Comparing urban greenhouse gas emission inventories in Brazilian cities

Gilsâmara Catarina Alves Conceição* and
Marcia Mara de Oliveira Marinho

Environmental Engineering Department,
Federal University of Bahia – UFBA,
Salvador, Bahia, Brazil
Email: gil.smra@gmail.com
Email: marma@ufba.br
*Corresponding author

José Célio Silveira Andrade

School of Management,
Federal University of Bahia – UFBA,
NPGA Salvador, Bahia, Brazil
Email: jcelio.andrade@gmail.com

Abstract: The urban greenhouse gas emission (GHG) inventory is an important tool for climate change mitigation. In Brazil, 15 years after the publication of the first municipal GHG inventory, few cities have measured their emissions. It depicts the timid advance in the country's urban climate agenda. In this paper, publicly available inventories were mapped, and then methodologies, emissions and reports were compared, with the aim to identify similarities, divergences and challenges to consolidate this instrument. The results show that the municipal inventories in Brazil are not easily comparable. In many cases, it lacks transparency there are different interpretations of the methodology and gaps of information. The definition of quality criteria and the dialogue among cities may help to refine the tool. Comparative perspective allows the exchange of knowledge between localities with similar profiles, such as Latin American cities. Sustaining discussion on municipal inventories is important for its improvement as a tool to support local interventions.

Keywords: greenhouse gas emissions; GHG; urban GHG inventories; Brazilian cities.

Reference to this paper should be made as follows: Conceição, G.C.A., Marinho, M.M.d.O. and Andrade, J.C.S. (2021) 'Comparing urban greenhouse gas emission inventories in Brazilian cities', *Latin American J. Management for Sustainable Development*, Vol. 5, No. 2, pp.110–129.

Biographical notes: Gilsâmara Catarina Alves Conceição holds a Master in Environmental Engineering and a Bachelor in Chemical Engineering from the Federal University of Bahia. Her research interests include carbon emissions, energy and sustainable urban development.

Marcia Mara de Oliveira Marinho is an Associate Professor at the Federal University of Bahia. She holds a PhD in Environmental Sciences from the University of East Anglia (UK) and a Master in Environmental Resources from the University of Salford (UK). She has experience in environmental engineering, with emphasis in public and private sector's environmental management.

José Célio Silveira Andrade holds a PhD in Public Administration, Professor at the Federal University of Bahia (UFBA), Brazil and Coordinator of the Global Environmental Governance and Carbon Market Group at the UFBA. His area of expertise revolves around low carbon governance, especially with regard to integrative modes of analysis. An example is a recent and ongoing investigation of contributions to sustainable development associated with carbon market projects – including case studies in Brazil within six sectors: energy efficiency, reforestation, waste, fossil fuel replacement, swine and renewable energy – solar, bioenergy, wind, etc.). This investigation intends to provide specific recommendations to address more co-benefits and regional impacts into carbon market projects, including clean development mechanism (CDM), nationally appropriate mitigation action (NAMA) and reducing emissions from, deforestation and forest degradation (REDD+). His fields of research are global environmental governance, low carbon economy, world carbon market, CDM project, renewable energy and sustainable development.

1 Introduction

The challenge of containing, mitigating and adapting to climate change has been one of the greatest issues faced by humanity. Limiting global warming to 1,5°Celsius above pre-industrial levels demands the commitment of actors before less requested such as the municipalities, as well as conscious and engaged citizens. In developing countries, in general, cities are not yet considered the biggest emitters of greenhouse gases, but they are exposed to the severe consequences of climate change. The contribution of urban emissions in these countries varies from 26% to 33% of total emissions, while in those considered developed countries the percentage achieves 47% to 65%, according to a study published by Albrecht et al. (2013). In Latin America and Caribbean, second world's most urbanised region, sea-level rise, the severity of weather extremes, and variations in temperature and precipitation threatens food security, energy and water supply, impacting mainly those who live in poverty.

Joining city coalitions and preparing a local GHG inventory are usually the first steps taken by a city as a sign of its interest in contributing to mitigate climate change. Brazil occupies a relevant position between countries of Latin America, for it is one of the greatest economies and also one of the largest emitters of this region. In recent years, Brazilian scientists have developed an independent system for regular estimation of national and regional GHG (Azevedo et al., 2018), but the country still lacks information on urban emissions.

