Energy Policy 38 (2010) 4838–4847

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Emission inventory: An urban public policy instrument and benchmark

Alexander D' Avignon *, Flávia Azevedo Carloni, Emilio Lèbre La Rovere, Carolina Burle Schmidt Dubeux

Centro Clima/PPE/COPPE/UFRJ (Center for Integrated Studies on Climate Change and the Environment/Energy Planning Program/Alberto Luiz de Coimbra Engineering Graduate School and Research Center/Federal University of Rio de Janeiro) and National Scientific and Technological Institute of Public Polices, Strategies and Development (UFRJ)

ARTICLE INFO

Article history:
Received 23 February 2009
Accepted 1 October 2009
Available online 25 November 2009

Keywords:
Greenhouse gases
Municipalities
Inventory

ABSTRACT

Global concern with climate change has led to the development of a variety of solutions to monitor and reduce emissions on both local and global scales. Under the United Nations Framework Convention on Climate Change (UNFCCC), both developed and emerging countries have assumed responsibility for developing and updating national inventories of greenhouse gas emissions from anthropic sources. This creates opportunities and incentives for cities to carry out their own local inventories and, thereby, develop air quality management plans including both essential key players and stakeholders at the local level. The aim of this paper is to discuss the role of local inventories as an urban public policy instrument and how this type of local instrument may bring advantages countrywide in enhancing the global position of a country. Local inventories have been carried out in many cities of the world and the main advantage of this is that it allows an overview of emissions produced by different municipal activities, thereby, helps decision makers in the elaboration of efficient air quality management plans. In that way, measures aimed at the reduction of fossil fuel consumption to lower local atmospheric pollution levels can also, in some ways, reduce GHG emissions.

1. Introduction

The increasing emission of greenhouse gases (GHG) is believed to be responsible for global warming and recently it has been attracting the attention in many different parts of the world, resulting in increased legislative requirements on a global basis. Although localized effects are not directly generated by GHG, wherever they are emitted in the world, they cause climate alterations (Baede et al., 2001). So, the concerns about global climate change have resulted in the development of a variety of solutions to monitor and reduce emission in global and local scales. In local scale, air pollution has also been one of the major environmental problems in big cities, affecting health of thousands of urban residents (Jain and Khare, 2008; Kimmel and Kaasik, 2003; Peng et al., 2002; Venegas and Mazzeo, 2006). Other environmental impacts include damages to buildings and structures, agriculture crops, and vegetation and forests; reduced visibility; and even increasing greenhouse gas emissions (Kojima and Lovei, 2001). Therefore, the possibility of the quantification of local emissions has become an important element in understanding the problem and searching for solutions.

Under the United Nations Framework Convention on Climate Change (UNFCCC), both developed and emerging countries have assumed responsibility for developing and updating national inventories on GHG from anthropic sources. In accordance with the principle of common but differentiated responsibility, only the countries listed in Annex I of the Convention currently have commitments to reducing or limiting emissions. However, it is recognized that the countries not belonging to this group will contribute to the increase in greenhouse gases emission in social and economic development. So, amongst the commitments assumed by Brazil under the UNFCCC is the regular development and updating of national inventories of anthropic emissions and removals through sinks of the greenhouse gases not controlled by the Montreal Protocol. The first Brazilian National Communication prepared in accordance with the Intergovernmental Panel on Climate Change (IPCC) was released in 2004 at the 10th Conference of the Parties of the UNFCCC in Buenos Aires. The document contained the first Brazilian greenhouse gases inventory and covered the period of 1990–1994 (MCT, 2004).

In the methodology from IPCC, the sectors are inventoried from a national perspective and it does not allow the particularities associated with cities and metropolitan regions to be identified. The inventory produces information in an aggregate form on the energy, residue, forestry, agriculture, livestock, industrial processes and product use sectors. The desegregation of these sectors in relation to municipalities would create opportunities and it stimulates cities to carry out their own local inventories, allowing the identification of the most effective areas of action and the preparation of more feasible public policies,

* Corresponding author at: Center of Technology, Block C, Sala 211, Cidade Universitária, Ilha do Fundão, Rio de Janeiro/RJ, CEP: 21949-900, Brazil. Tel.: +55 21 97166705; fax: +55 21 2562 8805.

E-mail addresses: davignon@uol.com.br (A. D' Avignon), fbcarloni@lima.coppe.ufrj.br (F.A. Carloni), emilio@ppe.ufrj.br (E.L. Rovere), carolina@ppe.ufrj.br (C.B. Dubeux).

0301-4215/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.enpol.2009.10.002

leading to the development of effective and efficient local air quality management plans including essential key players and stakeholders.

The aim of this paper is to discuss the role of local inventories as an urban public policy instrument and to know how this may benefit countries and cities by diminishing local pollution levels and contributing to reduce, in some ways, GHG emissions whilst helping local public administration. This analysis was made based on the examples of two important Brazilian cities: Rio de Janeiro and São Paulo.

2. The climate problem and cities

The Fourth Report of the Intergovernmental Panel on Climate Change (AR-4, IPCC) states that CO_2 concentrations have reached 370 ppm, an increase of more than 35% in relation to the beginning of the Industrial Revolution (IPCC, 2007). According to AR-4 it is almost certain that this increase is associated with the greenhouse effect caused by man, i.e., anthropic effects, due to GHG emissions and economic activities.

At the present moment developing countries do not have any obligation to reduce their emissions of greenhouse gases; however, the commitments and goals finish in 2012. They are currently being re-negotiated and countries without goals, i.e. Brazil, may have to reduce their emission levels if a second commitment period for the Kyoto Protocol is agreed in Copenhagen.

In general the proposals that deal with the participation of developing countries accept that different types of countries must have distinct types and/or levels of commitment. Different criteria for setting goals have been advanced, such as per capita income, emissions, emissions per GDP unit, historical population emissions and current emissions, amongst others. These criteria demonstrate that annual emissions do not represent a good approach to responsibility for climate change, and they further suggest alternative applications of the principles of common but differentiated responsibilities and the 'polluter pays' when considering the establishment of limits for GHG emissions from countries listed in Annex I of the UNFCCC due to their responsibility for the temperature increase in the planet. Another proposal to be discussed in the negotiations for the second commitment period is the subdivision of the Non-Annex I countries in order to allow a greater differentiation of responsibilities and capacities among the countries that form this group as a motivating factor in the negotiation process. Something that has also been stressed is a new form of active participation of Non-Annex I countries related to the attribution of qualitative and not quantitative targets, notably in relation to policies and measures aimed at the reduction of GHG emissions.

