

# **The Contribution of Urban Areas to Climate Change: The Case Study of São Paulo, Brazil**

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# **The Contribution of Urban Areas to Climate Change: The Case Study of São Paulo, Brazil**

*Carolina Dubeux and Emilio La Rovere*

## **1. Introduction**

Due to the historical tendency of populations to concentrate in large urban centers, cities tend to consume a large part of the energy produced to meet the demands of transport, industrial and commercial activities and thermal comfort. Solid waste and domestic, commercial and industrial effluents are also mostly produced in urban agglomerations. These factors, amongst others, can cause local and regional pollution and contribute to increase global warming. In Brazil this phenomenon can also be observed following the accelerated urbanization that commenced in the 1950s.

Considering this great responsibility of cities in relation to greenhouse gas (GHG) emissions, this article examines how very high urbanized areas in metropolitan regions, as São Paulo city, contribute to GHG emissions, with a view to planning mitigation actions. A metropolitan region is taken to be a densely urbanized region consisting of municipalities that, irrespective of any administrative connections, are part of the same socio-economic community and whose interdependence creates the need for the coordination and carrying out of public functions of common interest. This is the case, for example, of the metropolitan regions of São Paulo, Rio de Janeiro, Buenos Aires, Mexico, Los Angeles, Barcelona, amongst others.

Planning actions to curb GHG emissions begins with the identification of the main emission sources, a task that can be achieved by conducting an emissions inventory. As a case study, the inventory of the São Paulo city, estimated for 2003, is analyzed.

## **2. São Paulo's main Characteristics**

The São Paulo Metropolitan region has 39 municipalities and 18 million inhabitants. Almost 60 percent of this metropolitan population lives in the city of São Paulo resulting in one of the highest population densities in the country with 7220 inhabitants per km<sup>2</sup>.

The city's GDP was US\$ 83 billion in 2003 with 62.5 percent coming from services, 20.6 percent from the industrial sector and less than 0.01 percent from agriculture. The structure of the emissions reflects this sectoral composition when the highest emission share is due to transportation. Industry emits a relatively small share whereas agriculture's is negligible. Although 8,7 percent of population still lived in slums in 2003, its income per capita of US\$ 7.8 thousand was far above national average (IPEADATA, 2009).

Such development level poses environmental constraints and high opportunity land costs and encourages heavy industries to move to other cities in the metropolitan area, where demand for less skilled jobs and a lower level of urban density are more suitable to industrial plants.

Urban mobility is characterized by a complex transport system and several subsystems. People from São Paulo and neighbouring cities come and go from one city to another on a daily basis making the demand for transportation very high, so that the issue of mobility in the city necessarily encompasses the metropolitan and regional scale. In addition, São Paulo is known for the convergence of several state and federal highways with destinations other than

the city, so that cargo transport systems with different origins and destinations must pass through it, all that resulting in a highly congested traffic, mainly in peak hours.

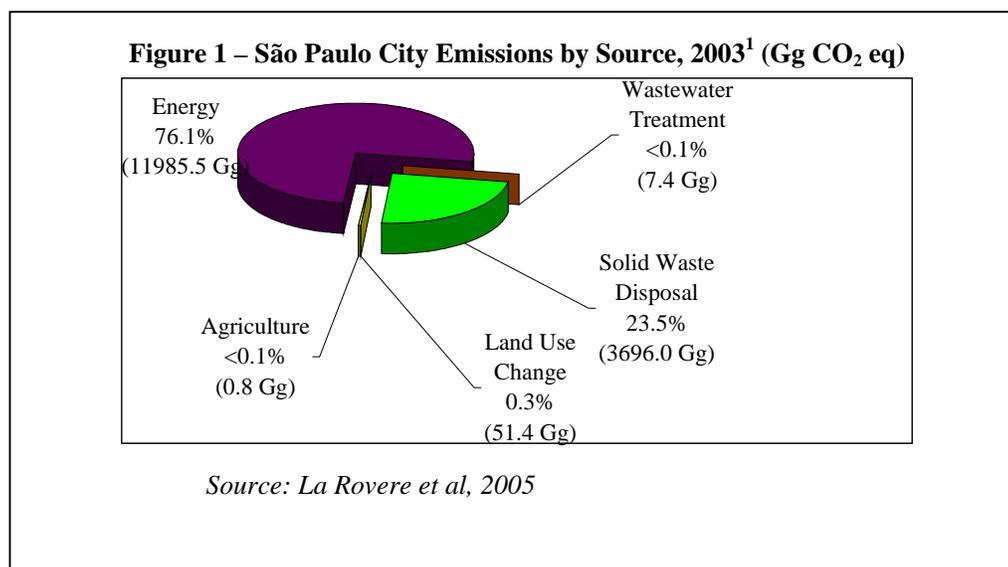
Despite a quite sophisticate net of bus services, the subway system is still reduced, only 61,3 km long, and rail one is deficient in quality so transportation is mostly by private cars. There are two airports, one for commercial and another for general aviation, the former carrying almost 18 million passengers per year (12 million passengers in 2003).

Around 93 percent of sewage is collected, although only 66 percent is treated, the rest being discharged in rivers.<sup>1</sup> Services for solid waste collection and disposal also have almost universal coverage with 9.5 thousand tons of waste collected and disposed of in sanitary landfills.