This article intends to contribute to the discussion on the impact of cities on climate change, through a comparative analysis of Brazilian municipal greenhouse gas inventories. Similarities, differences and challenges to account urban emissions are identified, taking into account the possibility of cooperation, among not only Brazilian cities themselves but also other cities in Latin America, due to the resemblance of their structures and problems.

2 Evidence and challenges of urban inventories

According to IPCC Guidelines (2006), the inventory is synthesised as a report that includes tables with information on all relevant GHG gases emitted, the categories and the registry of the methodology and data used to estimate the emissions. A well-structured inventory may be useful to diverse purposes such as risk management, identification of opportunities of mitigation, to track mitigation strategies, improve regulation, participation in carbon market (D'Avignon et al., 2009). It is a tool that expands knowledge on cities, mapping the level of activity of the main sectors through GHG emission rate.

Many articles indicate the lack of comparative studies and the difficulty to compare urban emissions (Sovacool and Kahn, 2016; Kennedy et al., 2012; Croci et al., 2011; Hoornweg et al., 2011; Dodman, 2009). Before GPC – the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) publication – diverse methodologies emerged as isolated initiatives to account emissions from cities and to adapt IPCC Guidelines to the context of local inventories. Despite being based on IPCC method, most of them were not considered comparable, disagreeing in aspects like: sectors and gases accounted, inventory limit, methodologies of calculation and report, emission factors (Bader and Bleichwitz, 2009). According to Croci et al. (2011), the availability of data is one of the critical aspects of accounting for municipal emissions. The same authors stated that emissions from products and services are rarely estimated, due to methodological complexity and lack of data. To Kennedy et al. (2012) the uncertainties are inevitable because they involve subjective issues related to which constructions or facilities to include, which industrial or agricultural processes to take into account, or even the limits of the inventory. They also suggest that inventories should always report the activity data and emission factors in order to allow sufficient critical understanding to plan actions and contribute to verification and reliability. In terms of quality, IPCC establishes five principles of inventories: transparency, completeness, consistency, comparability, accuracy (IPCC, 2006). These are also followed by GPC method.

In Brazilian cities, the number of published articles is even smaller and include mainly the cities of Rio de Janeiro and São Paulo, pioneers in the elaboration of urban inventories in the country. However, in recent years, new municipal inventories have emerged, propelled by the launch of the GPC, a methodology created with the purpose of becoming standard for local inventories. Nowadays, GPC and IPCC are the main methods applied in Brazil. Table1 below compares both methodologies with regard to emission sources.

Table 1 Comparison of emission sources categories

IPCC classification	*GPC classification (Scope 1)*
Energy	*Stationary energy*
Residential	Residential buildings
Commercial/institutional	Commercial and institutional buildings/facilities
Manufacturing industries and construction	Manufacturing industries and construction
Energy industries	Energy industries
Agriculture/forestry/fishing/fish farms	Agriculture, forestry, and fishing activities
Non-specified	Non-specified sources
Solid fuels (fugitive emissions)	Fugitive emissions from mining, processing, storage, and transportation of coal
Oil and natural gas (fugitive emissions)	Fugitive emissions from oil and natural gas systems
Road transportation	*Transportation*
Railways	On-road transportation
Water-borne navigation	Railways
Civil aviation	Water transport
Other transportation	Aviation
	Off-road transportation
Waste	*Waste*
Solid waste disposal	Solid waste disposal
Biological treatment of solid waste	Biological treatment of solid waste
IPPU	*IPPU*
Mineral industry	Industrial processes
Chemical industry	
Metal industry	
Electronics industry	
Non-energy products from fuels and solvent use	Product use
Product uses as substitutes for ozone-depleting	
Substances	
Other product manufacture and use	
Other	
AFOLU	*AFOLU*
Land	Land
Livestock	Livestock
Aggregate sources and non-CO_2 emissions sources on land	Aggregate sources and non-CO_2 emissions sources on land
Other	

Source: Adapted from GPC (p.156)

