demand for office space is still in Nariman Point, the traditional CBD. The
price of office space in Nariman Point is about the same as the average in
Manhattan. The number of passengers boarding and exiting at various
suburban train stations shows that the 2 stations the closest to Nariman Point
handle the larger number of commuters (*Figure 16*).

The map of maximum regulatory FAR (*Figure 17*) completely
contradicts demand as expressed by floor space price and the pattern of
boarding and exiting railway stations shown on *Figure 16*. A FAR value of
1.33 imposed on the CBD of a dense city of 18 million people is completely
unrealistic (as compared to 15, the value in New York and 25, the highest
value in Singapore). The highest FAR values are 4 in the slum of Dharavi
and in the new business center of Bandra-Kurla. Bandra Kurla for the
moment is not connected to the railway network and to access it from the
railway network requires a bus transfer. The railways cannot handle any
more passengers with the existing tracks. New metro lines are being planned
but without a clear spatial strategy yet for changing the current land use
regulations to adapt them to the new transport system and consumers’
demand.

The very low FAR values in Mumbai have only succeeded in making
land and floor space more expensive. Density has increased, because
location is everything in large metropolis, floor space consumption has
decreased to one of the lowest in India (and probably in Asia).

The absence of a clear spatial strategy linking land use regulations,
consumers demand and transport network has been the major failure of the
urban management of Mumbai. The major lesson to be drawn form the
Mumbai example is that designing cities through regulations without taking
into account consumers’ demand does not work. If the strict low limit put on
the regulations of FAR had succeeded and jobs and population had dispersed
the impact on GHG emissions would have been disastrous. The current transit system, for all its flaws, would have been made less efficient as it would have not have been able to connect commuters to dispersed businesses. Motorcycles and minibuses would have been the most practical and efficient mode of transportation.

Figure 17: Mumbai - Regulations of the Floor area ratio
4.4. Summary of measures taken in New York and Singapore that maintain a high level of transit share

Singapore and New York are succeeding in maintaining a high rate of transit use even among high income population. This strategy will contribute in the future in significantly lowering GHG emissions due to transport.

It is useful to summarize the measures that have been taken by New York and Singapore to maintain a high density of jobs and activities in their downtown areas:

(1) High floor area ratio in the CBD (up to 15 in midtown Manhattan, up to 25 in Singapore);

(2) physical expansion of downtown through land reclamation in both Singapore and New York;

(3) prioritizing and improving connections to public transport; high level of transit services by buses and metro (in other cities BRT might be a more cost effective way of conveying commuters toward areas with high job concentration than underground metro);

(4) high cost for the use of cars in downtown area through congestion pricing in Singapore, tolls to enter Manhattan from bridges and tunnels and price of parking set by market in New York and Singapore;

(5) high level of amenities that make the downtown area attractive outside office hours:
   i. theater districts and museums, new Chelsea art gallery district in New York
   ii. cultural centers, auditoriums, rehabilitation of ethnic districts and waterfront with restaurants, leisure and entertainment, commerce, seaside promenade, pedestrian streets, etc in Singapore

(6) In Singapore large but compact mixed use buildings located at integrated bus-transit transport hub like Ang Mo Kio and Woodlands new towns where shopping center + amenities + offices + civic functions in bus/metro hub allows linked trips while using transit.
5. Which type of city should try to retain a dominantly monocentric structure? How to do it?

5.1. The possibility of shift toward Transit mode depends on retaining a high degree of monocentricity. Could cities manage to do it?

We have seen that if a large number of car commuters were able and willing to shift to transit this would significantly reduce GHG emissions from urban transport. This shift is possible mostly for those commuting toward a dense employment/commercial/cultural center. In many cities of the world, the traditional city center becomes less accessible because of congestion or in the case of Mumbai because of a deliberate government policy. Business and jobs move then toward the periphery. Many commuters then move to individual cars or minibuses because it is the most convenient way for moving from low residential density suburbs to low job density suburbs. This forms a chain reaction – decaying city center, jobs moving to suburbs, commuters abandoning transit for minibuses, motorcycles or car. Can this chain reaction be reversed?