### 3. Emissions Sources in São Paulo

The GHG Emissions Inventory of São Paulo (La Rovere *et al*, 2005) estimated carbon dioxide (CO<sub>2</sub>) and methane (CH<sub>4</sub>) emissions, the two main GHG, for 2003<sup>2</sup>, based on the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (1996). The inventory included emissions from the following sources:

- Energy Use (generation of electricity, industrial, individual transport, public and cargo transport, air transport, residence and commercial, and others);
- Land Use Change and Forestry (deforestation and liming);
- Agricultural Sector (domestic livestock);



<sup>1</sup> It is worth mentioning that differently from the 2006 Guidelines, the IPCC 1996 Guidelines - used as the methodology guidance for São Paulo's inventory- only estimate emissions from sewage treatment systems. Other discharges, as in rivers for example, remain not accounted.

<sup>2</sup> Emissions from industrial processes were not taken into account due to the non-existence of industrial processes producing emissions.

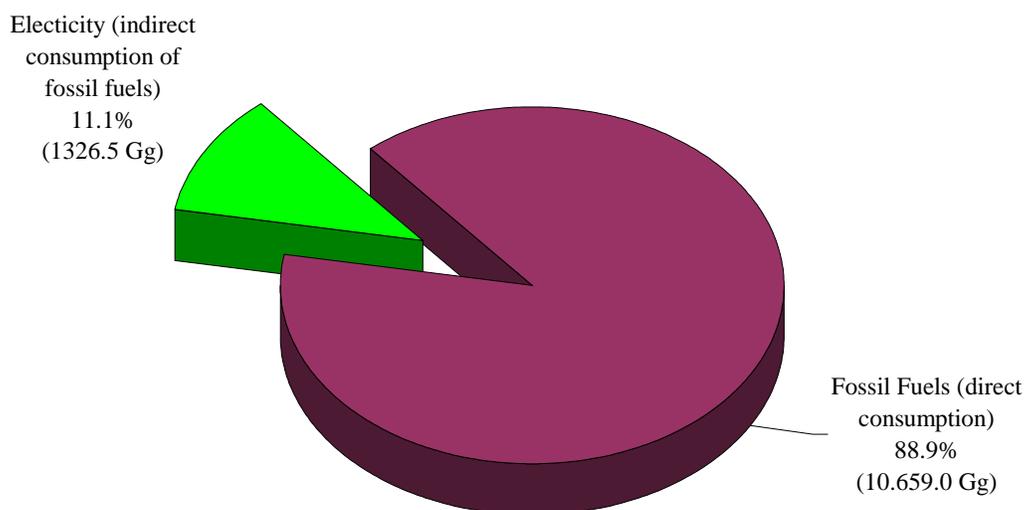
- Solid Waste Management;
- Domestic, Commercial and Industrial Wastewater Treatment

Among these sources, **Energy Use** had the highest share of total emissions with 76.1 percent, followed by **Final Disposal of Solid Wastes**, responsible for 23.5 percent. Together these two sources accounted for 99.6 percent of the total emissions from the city.

**Land Use Change and Forestry** accounted for 0.3 percent, **Sewage Treatment from Domestic, Commercial and Industrial Sources** was responsible for 0.1 percent and finally the **Agricultural Sector** contributed with less than 0.01 percent of total emissions. Figure 1 shows the emissions by sources.

In relation to Energy Use, emissions are those resulting from the direct and indirect consumption of fossil fuels. In the latter, emissions occur due to the consumption of electricity that is partially produced from fossil fuels. The direct use of fossil fuels is responsible for 88.8 percent of total Energy Use emissions, while the consumption of electricity accounts for 11.2 percent. Figure 2 below shows the values.

Figure 2 - São Paulo City Emissions from Energy Use - Direct Consumption of Fossil Fuels and Electricity, in 2003 (Gg CO<sub>2</sub>eq)



Source: La Rovere et al, 2005

Of the fuels consumed directly and indirectly in São Paulo, motor gasoline<sup>3</sup> accounts for 35.7 percent of total emissions (mostly used by the light duty fleet), followed by diesel oil (32.6 percent), liquified petroleum gas – LPG (10.9 percent), natural gas (10.0 percent), jet fuel<sup>4</sup>

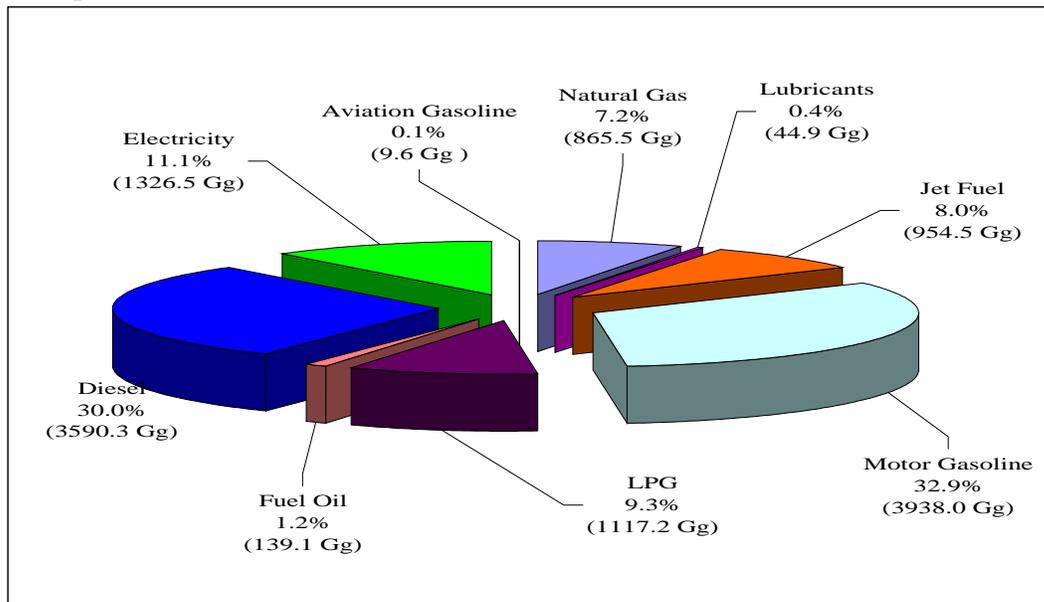
<sup>3</sup> Gasoline in Brazil is a blend of pure gasoline and sugar cane ethanol. In the year of inventory this blend had 23 percent of ethanol

<sup>4</sup> Bunker emissions were not separated.