Some Brazilian cities have also defined GHG reduction targets, which can stimulate the emergence of new inventories in order to track the emissions. But those commitments are not necessarily fulfilled, as observed by Sovacool and Kahn (2016). This is the case of Brazilian Nationally Determined Contributions (NDCs), signed in the Paris Agreement. According to Rochedo et al. (2018) NDCs are at risk in Brazil, given the regression in environmental policies during recent years, leading to an increase in deforestation, the same sector that allowed the country to reduce by 54% its emissions between 2005 and 2012. This scenario claims for the increase in cities participation on mitigatory measures to face climate change. The urban inventory is an important tool to help define and monitor these measures.

3 Methodology

The first stage of this study consisted of mapping the Brazilian urban GHG inventories publicly available on the internet, and the identification of methodologies applied. The official reports from Brazilian cities were found on websites of public administration or research centres. The second stage corresponded to both individual and comparative analysis of the inventories. Firstly, they were separated by type of methodology used (basically IPCC or GPC) and then all inventories were compared together.

Although IPCC and GPC methodologies are considered compatible with one another (GPC, 2014), adaptations on the inventories were required, due to the diversity in the application of the methods. The steps for comparison were as follows:

1. Disaggregate, as much as possible, the emissions from each inventory.
2. Check on compliance towards the application of the chosen standard methodology (GPC or IPCC).
3. Check compatibility between scopes, sectors and sub-sectors of different inventories.
4. Lastly, to rearrange emissions, so they could match both with the other inventories and the standard methodology.

This process was intended to ease comparison.

In a third stage of the research, the information provided by inventories and the observation of the difficulties of comparison led to the identification of some criteria that could be used as a reference for the report of Brazilian urban inventories with good quality. In other words, a minimum quality that allows the understanding of the reported values, favouring comparability, and the use of the municipal inventory as a tool for discussing public policies and actions.

4 Results and discussion

The inventories analysed in this article belong to the following municipalities, in ascending order of the first publication: Rio de Janeiro (2003, 2011, 2013), São Paulo (2005, 2013), Belo Horizonte (2009), Curitiba (2011, 2016), Sorocaba (2014), Recife (2014), Fortaleza (2014), Salvador (2016) and Londrina (2017). This group includes some of the most populous cities in Brazil. São Paulo and Curitiba have published two inventories, and Rio de Janeiro is in its third edition. Therefore, an amount of 13 GHG reports of Brazilian municipalities were found publicly available until the end of this research.

As for the methodologies applied, in general, they use the methods IPCC and GPC. The latter having been applied in most recent inventories. Despite the use of only two methodologies, the reports are not uniform, given the variety of ways in which the methods are applied, under the influence of diverse forms of interpretation and other factors such as the availability of data. Concerning the inventoried gases, most of the cities report only CO_2, CH_4, N_2O emissions.

4.1 GPC methodology – Global Protocol for Community-Scale Greenhouse Gas Emission Inventories

The final version of the Global Protocol was published in 2014 with the aim of becoming the standard methodology to account urban GHG emissions. Calculation methods are compatible with those developed by IPCC, with some adjustments to the local context. It also offers flexible alternatives to different types of data sources. In the case of Brazilian cities, this is particularly interesting since most municipalities lack a uniform database. The GPC provides the accounting of GHG emissions that occur inside the city boundary as well as those emissions that occur outside the city limits. It makes easier to aggregate inventories, avoiding double counting. This division happens through the definition of the following scopes:

Scope 1 Direct emissions that occur inside the city boundary.

Scope 2 Indirect emissions from grid-supplied energy consumption.

Scope 3 Indirect emissions that occur outside the city boundary.

Besides the report of the scopes, GPC states that emissions shall also be classified into the following main sectors: stationary energy; transportation; waste; agriculture, forestry and other land use (AFOLU); industrial processes and product Use (IPPU).

The municipalities applying GPC methodology are Recife, Fortaleza, Salvador, Londrina, the third inventory of Rio de Janeiro and the second inventory of Curitiba. Table 2 presents the emissions by scope. For comparative purposes, the data below corresponds to the last year accounted by each inventory. It was necessary to adjust the inventory of Recife, whose emissions were originally segmented into government emissions and community emissions. They were put together to obtain the total amount of the municipality.