Due to the concentration of population in major urban centers in developing countries, cities consume most of the energy produced to meet transport, commercial and industrial activities, heating and cooling demands. Consequently, solid wastes and residential, commercial and industrial effluents are mostly produced in urban agglomerations, as well as urban air pollution has also became an increasing problem (Carnevale et al., 2006; Dubeux and Rovere, 2007; Kimmel and Kaasik, 2003; Peng et al., 2002; Venegas and Mazzeo, 2006). Anthropogenic air pollution originates from a variety of sources, including households, vehicles, large stationary sources, small and medium-size industries, agriculture, and forest burning (Kojima and Lovei, 2001). According to Kojima and Lovei (2001), pollution from many of these sources is closely related to the production and consumption of energy, specially the combustion of fossil fuels, just like GHG emission are mainly produced from these sources. So, some of the same combustion processes that emit gases which locally affect human health, ecosystems and agricultural productivity—such as sulfur dioxide (SO_2), nitrous oxide (NO_x), suspended particulate matter, volatile organic compounds (VOC) and carbon monoxide (CO)—also cause the emission of gases that have impact on climate—such as carbon dioxide (CO_2), methane (CH_4) and nitrogen oxides (N_2O). This is because fossil fuels are not only the main source of many local and regional pollutants but also of greenhouse gases (GHG). According to Wilbanks and Kates (1999), global changes in climate, environment, economies, populations, governments, institutions, and cultures converge in localities. Changes at a local scale, in turn, contribute to global changes and also are affected by them. Therefore, measures aiming to reduce fuel consumption in order to lower local atmospheric pollution levels may, at the same time, reduce GHG emissions, or vice versa.

Most developing cities may lack the data and resources to carry out initiatives for mitigating air pollution. So, policymakers often have to choose among alternative measures without having the necessary information about them. Under these circumstances, there is often a temptation to import standards and technologies from developed countries without assessing their costs, their benefits, and the feasibility of operating and maintaining them, which is seldom the answer (Kojima and Lovei, 2001). However, with the support of local research institutions, as the university, it is possible to develop adaptations to these standards and methodologies to fit local needs.

Politically, suggestions for GHG mitigation measures in developing countries are often received warily and can be perceived as a denial of these countries' basic right to economic growth and improvement of wellbeing (Kojima and Lovei, 2001). According to Kojima and Lovei (2001), the keys to changing this perception are (a) to link GHG mitigation to emission-reducing policies whose goals are of far greater immediate relevance than GHG mitigation and (b) to facilitate financial assistance from industrial countries to reward developing countries for the global benefits of accelerating the introduction of such local measures. GHG mitigation strategies have specific positive effects on public finances through savings in health and the avoidance of damages caused by local pollutants (Garg et al., 2002; Kimmel and Kaasik, 2003; Lin and Rosenquist, 2008; Peng et al., 2002; Ramanathan, 1999; Wang et al., 2005; Yedla et al., 2005). Kousky and Schneider (2003) list many efficiency projects with a high potential for GHG mitigation and a positive internal rate of return that can lead to improvements in local finances. Kojima and Lovei (2001) also mention that the enormous gains made in improving fuel economy in the 1970s and the first half of the 1980s have contributed to decreasing both local and global pollution in industrial countries. Another possibility for emerging countries is the use of financial resources from the carbon market to upgrade environmental management systems.

However, there are not always synergies between measures to reducing local pollution and those for mitigating GHG emissions. For example, diesel is a particularly efficient fuel, and hence favorable from the point of view of reducing GHG emissions. However, recent scientific findings suggest that diesel emissions are more damaging to human health than emissions from other fuels (Kojima and Lovei, 2001). There are a variety of measures that provide the positive association between GHG reductions and improvement in environmental local conditions, especially in Brazil through biofuel, energy efficiency and waste management, for instance. Table 1 shows some of the possible measures that can be taken after the inventory measurement has been carried out.

3. Emission inventories and cities

Local GHG inventories have been carried out in many cities of the world with different goals, and their principal advantage is

Table 1
Recent trends, evaluation of human influence on the trend and projections of extreme events for which a trend has been identified at the end of the 20th century.
Source: IPCC AR4—2007.

Phenomenon and trend	Probability of trend being verified at the end of the 20th century (from 1960)	Probability of human contribution to the observed trend	Probability of future trends in projections for the 21st century
Hotter days and nights and slightly colder days and nights in large parts of terrestrial regions	Very probable	Probable	Virtually certain
Hotter days and nights and a higher frequency of hotter days and nights in large parts of terrestrial regions	Very probable	Probable (for nights)	Virtually certain
More frequent heat waves in most parts of terrestrial regions	Probable	More probable that not probable	Very probable
Heavy rain. Frequency (or ratio of total and heavy rain) higher in most areas	Probable	More probable that not probable	Very probable
Increase of areas affected by drought	Probable in many regions since 1970	More probable that not probable	Probable
Increase of intense activities of tropical cyclones.	Probable in some regions since 1970	More probable that not probable	Probable
Greater incidence of high sea levels (not including tsunamis)	Probable	More probable that not probable	Probable

enabling an overview of emissions produced by the different activities carried out in the city. For example, through an emission inventory it is possible to identify the different impacts caused by exposure to these emissions; evaluate energy demands met by the use of fossil fuels; recommend measures to reduce air pollution levels and further investigate with the aim of improving air quality assessment and management. It is also possible to develop models to provide current and alternative emission scenarios and assist in evaluation of the effectiveness of emission control strategies, among other actions and policies (Carnevale et al., 2006; Jain and Khare, 2008; Kimmel and Kaasik, 2003; Wang et al., 2005). Several local benefits can be identified with policies dealing with the control of local and regional atmospheric pollution, as well as policies directed towards global environmental problems (global warming) (Wilbanks and Kates, 1999).

Although there are differences in institutional and political organization of cities in the world, most of them can be considered as a unit of analysis in relation to climate. Even in some countries, where political autonomy is not possible, the investigation of local actions can open opportunities for policies, including national ones. The inventory assumes a previous step to mobilization for projects related to flexibilization mechanisms, being a tool for construction of future scenarios of GHG emissions and creation of policies. The dimensioning of GHG mitigation potential in cities becomes urgent not only due to the urgent need of contributing more in the near future to the global reduction of emissions, but also due to the possibility of reducing costs in sectors such as health and conservation of urban equipment, or obtaining resources in the carbon market, especially in developing countries that have large cities with several infrastructural problems.

The identification of opportunities that can result in benefits and not just costs is important since it can reduce the efforts that a developing country has to take to mitigate global climate changes. Therefore, amongst other actions, it is useful to analyze the options cities have been contributing through their collective efforts and identify actions that can be implemented by local governments. The identification of these emission mitigation and GHG removal options requires the preparation of inventories and scenarios as planning tools.

The inventory is a stage in the planning process that shows the current status of emission levels and their sources. Various sources of GHG emissions are analyzed and their respective gas emissions are estimated in accordance systematically including the majority of emissions resulting from the socio-economic activities of the city in question.

Based on the identification of emissions that are responsibility of a specific city, local actions can be carried out in the energy, industry, waste treatment, transport, soil use, and forest and agriculture sectors aimed at reducing these emissions. The methodology contained in National Inventories of Greenhouse Gases Emissions of the Intergovernmental Panel on Climate Changes (IPCC, 2006) is aimed at the national sphere; however, it can be adapted to a regional or metropolitan inventory. The methodology varies from simple methods and hypotheses (top-down) covering the biggest GHG sources and sinks to more elaborate ones that require detailed databases. As a result, countries have the option to use various methods and levels (tiers) of detail depending on their own needs, the availability of data and technical capacities. Inventories can, and should, be more detailed, using local factors of emission and observing the characteristics of emission sources. So, it can be the reference for preparation of specificities for cities, both in relation to the adjustment of emission factors and the definition of responsibilities and geographic borders.