(8.8 percent), fuel oil (1.3 percent) and aviation gasoline and lubricating oil, which together account for 0.6 percent. Figure 3 shows the values.

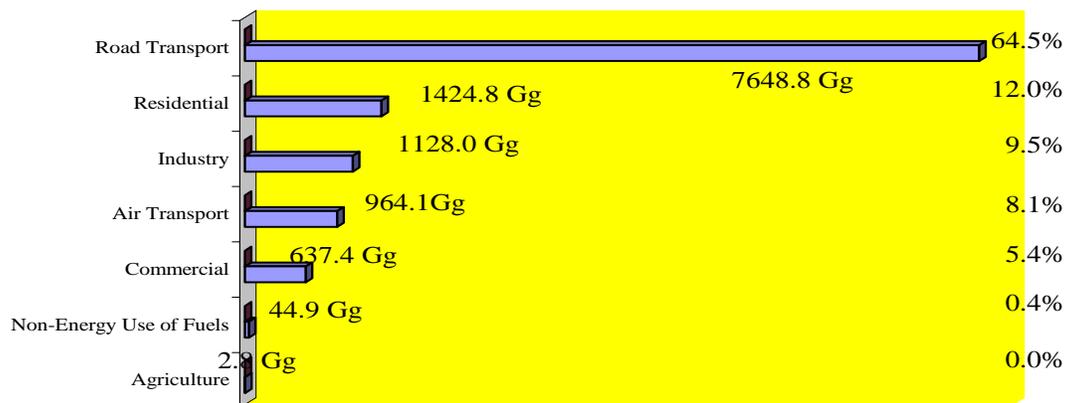
Breaking down the analysis into the socio-economic sectors shows the importance of fuel consumption by the transport sector to the overall emissions from São Paulo. Figure 4 shows the shares of the different sectors.

**Figure 3 - São Paulo City Emissions from Fossil Fuels – direct and indirect use, in 2003 (Gg CO<sub>2</sub> eq)**



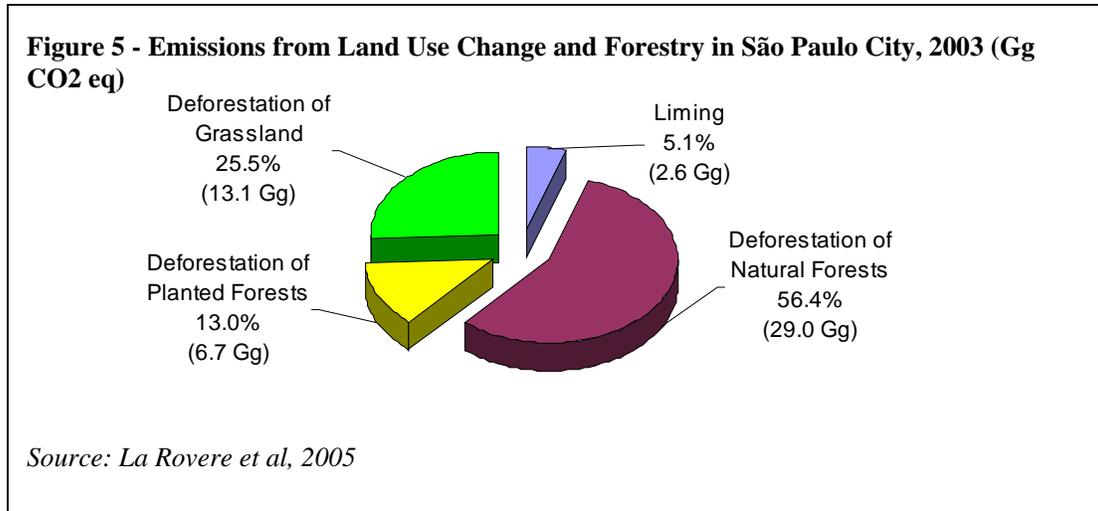
Source: La Rovere et al, 2005

**Figure 4 - Shares of Socio-Economic Sectors in Energy Use Emissions in São Paulo City, in 2003 (Gg CO<sub>2</sub> eq)**