The inventories in Table 2 account emissions from the years 2012 or 2013. This proximity makes the comparison more consistent. Rio de Janeiro presents by far the highest value of emissions, surpassing the summation of all the other cities in the table. It is also the only inventory to include emissions from the sector IPPU. Except for Londrina and Rio de Janeiro, the other cities can be considered to have a similar profile of emissions. Although declaring the use of the GPC methodology, Londrina's inventory does not exhibit emissions by scope, only by sectors, as can be seen in Table 2. Salvador alone accounts for biogenic emissions separately, that is, those corresponding to the combustion of biomass materials. These emissions are considered to be offset by sequestration occurring during biomass cultivation. In GPC methodology, they are estimated but not added to the total of emissions, while according to IPCC they should not even be estimated, since they are supposed to be included in the emissions and removals of the sector AFOLU. The CO_2 removal displayed by Rio de Janeiro is attributed to reforestation and urban afforestation. According to Rio's inventory, 100% of the emissions due to municipal deforestation (land use) in 2012 was neutralised. Unlike the original inventory, removals from Table 2 were not included in total emissions.

Table 2 Emissions of Brazilian municipal GPC inventories

	Londrina	*Recife*	*Salvador*	*Fortaleza*	*Curitiba (2nd)*	*Rio de Janeiro (3rd)*
Year accounted	2013	2013	2012	2013	2012	2012
Total emissions (tCO_2e)	1.105.964	3.120.426	3.698.964	3.827.521	4.125.853	22.648.800
Emissions/capita (tCO_2e/hab.)	2.26	1.56	1.27	1.49	2.29	3.58
Scope 1	-	1.693.231	3.242.166	2.162.866	2.686.651	19.356.470
Scope 2	-	200.567	366.395	213.992	349.791	1.413.430
Scope 3	-	1.226.628	90.403	1.450.663	1.089.411	1.878.900
Stationary energy	164.496	477.060	670.129	529.513	515.007	11.188.640
Transportation	660.887	2.041.976	2.729.700	2.338.261	2.976.179	6.753.770
International transportation (bunker)	-	-	-	-	-	1.632.100*
Waste	280.581	601.390	299.135	959.746	632.514	2.330.830
IPPU	-	-	-	-	-	2.355.330
AFOLU	-	-	-	-	2.153	20.230
Removals	-	-	-	-	-	–11.660*
Biogenic emissions	-	-	1.454.344*	-	-	-

Note: *Data not included in the total of emissions.

Source: The authors, using data from Brazilian GHG inventories and IBGE – Instituto Brasileiro de Geografia e Estatística

Concerning the scopes, which are the most notable feature of the GPC methodology, except for Rio de Janeiro, Salvador is the city with more emissions allocated in scope 1 (emissions generated within the city boundary) and in scope 2 (emissions from grid-supplied energy). It also presents the lowest value of emissions allocated in scope 3 (emissions occurring outside its border). This means that most of the emissions estimated by Salvador are considered to occur within the city boundary, as its unique and direct responsibility. Recife, Fortaleza and Curitiba have more sectors assigned to scope 3; thus, more emissions considered indirect. This results of the diverse interpretations regarding the definitions of the scopes. The differences can be seen in Table 3.

In Table 3, it is possible to see that Salvador imputes all transportation emissions to scope 1. This justifies the higher value that scope 1 of Salvador has when compared to Recife and Fortaleza. These two cities include only on-road transportation in scope 1 and all others in scope 3. In Recife, waterborne transportation is allocated in scope 3 and the inventory alleges that the port is operated by the regional government, thus this emission would not be a local responsibility. In Curitiba, about 20% of transportation emissions are placed in scope 3, but it is not possible to identify which transport modes belong to each scope. The same applies to waste sector emissions. The inventory of Fortaleza is the only one that includes off-road transportation, however, without providing detailed information on the emission sources. Rio de Janeiro allocates transportation in scope 1, except for a portion of the railway transportation that uses electricity (scope 2). In accounting for the aviation sector, Rio's inventory excludes the consumption of aviation kerosene on international flights and diesel for long-haul international shipping. These are part of the bunker emissions (a category for international transportation emissions defined by the methodology IPCC) and are displayed separately, not computed in the total. The city of the Rio de Janeiro uses both GPC and IPCC methods in the same third inventory. It is not possible to identify the framework of the scopes in Londrina's inventory.