When using a methodology originally designed for states in a local context, the adequacy of the transposition and the extent to which adaptations are necessary have to be meticulously verified. Since the carrying out of national inventories estimation is an obligation assumed by countries under the UNFCCC in order to assist decision-making related to the adoption of limitations on national emissions, the methodology seeks to standardize the information in order to allow comparison of different inventories. In the case of cities, inventories must reflect the needs defined by the possibilities of implementation of emission mitigation policies. Therefore, they have to be configured in relation to this purpose.

Another important methodological question to be considered is the delimitation of the scope of the inventory to those emissions whose sources result solely from the socio-economic activities of the city and hence local governments can intervene. In accordance with the IPCC guidelines for national greenhouse gas inventories, 2006, "national inventories include GHG emissions and removals that occur inside the national territory and offshore in areas where the country has jurisdiction" (IPCC, 2006). If these guidelines were observed in the case of municipal inventories in Brazil, where, for example, electric energy is offered through an interlinked system, cities with a large consumption of electric energy, but a low participation in generation would not be great GHG emitters, since electric energy consumption does not generate emissions but its generation does, even the if the country has a hydroelectric generation base of around 78%, according to National Energy Balance of 2008 (BEN, 2008). In the same way, cities which have a large production of oil derivatives and natural gas but which export a large proportion of this energy should be penalized and assume responsibility for the emissions generated by economic activities of other consumers. One suggestion to solve this problem is, whenever possible, to present emissions generated within the borders of a city but those that cannot be determined as its responsibility separately and is not included in the total inventory.

Some important initiatives have shown that the efforts of Non-Annex 1 and Annex 1 countries to understand the contribution of large cities to global warming are becoming aligned. For instance, the Clinton Climate Initiative (CCI) was launched in August 2006 to tackle climate change in measurable and significant ways (ClintonFoundation, 2008b). In its first phase the CCI has served as the exclusive partner for the implementation of the C40 Large Cities Climate Leadership Group, an association of large cities from around the world that have pledged to accelerate their efforts to reduce greenhouse gas emissions (ClintonFoundation, 2008a). The initiative is assisting partner cities to develop and implement large scale projects that can result in substantial reductions in energy use and emissions. The C40 group consists of 40 large cities: Addis Ababa, Athens, Bangkok, Beijing, Berlin, Bogotá, Buenos Aires, Cairo, Caracas, Chicago, Delhi, Dhaka, Hanoi, Hong Kong, Houston, Istanbul, Jakarta, Johannesburg, Karachi, Lakes, Rasp, London, Los Angeles, Madrid, Melbourne, Mexico City, Moscow, Mumbai, New York, Paris, Philadelphia, Rio de Janeiro, Rome, São Paulo, Seoul, Shanghai, Sydney, Toronto, Tokyo, and Warsaw.

Other initiative is the Cities for Climate Protection (CCP), promoted by the International Council for Local Environmental Initiatives (ICLEI), which acts both regionally and nationally, in Australia, Canada, Europe, Japan, Latin America, Mexico, New Zealand, South Africa, South and Southeast Asia, and the United States. Its principal objective is to bring together local government efforts aimed at the adoption of policies and implement quantifiable measures for GHG emission reductions, as a way of improving life and air quality in urban centers. More than 800 cities participate in the CCP, integrating climate change mitigation measures in their decision-making processes. The campaign is based on a performance structure containing five milestones to which local governments are committed. These milestones allow them to understand how decisions taken in the municipal sphere could affect energy usage and how these decisions can be used to mitigate climate changes at the same time as they improved the quality of life of the community. The five milestones of the campaign and the methodology underpinning them offer simple and standardized ways of calculating emissions, establishing objectives to reduce emissions and for monitoring, measuring and producing performance reports. Tools and software were developed by ICLEI and they are available to help in implementation of the methodology and to assist cities to reach their objectives. The milestones are:

1. Conduct a baseline emissions inventory and forecast.
2. Adopt an emissions reduction target for the year forecast.
3. Develop a Local Action Plan.
4. Implement mitigation policies and measures.

Well planned mitigation actions can become opportunities for CDM in developing countries and in many cases they enable the inventories financing part of it. Mitigation corresponds to project activities that reduce greenhouse gas emissions (GHG) when compared with the base line. However, the mitigated amount (of GHG emissions) may neither be significant nor eligible for CDM. These projects are still concentrated in some countries, as China, India and Brazil, but as Clinton Foundation or ICLEI are interesting initiatives that can make possible elaboration of inventories. The main characteristic of these projects is their contribution to sustainable development. Therefore, their certified reductions of emissions can be commercialized in the volunteer market, often obtaining a higher price because of the social and environmental benefits that they bring. In many cases, these projects have lower transaction costs because they do not need to meet all the requirements for CDM qualification proposed in the UNFCCC.

A following step in the inventory management would be identifying alternative futures for the reduction of emissions through projects to be implemented by governmental bodies, preparing future scenarios and calculating the emissions prevented by the various mitigation measures that can be used. The construction of scenarios is a complementary stage that allows, on the other hand, a projection of the base line, in other words the identification of what the future would be in the event that nothing was done in relation to the climate. In addition, it also involves an evaluation of the results of different climate strategies that can be adopted to reduce emissions, such as action plans, projects, etc. As GHG emissions are the product of very complex dynamic systems determined by forces such as demographic development, socio-economic development and technological changes, their future evolution is highly uncertain. Therefore, the scenarios are alternative images of how the future may unfold, evaluating the driving forces that may influence future emissions and the uncertainties associated with them.

Based on the results of the inventory and the scenarios, it is possible to propose a Public Climate Change Policy and an Action Plan involving objective measures to be carried out by local authorities to tackle the problem of the anthropogenic generation of greenhouse gases. This Action Plan can also serve to stimulate the participation of the city in one of the Flexibilization Mechanisms stipulated in the UNFCCC. Carrying out emission inventories estimation and the subsequent development of emission scenarios constitute instruments that can allow the identification of areas of action where CDM projects (in the case of developing countries) or joint implementation (by the parties of Annex 1) can be developed. Projects that can be certified as reducing carbon emissions, as being covered by the CDM, and of interest to local governments include:

- increases in energy efficiency (both supply and use),
- substitution of energy of fossil origin with renewable energy,
- more intensive substitution of fossil fuel of carbon origin with fossil fuels that are less intensive in carbon,
- proper management of solid residues and industrial effluents,
- rationalization of the use of agricultural inputs,
- carbon sequestration (forestation and reforestation).

As the relation between local and global pollution is closely linked to the interaction between cities and their country, local measures or policies could generate great opportunities in national level. In Brazil, for example, a set of proposals for mitigation adopted in the country came from suggestions originating from local climactic forums, mainly after the presentation and discussion of local inventories (Rovere et al., 2008). In that way, the results from cities inventories may guide Federal/ Central Governments in elaboration of mitigation measures for activities such as airport infrastructure or other sectors, which is normally national responsibility.