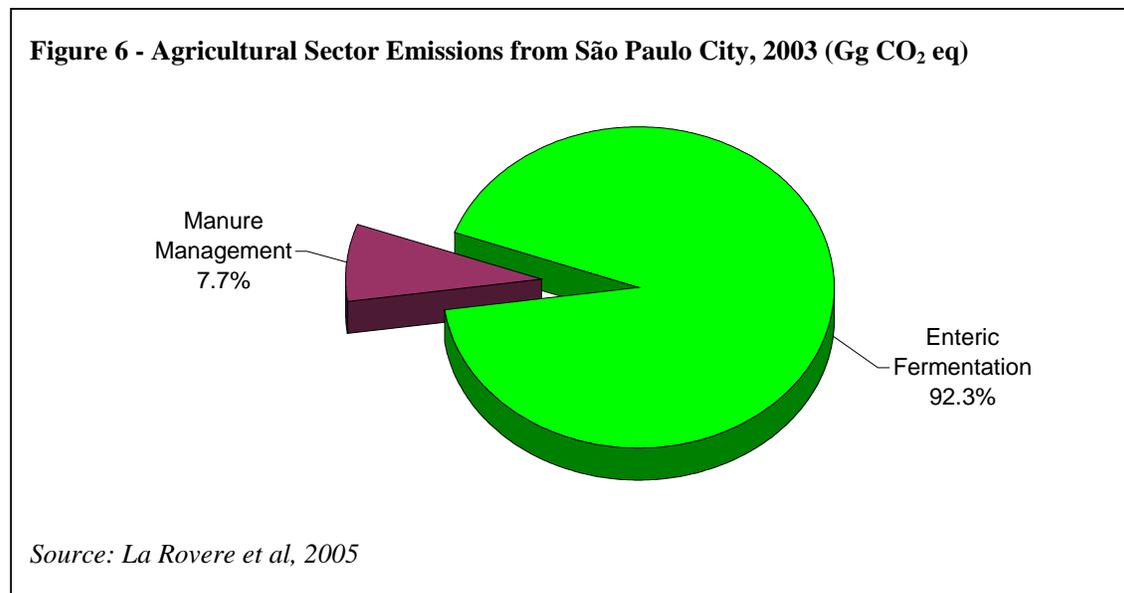


Source: La Rovere et al, 2005

CO<sub>2</sub> emissions from Land Use Change and Forestry cover the emissions from deforestation and lime application to soil<sup>5</sup>. Together they account for 0.33 percent of total emissions from São Paulo, with 0.31 percent being from the first and the remaining 0.02 percent from the second. Figure 5 shows these emissions.



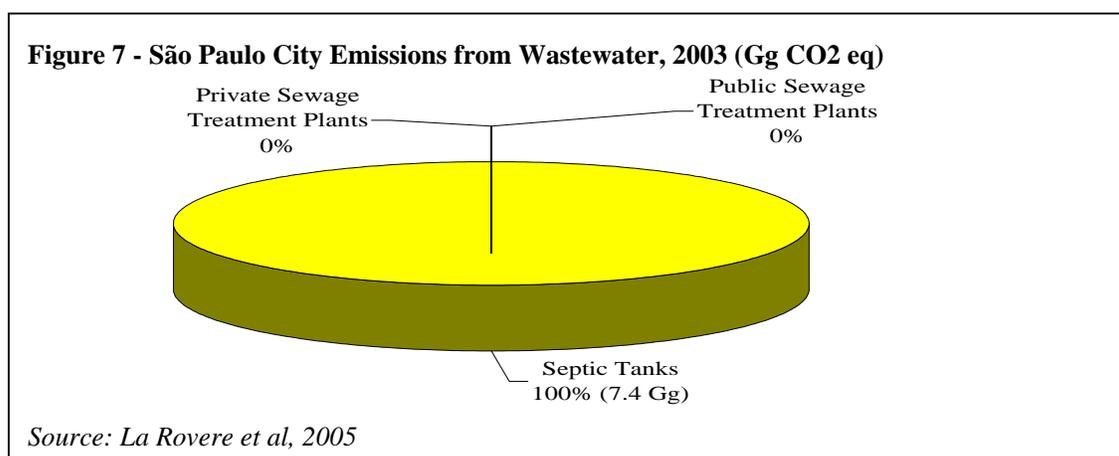
Emissions from **Agriculture (domestic livestock)** are marginal. This sector includes methane emissions caused by enteric fermentation and the disposal of animal wastes, with the former being responsible for 0.0046 percent of total emissions and the latter 0.0004 percent. Figure 6 presents the values.



<sup>5</sup> Liming is used to reduce soil acidity and improve plant growth in managed systems, particularly agricultural lands and managed forests. Adding carbonates to soils in the form of lime or dolomite leads to CO<sub>2</sub> emissions.

**Solid Waste Management** in São Paulo was responsible for a large share of GHG emissions in 2003 because at that time only 20 percent of the methane generated was burned and transformed into CO<sub>2</sub> (nowadays this percentage is much higher). It should be noted that CO<sub>2</sub> emissions from renewable sources does not contribute to climate change. Methane from waste management were mainly emitted by the two landfills operating in the city: Bandeirantes, with 44.9 percent, and São João with 55.1 percent, emitting together a total of 3696 Gg of CO<sub>2</sub> equivalent in 2003.

**Domestic, Commercial and Industrial Wastewater Treatment** represents only 0.047 percent of total emissions in São Paulo. Since the sewage treatment plants, which also treat industrial effluents, burn in flares 100 percent of the biogas produced in the process, the methane content of the biogas is transformed into CO<sub>2</sub> that, as mentioned above, does not contribute to climate change when from renewable sources. Therefore, the accounted emissions from this sector are only those from septic tanks existing in private houses as shown in Figure 7.



The Inventory shows that, as expected, carbon dioxide emissions are the most important, with a share of 76.25 percent, while methane accounts for only 23.75 percent.