Table 3 Scopes framework – categories of Brazilian municipal inventories

Scopes	*Recife*	*Salvador*	*Fortaleza*	*Curitiba 2nd*	*Rio de Janeiro 3rd*
1	Stationary energy On-road transportation Incineration	Stationary Energy On-road transportation Aviation Waterborne transportation Solid waste Wastewater	Stationary energy On-road transportation	Stationary energy Transportation Waste AFOLU	Stationary energy On-road transportation Aviation Waterborne transportation Solid waste Wastewater IPPU AFOLU
2	Electricity	Electricity	Electricity	Electricity	Electricity
3	Aviation Waterborne transportation Solid waste	Incineration	Aviation Waterborne transportation Off-road transportation Solid waste	Transportation Waste	Fugitive emissions Solid waste

Source: The authors, using Brazilian GHG inventories

GPC methodology suggests that only displacements occurring within the city, in other words, those starting and finishing within the limits of the city, shall be reported in scope 1. One can understand that all departure flights not occurring inside the territory should be accounted in scope 3 because these emissions across the border and may have shared responsibility between those who offer and those who demand the displacement. They should also be differentiated between domestic and international flights to facilitate integration among inventories (GPC, p.81). This approach cannot be observed in any of the inventories above. Although Recife and Fortaleza account for aviation and waterborne transport in scope 3, it is not possible to know if these emissions include only departure transport, nor differentiate between domestic or international displacements.

Therefore, cities differ as to the allocation of responsibilities for the emissions, making the direct comparison of the emission values of the scopes shown in Table 3 inconsistent.

The following general observations are made concerning the application of the GPC methodology to municipal inventories:

1 The scopes framework is an interesting methodology of reporting, showing the emissions on which the municipality has the possibility of direct action and has the potential to ease comparison among inventories. However, if the limits used by the inventories to define each scope are distinct, this division loses its function.

2 Four of the six inventories developed according to the GPC methodology do not account for emissions from AFOLU (Agriculture, Forestry and Land Use) and IPPU (Industrial Processes and Product Use), with the justification of lack of data or little relevance; also, they do not account for fugitive emissions or losses in electricity distribution. However, the absence of these emissions is in line with the GPC BASIC reporting level.

3 It can be suggested that this formalisation of a BASIC level of report, that excludes some sectors, brings convenience and a tendency towards a minimum report. The GPC protocol also states that the choice of the BASIC+ level (the complete report) should only occur if all BASIC level emissions are estimated (GPC, 2014, p.35). This can also be a factor of discouragement.

4 It can be considered that the transportation sector presents greater complexity for comparison. In order to account for those emissions, the inventories use the amount of fuel commercialised, making it difficult to identify the emissions under the responsibility of the municipality, disclosing differences in the definition of scopes 1 and 3, making it difficult to compare the values directly.

5 Scope 2 emissions can be considered more easily comparable, with a consensus about the application of the methodology. It is also the scope that presents the smallest emission value.

4.2 2006 IPCC guidelines methodology

The inventories applying the Intergovernmental Panel on Climate Change (IPCC) methodology are Belo Horizonte, Curitiba (1st inventory), Rio de Janeiro, São Paulo and Sorocaba. The main challenge pointed out is the definition of the boundary for a municipal inventory, since IPCC methodology was structured to guide national inventories. As a result, it promotes diversity in interpretation and disaggregation of emissions, which impacts comparability. Among inventories of the same city, variations in the methodology are also observed, reflecting the experimental and progressive character of the municipal inventories.

The major activity sectors defined by the IPCC guidelines to be inventoried are: energy; industrial processes and use of products (IPPU); agriculture, forestry and other land use (AFOLU); Waste. The sub-sectors inventoried by each municipality are shown in Table 4. It is possible to observe the absence of a standardised structure of the sub-sectors, even between reports of the same city, as in Rio de Janeiro e São Paulo. Although it is possible to observe that efforts have been made to improve emissions accounting and data organisation.