4. Case study—Inventories of Rio de Janeiro and São Paulo

The Greenhouse Gas Emissions Inventory of the City of Rio de Janeiro (COPPE, 2000) was an unprecedented initiative in both Brazil and Latin America. It was aimed at complying with the commitments signed by the municipal government in 1998 to adhere to CP campaign run by ICLEI. Furthermore, its pioneering nature at that time allowed a proper methodology to be developed, and was adapted from the methodology proposed by the Intergovernmental Panel on Climate Change for the scale and characteristics of the city, developed by Alberto Luiz Coimbra Engineering Graduate School and Research Center (COPPE-UFRJ). The main methodological question this work dealt with, taking into account its pioneering nature in inventorying municipal emissions of GHG, was to delimit its coverage so that it was restricted to those emissions which resulted solely from the socio-economic activities of the city. To overcome these obstacle geographic limits it was adopted, and the criteria of responsibility for emissions induced by the city was also adopted, whether or not these occurred within municipal territory.

The 2003 Inventory was concerned with quantifying annual CO_2 and CH_4 emissions for the period 1990–1998, and this was afterwards extended to cover future emission scenarios. Although this study was part of the ICLEI campaign, it was carried out by Centro Clima, a research institute that is part of the Energy Planning Program of the Alberto Luiz de Coimbra Engineering Graduate School and Research Center in the Federal University of Rio de Janeiro—PPE/COPPE/UFRJ.

The Revised 1996 Guidelines for National Greenhouse Gas Inventories (IPCC, 1996) were adapted to local specificities and applied to the energy, changes in land and forest use, agriculture, and waste sectors. The proposed approach is considered to be feasible from the point of view of Brazilian urban dynamics and the availability of data. The methodological approach is mentioned when there are options in the 1996 IPCC guidelines or when the original IPCC methodologies were adapted. Emissions from electric energy are attributed only to the Power Generation Sector and not to end use sectors to avoid double counting. The energy consumption sector has the greatest responsibility for emissions, accounting for 60% of the total, and transport is the most important source in this sector. The solid wastes management sector is the second largest source of emissions with a significant 37% share. The other sectors are quite insignificant. Fig. 1 shows the carbon dioxide and methane emission flow charts resulting from the methodology adapted in Rio de Janeiro inventory.

The energy sector approach was top-down, expressed in terms of the fuel consumption of the following large final consumer sectors: power generation, industry, individual transport, collective and cargo transport, air transport and households and commerce. Industrial processes were considered of very low significance from the perspective of the municipal administration of Rio de Janeiro and therefore these emissions were not taken into account. The agriculture sector was estimated in terms of CH_4 produced by livestock, manure management, rice fields and burning of savanna. As in Rio de Janeiro there are no rice fields or burning of savanna, only enteric fermentation and manure management emissions were estimated. This category is considered to have very low climate interference from the perspective of the municipal administration of Rio de Janeiro and therefore it was recommended that they need not be taken into consideration, except under specific conditions where local

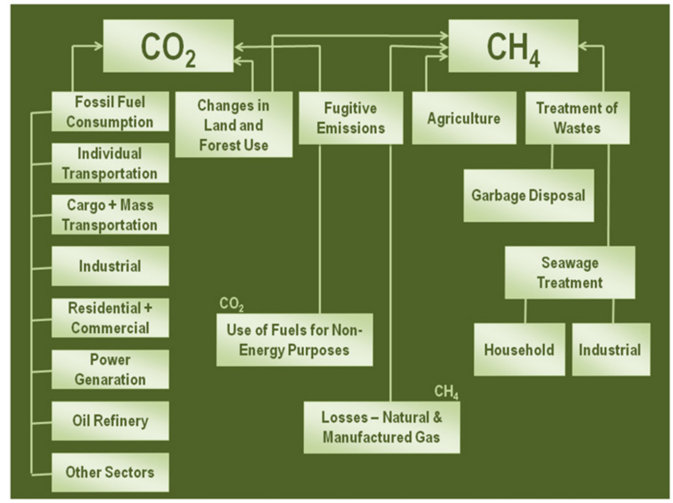

Fig. 1. CO_2 and CH_4 emissions flow chart for the Rio de Janeiro Inventory. *Source*: Rio de Janeiro inventory

administration saw opportunities to establish partnerships or if the costs of estimating such emissions were marginal in relation to the general assessment.

Changes in land and forestry use were estimated based on CO_2 emissions caused by the removal of forests due to the expansion of urban areas. However, the great majority of Brazilian municipalities focus on the conservation of remaining native forests if urbanization is responsible for deforestation. In these cases, deforestation is a phenomenon that advances slowly with vegetation removal and dumping in landfills or leaving to decay in inner parts of the forest. As a result the methodology used took into account only CO_2 emissions from the carbon content of vegetation, since emissions from fires are marginal. The CO_2 removal due to annual increases in biomass (reforestation) was also considered. Similar to reforestation, the carbon sequestration that occurs due to municipal initiatives is peculiar since it is related to forest recovery, as public squares or planting trees in streets, etc.

Emissions from the waste sector were estimated in terms of CH_4 produced by landfills. Due to new CDM rules covering the estimation of CH_4 formation in landfills for mitigation projects, it is highly recommended that new inventories use the IPCC methodology for the 'First Order Decay' rate, since this is compatible and allows a better evaluation of CDM potentials.

Fig. 2[1] shows emissions per energy source and per sector demand in Rio de Janeiro in 1998. Emissions from electric energy are attributed solely to the Power Generation Sector and not to the end use sectors to avoid double counting.

As shown in Fig. 2 the energy consumption sector has the greatest responsibility for emissions, representing nearly 60% of the total area, the transport being the most important source in this sector. The solid waste management sector is the second largest source of emissions with a significant 37% share. The other sectors are quite insignificant. Fig. 3 shows the evolution of emissions in the period analyzed by the inventory.

[1] CO_2 and CH_4 emissions were estimated in 100-year GWP—Sector emissions—Rio de Janeiro city, 1998. (Global warming potential: an index, describing the radioactive characteristics of GHG, that represents the combined effect of the differing times these gases remain in the atmosphere and their relative effectiveness in absorbing infrared radiation. This index approximates the time-integrated warming effect of a unit mass of a given greenhouse gas in toda atmosphere, relative to that of carbon dioxide (SAR-IPCC, 2000).)

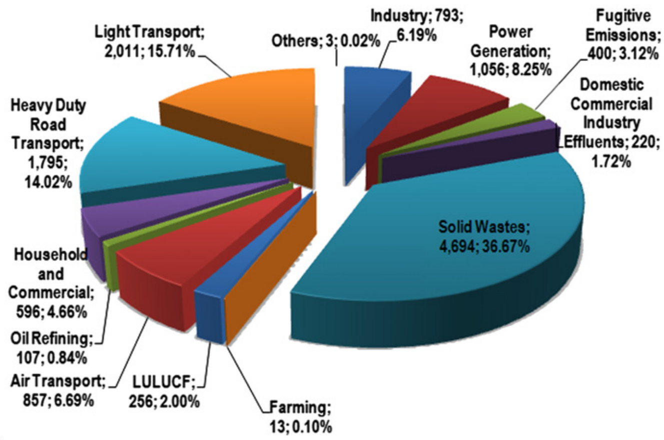

Fig. 2. CO_2 and CH_4 emissions (Gg CO_2eq). *Source*: Based on Inventory (2003).