The policy followed by Singapore and New York shows that the suburbanization trend can be reversed or at least stabilized. Is the experience of Singapore and New York replicable in cities with a lower quality of governance? We think that the possibility of doing so depends first on a city’s current morphology. A city spatial structure changes with time but only slowly and is largely path dependent.

Cities could be classified depending on their built-up density and their degree of monocentricity (*Figure 18*). There is usually a correlation between density and monocentricity with some exceptions like Tehran and Mexico City. As seen on *Figure 18* we could divide cities into 3 types:

1. high density strongly monocentric cities
2. medium and low density cities retaining a dominant center
3. Low density polycentric cities.

Depending on their location on the scatter gram shown on *Figure 18* cities retain a possibility of increasing transit mode. For the cities in the first category (1) located in the right part of the graph, retaining transit as a principal transport mode is a necessity because of the average high density of the city, individual cars would use too much street space if they became a dominant transport mode. For the cities in category (2) in the central part of the graph, a mixed mode transit/ cars-minibuses is unavoidable but they have a chance to increase the
share of transit mode through measures similar to the one described above taken by Singapore and New York. Finally, for the cities of type (3) in the upper left of the graph, improving car traffic, shifting fuel source and improving engine technology is probably their best chance of reducing GHG emissions from transport.

Figure 18: Densities and Monocentricity in selected cities

Cities structures do change over the years but they change slowly and usually toward lower densities and more polycentricity; in 20 years most cities shown on the graph would have diagonally to a position in the upper left part of their current position. The only exceptions would be cities that consciously reinforce their current CBD the way Singapore and New York did.

On the graph of Figure 18, let us consider the position of Mexico City. Some 20 years ago the city was probably more monocentric and with a higher density than what it has now. As its spatial structure changed with time so did its dominant transport mode. Mexico City has the second longest metro network in America after New York. The design and
operation of the Mexico metro, inaugurated in 1963, is much more modern and efficient than New York City metro. The density of Mexico City is also about double the one of New York. One would expect that transit would represent a large share of transport mode. Let us look at the evolution of transit share between 1986 and 2000 (Figure 19). The share of transit has decreased from 64% in 1986 to 24% in 2000! Minibuses have replaced transit over the years. This shift is in great part due to a change in spatial structure. As the city developed the traditional CBD failed to adapt with higher FAR and better traffic management. A large part of the land area around the CBD has been frozen from redevelopment by rent control, preventing the extension of the original CBD in adjacent areas. It is also possible that the seismic risk discouraged developers from building higher and more dense structures.

**Share of daily trips by mode for the Mexico City Metropolitan Area**

![Chart showing the share of daily trips by mode for Mexico City between 1986 and 2000.](chart.png)

Source: Secretaría de Transito y Viabilidad (SETRA VI) Embarq - World Resources Institute

Figure 19: Mexico City - Evolution of transport mode between 1986 and 2000

The result was a dispersion of jobs in various areas of the city for which the metro network didn’t constitute a convenient mode of transport anymore. The failure to control car traffic and on street parking in such a dense city decreases also the efficiency of buses. Minibuses are much more agile in negotiating traffic and can use smaller streets. While we are not aware of data being calculated concerning the change of GHG emissions between 1986 and 2000, it is certain that it has not been favorable and that
GHG emissions have increased much more because of the change in transit mode than because of the increase in VKmT due to the city expansion.

Recently a new BRT system has been built in Mexico City to try to reverse the trend in transit share losses. If this were followed by new land use policy and strict traffic management concerning parking in particular, the share of transit could increase over the year to get back to what it was in 1986!

The case of Mexico shows that the coordination between land use, traffic management and the supply of new transit line is indispensable to maintain a high level of transit. Building new transit is not enough to create demand for it, if jobs are being dispersed in distant suburbs.

A number of cities that are now building BRT could benefit from having a coordinated approach to traffic management and land use. In most of these cities, trips using individual cars, motorcycles and minibuses will still represent a large part of the total number of trips. To reduce GHG emitted by these vehicles carbon pricing will remain indispensable.
6. Conclusions: energy prices are the driver of city shapes, carbon based market incentives have an important role to play, but infrastructure investments and land use regulations have to be consistent with the new demand created by changing prices and incentives.