Table 4 Categories of GHG emissions of IPCC Brazilian municipal inventories

		Belo Horizonte	*Curitiba (1st)*	*Sorocaba*	*São Paulo (1st)*	*São Paulo (2nd)*	*Rio de Janeiro (1st)*	*Rio de Janeiro (2nd)*	*Rio de Janeiro (3rd)*
ENERGY	STATIONATY	*Combustion* *Electricity:* • Residential • Commercial • Industrial • Rural • Public administration	Residential Commercial Industrial Agriculture Public administration Energy industries	Residential Commercial Industrial Rural Public administration	Residential Commercial/services Industry Farming Public administration Energy industry Others	*Combustion of fossil fuels* *Energy generation* *Manufacturing industries and other sectors:* • Residential • Commercial • Industry • Co-generation • Kerosene • Oil iluminação	Residential/ commercial Industry Energy generation Petroleum refining Others	*Industry* *Public administration and others* *Petroleum refining* *Other sectors:* • Residential • Commercial	Residential Commercial/services Industry Public administration Farming Energy sector
	TRANSPORTATION	On-road and waterborne Aviation Fugitive emissions	Aviation On-road Railway	Gasoline Ethanol Diesel Natural gas Aviation kerosene Aviation gasoline	Gasoline Diesel Natural gas Aviation kerosene Aviation gasoline	On-road and waterborne waterborne Aviation Fugitive emissions	Individual on-road transportation Aviation Fugitive emissions	On-road Railway Waterborne Civil aviation Bunker emissions Fugitive emissions	On road Railway Waterborne Civil aviation Bunker emissions Fugitive emissions
WASTE		*Solid waste:* • Landfill *Wastewater:* • Wastewater treatment • Discharge into surface water bodies • Independent systems (septic tanks)	*Solid waste:* • Urban solid waste • Incineration *Wastewater:* • Residential and commercial • Industrial	*Solid waste* *Wastewater*	*Solid waste* *Wastewater:* • Residential and commercial • Industrial • Septic tanks	*Solid waste* • Landfill • Biological treatment • Incineration *Wastewater*	*Solid waste* • Urban solid waste • Health care waste • Industrial waste *Wastewater:* • Residential and commercial • Industrial	*Solid waste* • Urban solid waste • Industrial waste *Wastewater:* • Residential and commercial treatment • Industrial	*Solid waste* • Urban solid waste • Health care waste • Incineration *Wastewater:* • Residential and commercial • Industrial
AFOLU		Land use	Land use and forest Livestock Agriculture	Land use and forest Livestock Agriculture	Land use and forest Agriculture + livestock	Land use and forest Livestock Agriculture	Land use and forest Agriculture + livestock	Land use and forest Livestock Agriculture	Land use and forest Livestock Agriculture
IPPU						Industrial processes Solvent use and non-energy products	Industrial processes Product use	Industrial processes Product use	Industrial processes Product use

Source: The authors, using Brazilian GHG inventories

Table 4 may be better analysed by sector/sub-sector:

a *Energy sector – stationary energy*: It should include all emissions from stationary combustion of fossil fuels, including those used for electricity generation. It should be estimated for each sub-sector: residential, institutional, commercial, manufacturing/construction industries, energy industries, agriculture. That is what happens, for instance, in Curitiba, Sorocaba, and in the first inventory of São Paulo. However, in Belo Horizonte it was not possible to dissociate the emissions by sub-sector, thus it is not possible to compare these emissions with the other cities. Something similar happens in the second inventory of São Paulo, with the emissions of co-generation, kerosene and oil which could not be disaggregated. Not all inventories account for emissions from combustion of fossils for power generation/energy industry, which can cause considerable differences in the emission values.