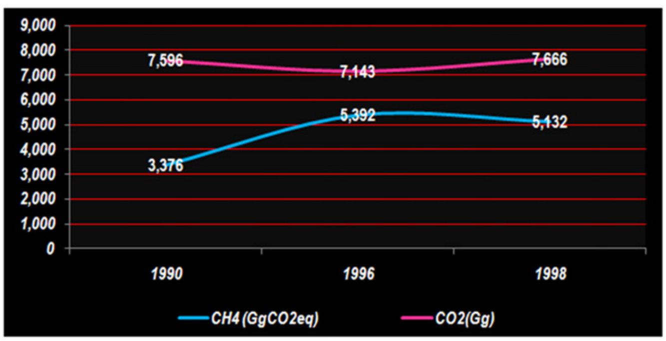

Fig. 3. Historical overview of total emissions in the Rio de Janeiro Inventory (Gg CO_2eq). *Source*: Based on Inventory (2003).

The growth of CH_4 emissions coincides with the implementation of control systems in the largest city landfill in 1996. The relationship between the growth of land occupation and the increase in garbage and sewage treatment needs is quite significant.

The principal methodological question faced in this work was the definition of responsibilities for greenhouse gas emissions in the city. The first criterion was the use of the political and administrative boundaries, in other words emissions produced inside the geographic borders of the city. This option in itself is insufficient, since it does not take into account important sources of emissions induced by Rio de Janeiro or the compensation in other municipalities. For example, a large part of the urban solid residues of the city have been deposited for years in Gramacho Landfill, in the neighboring municipality of Duque de Caxias, where the emanations of methane corresponding to the anaerobic fermentation of these residues physically occur. It would not be correct to exclude these emissions from the inventory.

On the other hand carbon dioxide emissions from alcohol powered vehicles within Rio de Janeiro city are compensated by the cultivation of sugarcane in a renewable form in other Brazilian municipalities where sugarcane is grown for alcohol production. Similarly, it would not be appropriate to impute to Rio de Janeiro city emissions that are being compensated within Brazil, because after all the choice of using a renewable fuel vehicle was made by a consumer in Rio de Janeiro. In the case of the transport of inter-municipal passengers, it is the socio-economic activities carried out in Rio de Janeiro that cause much of the movement of people from municipalities neighboring the metropolitan region. Therefore, instead of taking into account the location of vehicle license plates, it is more appropriate to consider for the effects of the inventory of municipal emissions the consumption of fuel sold inside Rio de Janeiro city.

As a result, in addition to the geographic location of the emissions, the criterion of responsibility for emissions caused by the city was used in this inventory, whether or not they occurred within the city. Thus, it is called The Inventory of Greenhouse Gas Emissions **of** Rio De Janeiro City, (and not **in** Rio de Janeiro) to indicate that it took into account the existence of emissions induced or compensated in other cities, as illustrated above.

The Greenhouse Gas Emissions Inventory of São Paulo was carried out in a different way compared to that of Rio de Janeiro. A contract was signed by Centro Clima (COPPE/UFRJ) and the São Paulo Municipal Environmental Secretary on 18 May 2004, and the final document was issued in March 2005. The Agreement created a new municipal structure responsible and suited for climate changes issues. It trained municipal specialists for preparing GHG inventory and GHG scenarios and for drafting municipal legislation for GHG reduction policies. Like the Rio de Janeiro inventory, in São Paulo the carbon dioxide (CO_2) and methane (CH_4) emissions caused by socio-economic activities within the municipality were taken into account. The period of analysis chosen was 2003, and energy, land use, agriculture, and waste and sewage treatment all were analyzed. The technical staff at Centro Clima also developed a specific methodology tailored to the particular features of São Paulo city. The starting point for drawing up this inventory was the methodology presented in 1996 by the Intergovernmental Panel on Climate Change (IPCC). Table 2 shows the São Paulo inventory structure for the energy sector.

The methodology used in the São Paulo inventory was top-down for the energy sector. This methodology was chosen due to the type of information available, since its use allows CO_2 emissions to be counted solely as a function of data on the quantity of energy supplied to the city. The methodology assumes that in a specific year, once introduced in the municipal economy, the carbon contained in fuel will either be released into the atmosphere or removed in some form (such as through the increase in fuel stocks, incorporation in non-energy products, or its partially non-oxidized retention). The great advantage of top-down methodology, therefore, is that it does not need a detailed information on whether the fuel is used by the final user or on through which intermediate transformations it passes before being consumed.

The methodology involves obtaining a balance of primary and secondary fuel consumption. Primary energy is understood as those sources provided directly by nature. As examples of primary fossil sources of energy we can cite oil, natural gas and coal, and as primary renewable sources of energy, firewood, sugarcane products and hydroelectric energy. Most primary energy is transformed in oil refineries, natural gas plants, hydroelectric stations, coke plants, etc., where it is converted into secondary energy sources. Another part of primary energy is consumed directly in various economic sectors, as is the case of firewood for residential use, and coal in furnaces and boilers, amongst others. Secondary energy normally goes directly to final consumption in the different sectors of the economy; however, it is also partially used in other transformation centers, where it is converted into other forms of secondary energy, such as the transformation of the oil into electricity and of naphtha into piped gas.

In the inventory of São Paulo it was considered that there was no domestic production of primary energy; the importation of primary and secondary energy was equivalent to the sale of fossil fuels and to the natural gas and electricity entering into the municipality. No primary and secondary energy is exported.

Table 2
Structure of the emissions inventory of São Paulo city—energy sector.
Source: São Paulo Inventory.

Emissions from direct fossil fuel use	Emissions from the use of electric energy (indirect fossil fuel use)			Emissions from public administration	Total emissions of the City of São Paulo
	Imports from Southeast and South via the interconnected system/ Center-West	Net energy produced in the Munic. of São Paulo	Self-producers		
A	**B**	**C**	**D**	**E**	**A+B**

Notes: C and D are contained in E and is contained in + B.

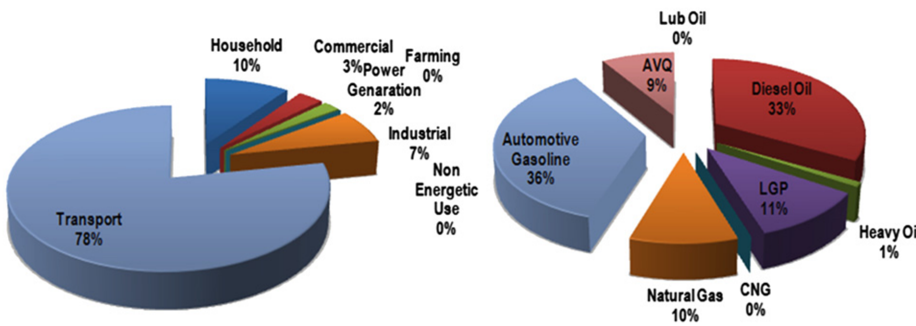

Fig. 4. Share of emissions by sub-sector and by fuel type. *Source*: São Paulo Inventory.