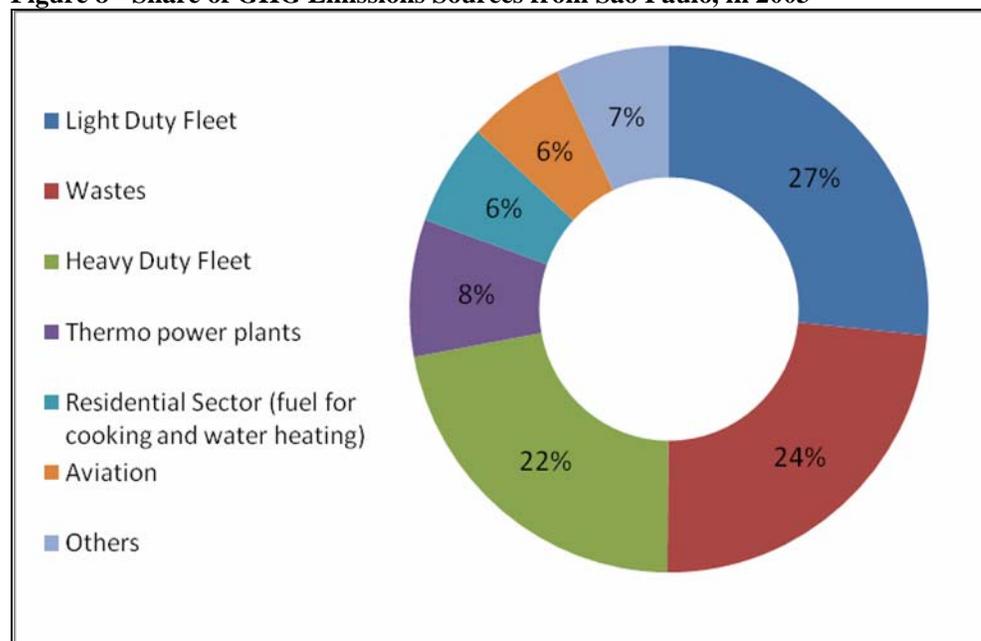
#### 4. Analysis of São Paulo's Emission Profile

São Paulo's emissions profile reveals that the transport sector is the major emission source mostly from individual transport that demands the biggest share of gasoline in Brazil. The Solid Waste sector is the second largest source followed by public and cargo transport systems that run mainly on diesel oil. These sectors are those with greater opportunities to GHG mitigation activities. Figure 8 shows the shares of the main emission sources.

Practically all the methane emissions inventoried in São Paulo result from urban solid waste management. It should be pointed out that these values have been substantially reduced from 2004 onwards due to GHG mitigating projects that allow for electricity generation from the gas produced on site<sup>6</sup>. Since the new landfills being projected for the city will incorporate mitigation practices and technologies, one can conclude that the required efforts to curb emission in this sector are advanced.

<sup>6</sup> Using financing scheme from the Clean Development Mechanism (CDM)

**Figure 8 - Share of GHG Emissions Sources from São Paulo, in 2003**



Source: La Rovere et al, 2005

Dubeux et al. (2005) state that since landfills are the most suitable method (safe and cheap) for waste disposal in the majority of the Brazilian municipalities and that according to PNSB 2000 (the National Survey of Basic Sanitation) they occur only in 13.8 percent of municipalities (the other share remaining untreated), there is a great potential for low methane emissions landfills in the country in the near future.

In relation to carbon dioxide emissions, the road transport sector is the greatest contributor to the climate problem, mainly by private vehicles. Nevertheless, its share should be reduced in the medium term due to the advent of flex fuel vehicles<sup>7</sup> that allows gasoline to be replaced by ethanol in the light transport Otto cycle fleet.

## 5. Comparison with other Inventories in Brazil

In order to provide a parameter of the magnitude of São Paulo's emissions, Table 1 shows total emissions and the emissions resulting from energy use obtained in the Inventory for São Paulo and the Brazilian Inventory for the National Communication, (MCT, 2004), as well as per capita emissions<sup>8</sup>.

<sup>7</sup> In 2002, flex fuel vehicles that run either on ethanol and gasoline in any proportion, began to be sold in Brazil allowing car owners to choose the fuel according to their prices. This technology is an adaptation of existing engines and has a big share of the market nowadays.

<sup>8</sup> Since the inventories were carried out in distinct and distant years— consequently reflecting different technological, economic and social development — this comparison has a merely illustrative purpose.

**Table 1 - Comparison of Emissions from São Paulo and Brazil**

	National Emissions (1994)*	Emissions from São Paulo City (2003)*
<b>Population</b>	157,290,000	10,710,997
<b>percent In relation to Brazilian total</b>	100 percent	6.8 percent
<b>Total Emissions (t CO<sub>2</sub> eq)</b>	1,289,406,000	15,738,241
<b>percent In relation to Brazilian total</b>	100 percent	1.2 percent
<b>Per Capita Emissions (t CO<sub>2</sub> eq)</b>	8.20	1.47

\* Only CO<sub>2</sub> and CH<sub>4</sub>

Source: La Rovere et al, 2005

It is important to note that although São Paulo city holds 6.8 percent of the population of Brazil; its emissions are relatively small, as shown in Table 1. This is because Brazil is a large emitter of GHG from Agriculture, Land Use Change and Forestry (covering agricultural practices deforestation and domestic livestock). In the case of deforestation, due to high rates, emissions account for 63.1 percent of total national emissions of CO<sub>2</sub> and CH<sub>4</sub> in CO<sub>2</sub>e. The agriculture sector as a whole is responsible for 16.5 percent of the same gases, mainly because of the size of the national herd (Comunicação Nacional, 2004). In the case of the extremely urbanized city of São Paulo these emissions are very low (less than 0.01 percent of the total).