b *Energy sector – transport*: Emissions from the transport sector were estimated based on the volume of commercialised fuel and there are some difficulties in obtaining emissions by modal of transportation. For example, in Sorocaba and in the first inventory of São Paulo, the emissions are presented by type of fuel and not by modal as the methodology suggests. On-road and waterborne transportation emissions were accounted for together in Belo Horizonte and in the second inventory of São Paulo. Only Rio de Janeiro (2nd and 3rd inventories) accounts for international emissions explicitly and separately, as indicated in IPCC guidelines. The emissions from Guarulhos International Airport were not considered in the inventories of São Paulo, with the justification of this airport being located in another municipality and the impossibility to identify the parcel of its traffic originated in São Paulo.

c *Energy sector – fugitive emissions*: This sector considers, in general, the losses in the natural gas distribution network of the municipality. The inventory of Rio includes, besides that, the fugitive emissions from the Manguinhos oil refinery (which operates within the limits of the city) and the coal imports used by the steel industry.

d *Waste sector*: Subdivided into two main categories – solid waste and liquid effluent. In Sorocaba and Curitiba, only emissions from wastewater treatment plants were considered. Belo Horizonte, São Paulo and Rio de Janeiro also include emissions from sewage discharged directly into surface water bodies and effluents stored in independent systems (septic tanks) not connected to the public sewage collection network.

e *AFOLU sector*: It is subdivided into emissions of land use, agriculture and livestock. Belo Horizonte is the only municipality that does not count emissions from agriculture and livestock, due to little relevance.

f *IPPU sector*: Only the inventories of Rio de Janeiro and São Paulo (second inventory), account for industrial processes and product use emissions. According to the inventory of Curitiba, the industrial activity within the limits of the municipality is not relevant. Sorocaba and Belo Horizonte do not justify the exclusion of this sector.

4.3 Comparing Brazilian municipal GHG inventories

The comparative perspective can be seen as a resource of knowledge and improvement of GHG inventories. As the division of the emission sources into sectors is a common aspect of all inventories, in this section that framework will be used to compare emissions from municipalities that use the IPCC methodology along with those using the GPC methodology. The result of the comparative analysis of the emissions is exhibited in Table 5. This table was built to display all sectors, sub-sectors and emissions in a more comparable manner. The emission values correspond to the most recent inventoried year of each municipality.

Regarding total emissions, Rio de Janeiro and São Paulo have emission values at least three times higher than any other city analysed. The municipality of Rio de Janeiro emits 22,648,800 tCO_2e, approximately 1.5 times São Paulo emissions. This value is even more expressive if one considers that São Paulo is, approximately, 1.7 times greater in population than Rio and has also higher GDP. The sectors that contribute most to this difference are stationary combustion and IPPU. Together, these two megacities emit 37.793.690 tCO_2e, twice the emissions of all the other cities together. Curitiba occupies the third place, but it has similar values to Fortaleza, Salvador, Belo Horizonte and Recife, all included in the group of the largest Brazilian cities.

With the exception of Londrina and Rio de Janeiro, for the other inventories of Table 5, the residential sub-sector is the largest emitter of stationary energy. In Londrina, the commercial/institutional sub-sector stands out, followed by industry. In Rio de Janeiro, the energy industry accounts for 3.171.930 tCO_2e. According to the inventory, 2.084.400 tCO_2e of that amount comes from losses in energy distribution. Adding the fugitive emissions (1.436.910 tCO_2e, from the coal mined outside the city's boundary), there are 3.521.310 tCO_2e emitted as a consequence of energy loss in Rio de Janeiro. This value surpasses the total emissions of a city the size of Belo Horizonte. There was not enough data to segregate the emissions from stationary combustion for Belo Horizonte.

It is not simple to establish correlations between the values presented in Table 5. Londrina has lower residential emission than Sorocaba despite its similar population, and Rio de Janeiro has higher residential emission than São Paulo, which has a bigger population. For the waste sector also a direct relationship with the population could be expected, but this is not observed in Table 3. There might be other influences, such as the fact that some municipalities send waste outside their territory, while others receive external waste; or the technologies applied. It is possible that GPC may prove to be a better tool for the study of the determinants of urban emissions. Explaining the differences between cities requires more data and more inventories.