The city has no bunker emissions and there is no annual variation in energy stocks, since besides being located far from the coast, the city does not have an international airport. The airport inside the city operates only domestic flights and receives many passengers through connections. So it would be necessary to conduct research on origins and destinations of passenger to assign part of emissions to São Paulo City with more precision. In a conservative way all fossil fuel (AVQ) for the air transportation were assigned to the GHG inventory. The percentage of emissions per energy sub-sector and per fuel is shown in Fig. 4.

Diesel oil and gasoline consumption is responsible for the majority of the GHG emissions produced by the municipal energy sector, responsible for 69% of emissions. This is followed by LGP (responsible for 11%), natural gas (accounting for 10%) and AVQ (responsible for approximately 9% of the emissions of the analyzed sectors).

The emissions associated with consumption of electric energy in São Paulo city were calculated by combining two data groups and methodological approaches: (a) emissions associated with the consumption of electricity produced inside of São Paulo and (b) emissions associated with the consumption of electricity imported through the integrated electricity system. The electric energy that generates greenhouse gas emissions in the municipality of São Paulo comes from the burning of fossil fuel in thermoelectric natural gas and diesel oil powered plants in a number of self-generating units installed in various industries, malls, hospitals, etc.

The emissions associated with the consumption of electric energy imported from the grid by the municipality, on the other hand, are calculated by exclusion using a bottom-up approach that combines energy consumption estimates with specific emission factors. The consumption of imported electric energy was calculated by taking into account the difference between the total consumption of energy by municipality in 2003 and the estimated production of energy in the municipality based on information related to fuel sales (a proxy for consumption) for electricity production.

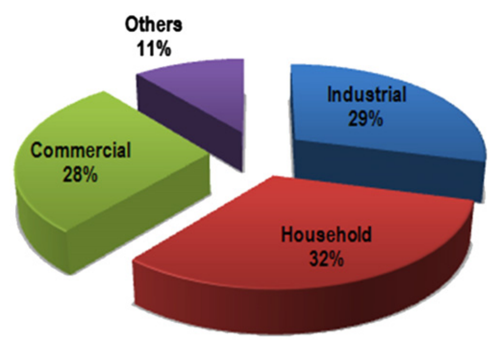

Fig. 5. GHG emissions from the use of electric energy per sector in the municipality of São Paulo, 2003. *Source*: São Paulo Inventory.

As can be observed in Fig. 5 emissions are distributed between residential, industrial and commercial sectors, responsible for, respectively, 32%, 29% and 28% of total emissions associated with the consumption of electric energy. Fig. 6 shows the share of GHG emissions resulting from the local production of electric energy in relation to the total. It can be seen that, although the production of energy in São Paulo represents only 1% of the consumption of electric energy by the city, it is responsible for 12% of emissions. This occurs because the electric energy produced inside the municipality is of fossil origin (diesel and natural gas), while most of the energy imported through the interconnected system is of hydroelectric origin.

In general terms the inventory of São Paulo showed that the energy use was responsible for the largest share of total emissions (76.15%), followed by the Final Disposal of Solid Residues (23.48%). Taken together these two sources account for 99.63% of São Paulo's total emissions. Change in Soil and Forest Use was responsible for 0.32% of the total. Domestic and Commercial Sewage and Industrial Effluent accounted for 0.047% while, finally, the Farming Sector contributed to 0.005% of total emissions. Fig. 7 shows emission sources and the respective absolute values.

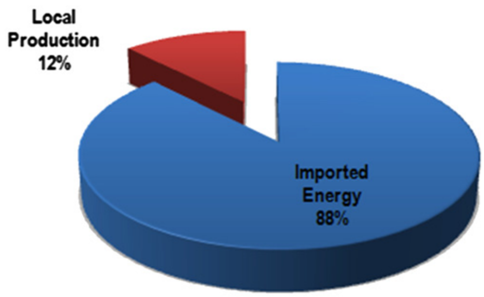

Fig. 6. Emissions associated with electrical energy consumption—local production and importation. *Source*: São Paulo Inventory.

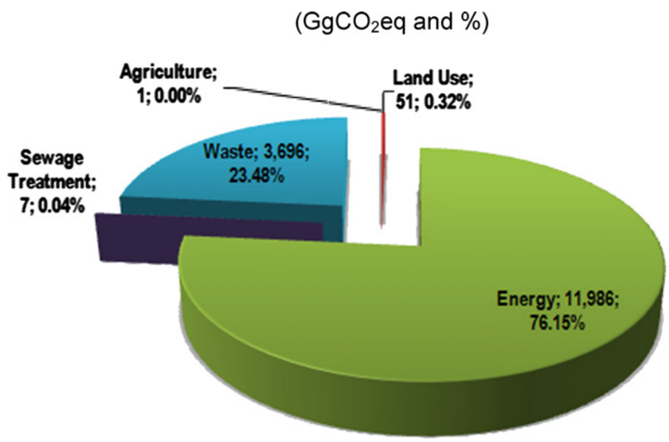

Fig. 7. São Paulo Municipality, GHG emissions by source—2003 ($GgCO_2$ eq and %). *Source*: São Paulo Inventory.

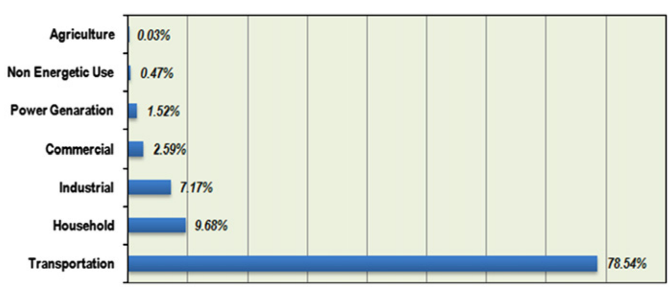

Fig. 8. Contribution of socio-economic sectors to fossil fuel emissions—2003 (%).

Analyzing fuel consumption by socio-economic sector, the overwhelming contribution of the transport sector to municipal emissions can be clearly seen. Fig. 8 shows the shares of the different sectors.

The municipal government's share of total emissions in the municipality is small. The most consumed fuel is automobile gasoline, followed by diesel. In terms of the relative share of fossil fuel consumption, gasoline consumption has 0.19% in total emissions, diesel has 0.21%, fuel oil 0.74% and LPG 0.20%. The municipal government is responsible for 0.17% of the total emission of these fuels. In relation to the consumption of electric energy by the municipal government, these correspond to 2.4% of total emissions. Fig. 9 shows the absolute values, and gives detailing on emissions from the consumption of electric energy in public buildings and in public lighting.