Comparing the values obtained for São Paulo with other cities, we get the following results:

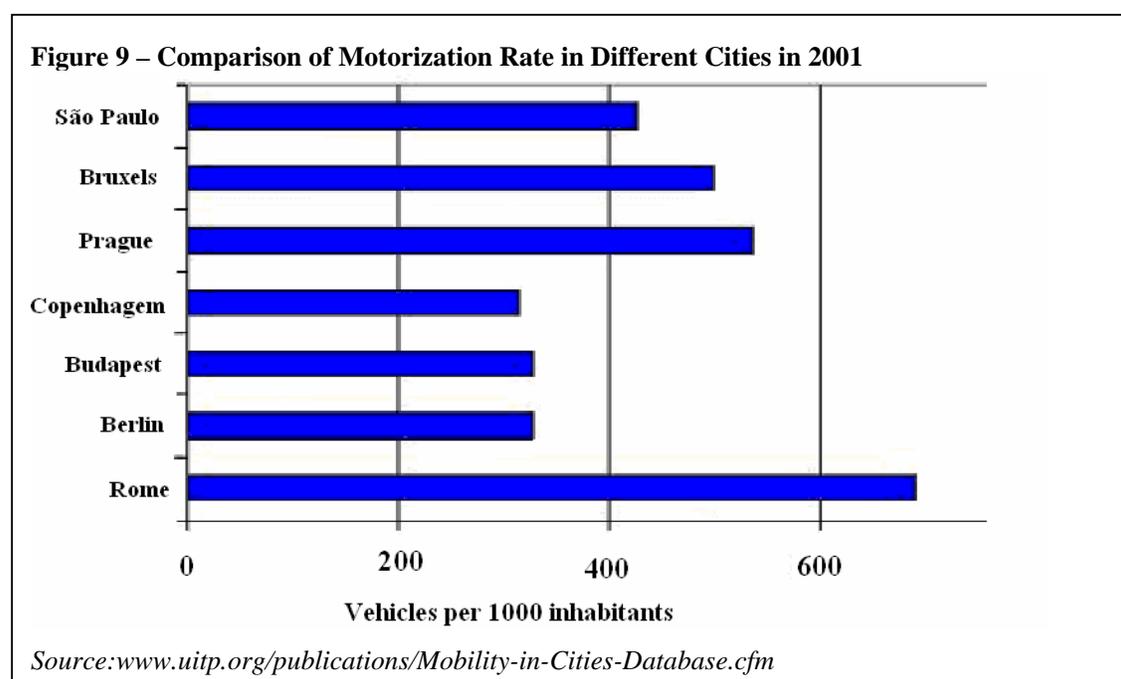
**Table 2 – Comparison of São Paulo Emissions with Other Cities**

City	Per Capita Emissions (tCO <sub>2</sub> /hab)	Year	GHG
São Paulo	1.5	2003	CO <sub>2</sub> , CH <sub>4</sub>
Rio de Janeiro	2.3	1998	CO <sub>2</sub> , CH <sub>4</sub>
Los Angeles*	9.3	1990	No Information
Rome*	5.2	1993	No Information
New York**	7.3	2007	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O,

Source: \* ICLEI (in La Rovere et al, 2003) and \*\* New York City Inventory (2008)

As can be seen in Table 2<sup>9</sup>, emissions from Brazilian cities are much lower than other cities. Although it can be explained by a number of factors, including, for example, income effect and consumption patterns, the low carbon contents of the Brazilian energy matrix plays a major role as 45.8 percent of total energy comes from renewable sources against the global average of 12.0 percent. This renewable participation is even more significant for electricity with a share of 88.7 percent (PNMC, 2008).

Although São Paulo city has a very high number of vehicles used for individual transport, one of the highest motorization rates in Brazil, with around 0.52 vehicles per inhabitant<sup>10</sup>, the mandatory blend of ethanol (23 percent) and gasoline (77 percent) used in most of the private fleet in inventoried year lead to a substantial low emission value<sup>11</sup>. Finally, as also said before, 54 percent of the waste produced is disposed of in sanitary landfills where biogas is collected and turned into fuel for electricity generation, while 100 percent of the methane of the sewage treatment plants is captured and burned in flares<sup>12</sup>.



<sup>9</sup> Ibidem.

<sup>10</sup> In 2002 there were more than four million automobiles and 400,000 motorcycles registered in the city (SVMA, IPT, 2004)

<sup>11</sup> Brazilian ethanol comes from sugarcane and is highly beneficial to the climate. When used in a pure form, as in pure ethanol or flex vehicles, the use of hydrated ethanol in substitution of gasoline represents a reduction of emissions by 2181 Kg CO<sub>2</sub>eq/m<sup>3</sup>. When used blended with gasoline, as an additive, hydrated ethanol avoids 2323 Kg CO<sub>2</sub>eq/m<sup>3</sup> of emissions (Macedo, 2007). These are values for emissions of fuel life cycles.

<sup>12</sup> No values were obtained for the efficiency of flares, therefore this is assumed to be 100 percent.

## 6. Methodological Questions:

### 6.1. Delimitations and Scope of Municipal Inventories

One important methodological question is the delimitation of the scope of the emissions to be inventoried. Emissions in or from the city? At first sight the most suitable criteria may seem to be 'political and administrative boundaries', in other words emissions created within the geographic boundaries of the city, following the IPCC guidelines<sup>13</sup>, according to which "national inventories should include emissions and removals that occur within the frontiers of national territories..."