Differential prices of energy sources based on carbon content is the only way to promote better urban transport efficiency and reduce GHG emission due to urban transport in the long run for most cities. However, as demonstrated in this paper, integrating transport and land use planning, investing in public transport, improving pedestrian environment and linkages, dynamically managing the parking provision and traffic management are equally important to improving the effectiveness of the transport network serving the city. GHG emissions due to suburb to suburb trips will be reduced through not only energy carbon pricing but also better traffic management to reduce congestion and improved car technology.

However, GHG emissions in many dense and still monocentric cities could be reduced if the demand for suburbs to CBD trips would increase. This would require coordinating carefully land use and transit network. Large increase in FAR in CBDs could trigger a transport mode shift toward transit if coordinated with new BRT networks and parking pricing policy.

An increase in job concentration in CBD could also increase urban productivity by increasing mobility without increasing VKmT or trip time. However, it does not mean that all economic activities should be concentrated in the CBD. To the contrary, flexibility in zoning should allow commerce and small enterprise to grow in the best location to operate their business as it has been the case in Singapore. Too often, zoning laws overestimate the negative externalities created by mixed used – preventing for instance small retail shops to locate in residential areas – while underestimating the positive externality of reducing trip length for shopping or even entertainment. Most current zoning laws should be carefully audited to remove the bias against mixed land use and against large concentration of business in a few areas.

The coordination needed between transport investment and management, pricing of roads and parking, and land use, managing existing and future transport infrastructure capacity and balancing priorities is difficult to achieve in the real world. Urban problems cannot be solved sector by sector but spatially. This is why the autonomy of municipal authorities is so important. In some cities, urban transport is managed by
national line agencies (this is the case in Mumbai). However, in very large cities the urban area covers several autonomous local governments, making it difficult to coordinate land use, transport network and pricing across the many boundaries of a typical metropolitan area.

The population of the city of New York includes less than half of the metropolitan area population, making coordination and policy consistency difficult. Most of Mumbai regulatory decisions and infrastructure investment budget are decided by the state of Maharashtra legislature, not by the municipal corporation, this may explain the lack of spatial development concept so far for zoning regulations.

Singapore, being a city state has the advantage of avoiding the contradictions and cross-purpose policies of a metropolitan area divided into many local authorities with diverging interests. This may explain in part the extraordinary consistency and continuity in urban development policies over a long period of time that has contributed to create such a successful city. The same could be said of Hong Kong, continuing the tradition of Italian renaissance city-states like Venice and Florence.

While good governance and policy consistency are important in reducing GHG emissions, in the long run, only the pricing of energy based on carbon content will be able to make a difference in urban transport GHG emissions. Pricing transport as close as possible to the real economic cost of operation and maintenance is the only way to obtain a balance between transport mode that reflects consumer convenience and maintain mobility.
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Appendix 1

For each motorized transport mode:

\[ Q = VKmT \cdot E \]

\[ VKmT = PKmT / L \]

\[ PKmT = 2D \cdot P \]

Where:

- \( Q \) is the total Carbon equivalent emitted per day by passengers while commuting to work (does not include non-commuting trips) in metric tons per day
- \( VKmT \) is the total vehicle kilometers traveled
- \( PKmT \) is the passenger kilometer travelled per day
- \( L \) is the load factor
- \( D \) is the average commuting distance per passenger
- \( P \) is the number of passengers per day using the transport mode

\[ Q = T \cdot \sum_{i=1}^{N} \frac{2 \cdot D_i \cdot P_i \cdot E_i}{L_i \cdot 10^6} \]

Where:

- \( Q \) is the total carbon equivalent emitted per day by passengers while commuting to work (does not include non-commuting trips) in metric tons per day
- \( T \) is the total Number of commuters per day
- \( N \) is the number of commuting transport modes types numbered from 1 to N
- \( D_i \) is the Average commuting distance one way per passenger in km per type i of commuting mode
- \( P_i \) is the percentage of commuters using transport mode type i
- \( E_i \) is the carbon emissions of vehicle used for mode i in gram carbon equivalent (full life cycle) per vehicle kilometer traveled
- \( L_i \) is the load factor expressed in average number of passengers per vehicle of type i