The GHG inventory results show that São Paulo City does not have significant differences in relation to other big cities. The tendencies are the same displays shares and diffusing similar to

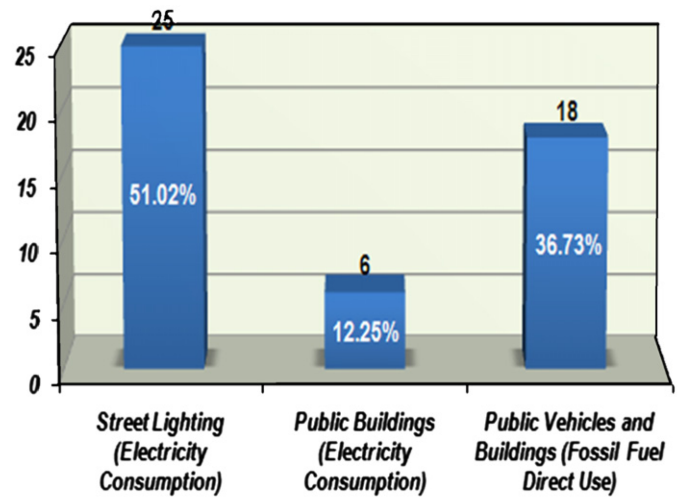

Fig. 9. Municipal emissions (local public sector), 2003 (Gg CO_2 eq). *Source*: São Paulo Inventory.

mega-cities. According to the 2006 Report of the International Energy Agency (IEA, 2006) by 2030 the worldwide demand for primary energy will rise to a little above half of the current value, corresponding to an annual growth of 1.6%. More than 70% of this increase will originate in developing countries and fossil fuels will continue as the main worldwide source of energy. In the Reference Scenario of their study fossil fuels represented 83% of the total increase in the demand for energy registered between 2004 and 2030. As a result its share in global demand will rise from 80% to 81%. The same scenario predicts that between 2004 and 2030 energy related carbon dioxide (CO_2) emissions will increase by 55%, a rate of growth of 1.7% a year. Developing countries will be responsible for more than three quarters of the global increase in these emissions; as a result these countries will replace the OCDE as the leading emitter of CO_2 after 2010 and the cities will be remarkably responsible for the emissions from this sector.

The energy sector is, thus, of extreme importance, deserving special attention in GHG emission inventories. Again according to the IEA study (IEA, 2006) in this scenario new policies and measures aimed at the minimization of fossil fuel use, essentially for transport and energy generation, would allow financial savings that could compensate the initial costs of investment demanded from consumers. In alternative policy scenarios prepared in the analysis for the period of 2005–2030, the total invested in different stages of the energy chain—from the producer to the consumer—was $560 billion less than the values indicated in the Reference Scenario. Investment in equipment and buildings was $ 2.4 billion higher. However, this value would be vastly exceeded by the $3 trillion of investments that would be saved on the supply side. During the same period the value of the fuel saved by consumers would amount $8.1 trillion; a value that would compensate the new investments that would have to be made in the area of demand. In Brazil the largest oil company is state run and could share this effort in relation to measures for the reduction of the use of fossil fuels in cities, once emission inventories are properly known. The rationing of electric power happened in Brazil in 2001 and 2002 is an important example of an event that impacted energy consumption in a singular way, as it brought about reductions in Brazilian consumption around 24% and influenced to such an extent that rationing was not necessary and these effects remained after the rationing ended (Bardelin, 2004). The substitution of lamps and utilization of more efficient appliances associated with incorporation of measures to use energy more efficiently in public establishments and industries postponed the installation of several thermoelectric plants. National emissions from national electrical sector would have increased much without these steps. This example is an illustration of how a regulatory apparatus involving reduction of GHG emissions could focus on energy use or emission limit. This could be made, for example, by an economic signal for rational use of energy inputs with high content of carbon and its replacement by renewable sources, such as greater use of public transport or introduction of renewable components into the fuel mixture.

Besides that, some problems associated with emissions of GHG may be related to the improvement of quality of life in cities in developing countries. For example, solid wastes and residential, commercial and industrial effluents, when adequately managed, can increase the production of CH_4. Although it may seem paradoxical, in the case of solid waste this occurs mainly when it is disposed off in sanitary landfills, one of the simplest and most environmentally sound forms of waste management. The more efficient this operation is, the more CH_4 is released into the atmosphere, since this gas is produced when organic matter is under anaerobic conditions and is not found at the same level in open air garbage dumps (Dubeux and Rovere, 2007). Nevertheless Brazil has some successful experiences in CDM projects based on local initiatives involving landfill gas burning. One example can be found in Nova Iguaçu in Rio de Janeiro state where funds from carbon credits are used to improve the operation of sanitary landfills (EcoSecurities, 2004). Unfortunately, these landfills do not yet generate electrical energy through the burning of gas, which would be a better alternative.

5. Conclusion

City emission inventories can be important tools for the identification of opportunities to implement public and business emission reduction policies. The possibility of adopting mitigation and adaptation projects can lead to the creation of new perspectives. The Rio de Janeiro and São Paulo inventories show how clear must be the main focus of action in these municipalities. Intervention in the transport sub-sector of the energy sector seems to be clearly necessary in the two cities, indicating that public transport has to be encouraged, while vehicle flows need to be rationalized through ring roads and by reduction of traffic congestion in the two cities. The waste treatment is also important, showing that urban growth is facing an aggravation of the residue disposal problem. In this case, it is important to go beyond conventional paradigms by improving the implementation of forms of energy cogeneration based on the residues created.

The data received on inventory along with other statistical information, such as demographic and economic growth associated with urban occupation and urban expansion, allows desired scenarios to be prepared and one then identifies the need for greater or lesser intervention by public authorities through public policies. This will certainly be the most important contribution of this instrument, since it allows interventions with a local character which can both benefit the city and also fight global warming. The inventory of the city is also useful for establishing benchmarks for emission conditions in the city in addition to the proposed intervention.

Moreover, since the Flexibilization Mechanisms of the Kyoto Protocol are being constantly improved, the results of these inventories together with the study of opportunities for emission reduction projects can create contributions to CDM in relation to new baseline methodologies or monitoring that is more efficient for small-scale projects. Despite the proximity of the first period of commitment, experiences and learning related to barriers to the implementation of CDM activities be very valuable for post-Kyoto developments. Analysis of barriers, as well as the appropriate technologies, sector scope options, and the complexity of the institutional arrangements are steps that can be taken after the inventory estimations for achieving successful emission reduction projects.

The methodological question is also important because the more refined and appropriate it is, comparison between emissions from different cities improves and cooperation between them for the mitigation and adaptation to climate changes can be increased (Table 3).

Measures aimed at the reduction of fossil fuel consumption in order to lower local atmospheric pollution levels can subsequently reduce GHG emissions or vice versa. In addition, air pollution inventory may also link local authorities and research institutions efforts in promoting a better environment. Brazil

Table 3
GHG emission reduction measures and local benefits.
Source: Based on the scenario studies developed for Rio de Janeiro.