In sum, IPCC methodology proposes to identify emissions from the production process and from the consumption of goods and services that occur within the political and administrative boundaries of a specific state, as mentioned above. Therefore, responsibility for emissions is restricted to these cases in which emissions that occur in productive processes outside these boundaries are not attributed to consumers. In other words, consumption does not lead to responsibility of extra boundary emission.

The same follows when this methodology is applied for cities. Most of the goods and services consumed are not produced in the cities where the consumption takes place. In that sense, to account for responsibility, the IPCC Guidelines should be revised and the methodological approaches incorporate the full life cycle emissions of a good or a service - although the current approach is also important since mitigation takes place where products are made.

Moreover, when the IPCC methodology for nations is used to perform an emissions inventory for a city, mainly in a metropolitan region, this issue may become even worse. This is due to the fact that there are no clear frontiers when going from one city to another and neighboring cities might be accounting for a share of other cities' emissions.

However, municipal policy actions have to be in accordance to national ones and such boundary issues cannot be neglected. In order to improve policy actions in the municipal context, the conventional approach have to be modified so that responsibility for emissions can be effectively attributed to its actual source.

To illustrate further this issue, specific procedures of municipal inventories in Brazil will be given. For example, most of the solid waste collected in Rio de Janeiro city is disposed in a neighbor municipality. That is, emission sources generated by the city occur beyond its` frontiers. This problem can also be observed in relation to sewage treatment systems when the cleaning process is shared by municipalities seeking to obtain economies of scale.

In this case the most appropriate methodological option adopted in the Rio de Janeiro Inventory (La Rovere et al, 2003) was to attribute emissions using the criteria of political responsibility rather than political and administrative boundaries and using the IPCC methodology on wastes for countries which compute emissions based on per capita production.

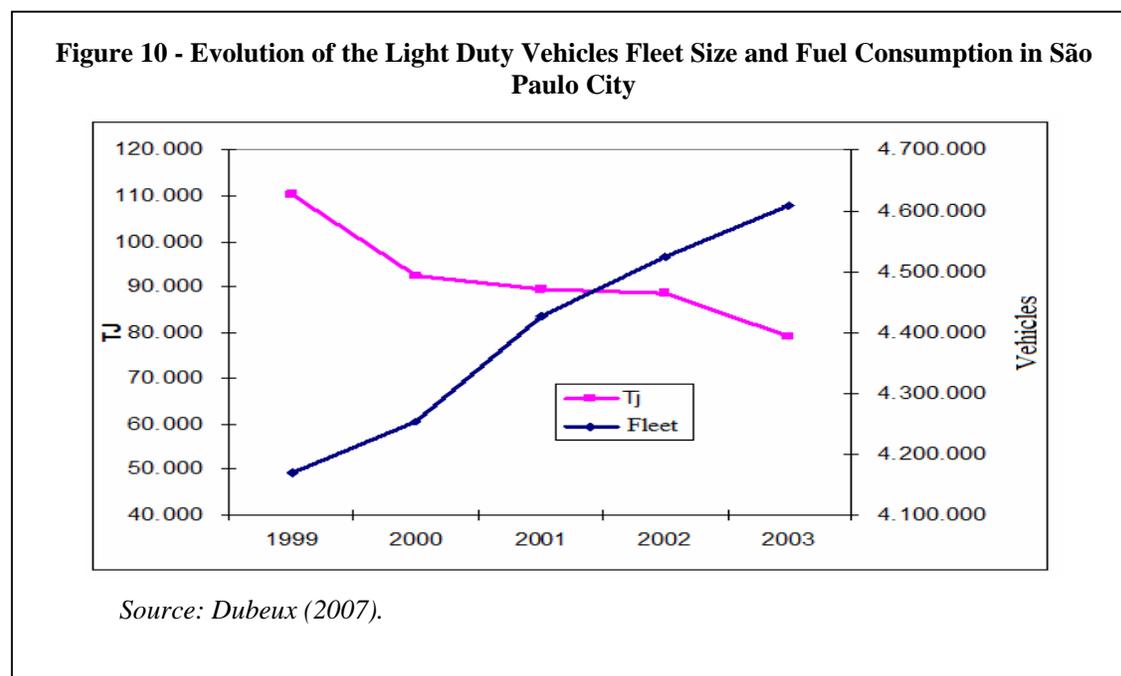
Transportation has an even great deal of extra boundary sources. In this case, estimation procedures will face an additional constraint regarding data availability and, therefore, it may prove necessary to avoid applying the top-down approach - the easiest way of accounting for emissions from energy use - by applying the bottom-up ones<sup>14</sup>. As in the case of the São

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<sup>13</sup> Reference Manual, Vol. 3, , p. 5 (IPCC, 1996)

<sup>14</sup> The top-down methodology approach (tiers 1 and 2 in the 2006 IPCC Guidelines) is fuel-based, since emissions from all sources of combustion can be estimated on the basis of the quantities of fuel combusted

Paulo Inventory, in order to verify the consistency of the application of the top-down methodology that uses fuel sales data from the city, Dubeux (2007) compared historical data series for the light vehicle fleet from São Paulo and fuel consumption from the National Petroleum Agency (Agência Nacional de Petróleo), with the latter being used in the application of top-down methodology in the emissions inventory. Historical series of fuel consumption show a decrease over a period during which the vehicle fleet expanded considerably, as shown in Figure 10. Since the efficiencies of vehicles remained the same during the period analyzed, some discrepancy in results was noted.