Sector	GHG emission reduction measures	Main local benefits
Energy	Replacement of diesel or gasoline vehicles owned or hired by the local government with alcohol, CNG or electrically powered vehicles	Reduction of local atmospheric pollutants
Transports	Rationalization of routes and modernization of bus fleet (Rio Bus Project)	Reduction of local atmospheric pollutants and the transport costs incurred by the population
	Capacity building in transport companies to improve management measures and to increase efficiency in the use of diesel in heavy duty fleet. (Economizar Project)	Reduction of local atmospheric pollutants
Electricity	Energy efficiency in public lighting (Rioluz/Procel Project)	Improvement of public lighting with reduction of public expenditure on electricity
Gas	Replacement of liquefied petroleum gas with natural gas in the domestic and commercial markets	Reduction of local atmospheric pollution
Solid wastes	Recovery of up to 42% of methane production in sanitary landfills by flaring for electricity production or vehicle fuel	Future possibility for replacing more polluting vehicle fuels or for generating less polluting electricity, decreasing public expenditure on energy
Land use and forest	Carbon sequestration through reforestation of small cleared areas	Improvement of urban landscape, better support of hills and less silting of rivers and lakes
Domestic and comm. sewage	Flaring or use methane generated in sewage treatment stations to generate electric energy or produce vehicle fuel	Reduction of local atmospheric pollution and fossil fuel usage
Industrial effluents	Reuse of biogas by industry to substitute natural gas	Reduction of local atmospheric pollution and fossil fuel usage

already has good examples of studies involving cooperation between the Alberto Luiz de Coimbra Engineering Graduate School and Research Center (COPPE-UFRJ) and of the cities of São Paulo and Rio de Janeiro. In the case of Brazil and other developing countries, local inventories may have an extra advantage of great interest. Through an inventory study cities can identify economic sectors that have the potential to reduce emissions and thereby attract investments to develop Clean Development Mechanisms projects. This can benefit both individual municipalities and the country as a whole by increasing local investments and helping the country reach a better position on a global scale.

A well structured and properly prepared GHG inventory is useful for various purposes ranging from management of risks related to GHG emissions to the identification of opportunities for emission reduction, and also for the encouragement of voluntary programs for the reduction or removal of GHG, the improvement of regulations, participation in GHG markets and the recognition of innovation and the anticipation of measures. Furthermore, costs are reduced in other services, such as health and the preservation of urban assets. The presentation of a municipal emissions inventory is thus a very important institutional landmark, which as well as helping the municipality develop an efficient and effective local air quality management plan, can also contribute to the country's compliance with its commitments as a Party to the United Nations Framework Convention on Climate Change (UNFCCC).

References

Baede, A.P.M., Ahlonsou, E., Ding, Y., Schimel, D., 2001. The climate system: an overview. In: Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., Linden, P.J.v.d., Dai, X., Maskell, K., Johnson, C.A. (Eds.), Climate Change 2001: the Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York p. 881.

Bardelin, C.E.A., 2004. Os efeitos do racionamento de energia elétrica ocorrido no Brasil em 2001 e 2002 com ênfase no consumo de energia elétrica, Escola Politécnica. Universidade de São Paulo, São Paulo p. 113.

BEN, 2008. Balanço Energético Nacional—Ano base 2007. Ministério de Minas e Energia/Empresa de Pesquisa Energética, Brasília.

Carnevale, C., Gabusi, V., Volta, M., 2006. POEM-PM: an emission model for secondary pollution control scenarios. Environmental Modelling & Software 21, 320.

Clinton Foundation, 2008a. In: C40 Cities. William J. Clinton Foundation, New York.

Clinton Foundation, 2008b. In: Clinton Climate Initiative (CCI). William J. Clinton Foundation, New York.

COPPE, 2000. Inventário de Emissões de Gases de Efeito Estufa da Cidade do Rio de Janeiro. Centro de Estudos Integrados sobre Meio Ambiente e Mudanças Climáticas/Fundo de Conservação Ambiental, Rio de Janeiro, p. 104.

Dubeux, C.B.S., Rovere, E.L.L., 2007. Local perspectives in the control of greenhouse gas emissions—the case of Rio de Janeiro. Cities 24, 353–364.

EcoSecurities, 2004. Projeto de Aproveitamento do Biogás de Aterro Sanitário—NovaGerar Documento de Concepção do Projeto. EcoSecurities Ltd. & S.A. Paulista, Rio de Janeiro, p. 52.

Garg, A., Kapshe, M., Shukla, P.R., Ghosh, D., 2002. Large point source (LPS) emissions from India: regional and sectoral analysis. Atmospheric Environment 36, 213–224.

IEA, 2006. In: World Energy Outlook. International Energy Agency.

IPCC, 1996. In: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. IPCC/OECD/IEA, London.

IPCC, 2006. In: IPCC Guidelines for National Greenhouse Gas Inventories. National Greenhouse Gas Inventories Programme/IGES, Japan.

IPCC, 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Intergovernmental Panel on Climate Change, Geneva, Switzerland, p. 104.

Jain, S., Khare, M., 2008. Urban air quality in mega cities: a case study of Delhi City using vulnerability analysis. Environmental Monitoring Assessment 136, 257–265.

Kimmel, V., Kaasik, M., 2003. Assessment of urban air quality in south Estonia by simple measures. Environmental Modeling and Assessment 8, 47–53.

Kojima, M., Lovei, M., 2001. Urban Air Quality Management—Coordinating Transport, Environment, and Energy Policies in Developing Countries. The World Bank, Washington.

Kousky, C., Schneider, S.H., 2003. Global climate policy: will cities lead the way? Climate Policy 3, 359–372.

Lin, J., Rosenquist, G., 2008. Stay cool with less work: China's new energy-efficiency standards for air conditioners. Energy Policy 36, 1090–1095.

MCT, 2004. Comunicação Nacional Inicial do Brasil à Convenão-Quadro das Nações Unidas sobre Mudança no Clima. Ministério de Ciência e Tecnologia, Brasília, p. 276.

Peng, C., Wu, X., Liu, G., Johnson, T., Shah, J., Guttikunda, S., 2002. Urban air quality and health in China. Urban Studies 39, 2283–2299.

Ramanathan, R., 1999. Selection of appropriate greenhouse gas mitigation options. Global Environmental Change—Human and Policy Dimensions 9, 203–210.

Rovere, E.L.L., d'Avignon, A., Azevedo-Carloni, F.B., Azevedo, M.A., 2008. Identificaç ão de barreiras e fornecer subsídios e recomendações referentes à consolidação de um marco regulatório, no âmbito de uma política nacional de mudança do clima. Fundação COPPETEC/UFRJ e CentroClima/COPPE/UFRJ, Brasília, p. 63.

Venegas, L.E., Mazzeo, N.A., 2006. Modelling of urban background pollution in Buenos Aires City (Argentina). Modelling & Software 21, 577–586.

Wang, X., Mauzerall, D.L., Hu, Y., Russell, A.G., Larson, E.D., Woo, J.-H., Streets, D.G., Guenther, A., 2005. A high-resolution emission inventory for eastern China in 2000 and three scenarios for 2020. Atmospheric Environment 39, 5917.

Wilbanks, T.J., Kates, R.W., 1999. Global change in local places: how scale matters. Climatic Change 43, 601–628.

Yedla, S., Shrestha, R.M., Anandarajah, G., 2005. Environmentally sustainable urban transportation—comparative analysis of local emission mitigation strategies vis-a-vis GHG mitigation strategies. Transport Policy 12, 245–254.