The use of the top-down methodology approach is highly dependent on energy consumption data, say, fuel sales. As a consequence, a significant fall in the consumption of energy occurred in the period 1999-2003 might be inconsistent with the actual growth of the vehicle fleet, since no large-scale projects in other transport modes have been identified, that could explain the simple transfer of passengers from light vehicles to public ones (reduction in the passenger-kilometer indicator in the former and an increase in the latter). According to Dubeux (2007) such discrepancy may be due to:

- 1) **Vehicles registered in São Paulo are supplied in other municipalities in the Metropolitan region due to people that live there, but work in a neighboring city.** This aspect reveals the difficulty in use a top-down approach when sources are inserted in a geographical context where various administrative locations exist and where there are no commercial boundaries. Would part of the emissions from

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(usually from national energy statistics) and average emission factors. The bottom-up approach (tier 3) for energy, accounts for emissions based either in detailed emission models or measurements and data at individual sources, taking into account the technology characteristics, the activity levels and so on.

vehicles that belongs to São Paulo citizens not being attributed to the city or would it be exactly the other way round?

- 2) **Transfer of Supply Points to Other Municipalities in the Metropolitan Region.** The high opportunity cost of land in the richest municipalities in metropolitan regions may induce a transfer of supply points (gas stations) to locations where urban land is cheaper. This phenomenon has been clearly observed in Rio de Janeiro, while it is less evident in São Paulo where there is a greater availability of land for civil construction. Nevertheless, it still cannot be ruled out that this phenomenon may be a probable explanation, at least in part, for the inconsistency of energy consumption data related to transport in this municipality, at that time;
- 3) **Falsification and Inadequate Fuel Use. The following events in the country hinder the use of actual energy consumption statistics:**
  - Adulteration of gasoline – due to the low level of taxation on naphtha, part of the gasoline has been substituted by naphtha;
  - Adulteration of alcohol – due to the fact that anhydrous alcohol is only taxed after being mixed with gasoline, part of the production is mixed with water to replace hydrated alcohol (known as ‘wet alcohol’) used in ethanol vehicles in Brazil; and
  - The “Cocktail Phenomenon” – gasoline powered vehicles (77 percent gasoline and 23 percent anhydrous alcohol) use gasoline adulterated with naphtha in blends with anhydrous alcohol clandestinely converted to hydrated alcohol.

In turn, there are also estimation problems with the application of the bottom-up approach when there is no reliable data on the fleet size, technology, age and activity level. To account for the mode activity level in terms of passenger-kilometer and ton-kilometers covered by each technology there is a need to make origin-destination surveys what is very costly and time consuming. Nevertheless, if these difficulties are overcome, the application of the bottom up approach is most suitable and also allows pollutants other than GHG (such as CO, NO<sub>x</sub>, SO<sub>x</sub>, VOCs, black carbon, etc)<sup>15</sup> to be estimated, thereby facilitating the task of discovering the origin of local pollutants, also facilitating the design of policies that can include the global, local and regional levels.

In the case of the road modal in public transport, great difficulty has been observed in using top-down methodology based on fuel sales data. Nevertheless, since as it is operated through public concessions, the control of cost spreadsheets by municipal authorities allows the problem of leakage to be minimized when the transport is merely local. It should be emphasized that there are clandestine transport services in all large Brazilian cities, which means that this control is problematic due to the absence of reliable statistics.

In respect to inter-municipal transport, whether road or rail, as in the case of individual transport, the application of bottom-up methodology based on an origin-destination survey is considered to be more appropriate.

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<sup>15</sup> The top down approach accounts accurately only for CO<sub>2</sub> emissions although other direct GHG can also be roughly estimated. When using the bottom-up approach, all other pollutants including local and regional ones that are not direct GHG can be accounted for.

## Conclusion

Although developing countries do not have commitments under the United Nations Framework Convention on Climate Change to reduce GHG emissions, ongoing negotiations may lead to the need for these countries to make a commitment to some form of control of their emissions, which in turn indicates the need for these countries to discover their emissions reduction potential.

As a result, planning activities by municipal administrations have to carry out studies which can reveal both current levels of GHG emissions and how to find ways to respect the future commitments. Therefore, a very promising action to deal with this challenge is to carry out municipal inventories of greenhouse gases emission that will allow the sources and responsibility for these emissions along with mitigation options to be identified.

In the case of São Paulo city, the inventory performed revealed that emissions are mainly originated by transportation and therefore this is the sector where most of the mitigation opportunities can be met. As fuels in Brazil are mainly renewable, mitigation opportunities lie mostly on modal substitution when private car use is replaced by public transportation and thereby increasing efficiency and reducing congestion.

For city inventories it is recommended that the methodology of the Intergovernmental Panel on Climate Change (IPCC, 2006) be used, once it is adjusted to the needs of the location where the study is being carried out. This adjustment should be made based on the observation of the local dynamic of pollution sources, taking into account the availability and the quality of data, so that the most appropriate calculation methodology will be used.

In the case of the urban road transport sector the simulations carried out by Dubeux (2007) reveal that the bottom-up methodology for the private vehicle fleet is best adapted to municipalities in metropolitan regions due to the difficulty in attributing specific fuel consumption to just one municipality because of the absence of trade barriers among all municipalities.

In the case of public transport, when these are strictly municipal the methodology can be top-down since there should be no difficulties in identifying fuel consumption since it is a public concession with municipal control. In the case of inter-municipal transport only by implementing a origin-destination survey required to perform a bottom-up methodology approach can adequate estimate the anthropogenic emissions at the local level.

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