The waste emissions of Rio de Janeiro and São Paulo have close values to each other, despite the difference in the number of inhabitants and in the total emissions. They are followed by Fortaleza, although it does not include the emissions of wastewater. Salvador has one of the lowest waste emissions, in spite of being the third most populous city in Table 5. It is also the only city in which wastewater treatment emissions exceed solid waste emissions. Recife and Fortaleza report only solid waste emissions, including incinerated waste. Some of the inventories do not present detailed information on waste emissions. To calculate landfill emissions, some cities use the first-order decay method, others use the default method suggested by IPCC (which assumes that all potential CH_4 emissions occur when the waste is disposed), and some other reports do not declare the accounting method.

Table 5 CO_2 equivalent emissions of Brazilian municipalities

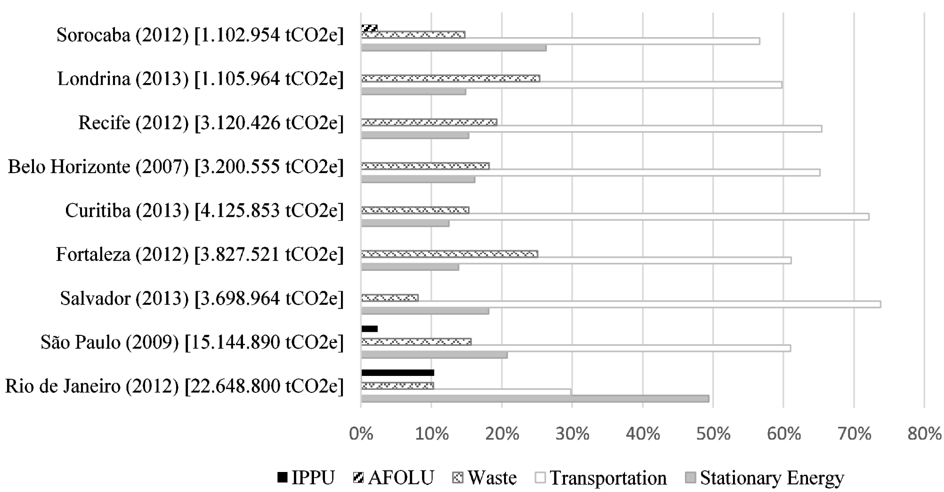
	Sector	*Rio de Janeiro 2012 [IPCC/GPC]*	*São Paulo 2009 [IPCC]*	*Curitiba 2013 [GPC]*	*Fortaleza 2012 [GPC]*	*Salvador 2013 [GPC]*	*Belo Horizonte 2007 [IPCC]*	*Recife 2012 [GPC]*	*Londrina 2013 [GPC]*	*Sorocaba 2012 [IPCC]*
Energy	*Stationary combustion:*	*9.751.730*	*3.086.766*	*515.008*	*529.513*	*670.129*	*501.742*	*477.060*	*164.496*	*290.009*
	Residential	1.889.650	1.173.301	169.469	302.382	425.583	-	202.165	41.278	127.760
	Commercial/institutional	2.189.680	328.006	166.867	157.661	203.709	-	122.956	62.685	52.097
	Industries	2.499.790	824.587	116.837	69.115	39.772	-	151.939	57.904	100.828
	Agriculture	680	-	-		354	-	-	2.497	278
	Energy Industry	3.171.930	650.211	61.691	355	711	-	-	133	-
	Others	-	110.661	143	-	-	-	-	-	9.046
	Fugitive emissions	*1.436.910*	*58.790*	-	-	-	*15.557*	-	-	-
	Transport:	*6.753.770*	*9.238.719*	*2.976.179*	*2.338.261*	*2.729.700*	*2.085.328*	*2.041.976*	*660.887*	*624.679*
	Land Transportation	5.078.560	8.521.229	2.508.192	1.854.896	2.022.851	1.777.171	1.416.042	627.843	-
	Waterborne	10.340	-	5	13.625	64.094		2.039	-	-
	Aviation	1.664.870	717.490	467.983	469.740	642.754	308.157	623.895	33.044	-
	Bunker (not included in the total)	(1.632.100)	-	-	-	-	-	-	-	-
	Total energy	*17.492.410*	*12.384.275*	*3.491.187*	*2.867.774*	*3.399.829*	*2.602.627*	*2.519.036*	*825.383*	*914.688*
Waste	Solid waste	1.706.580	2.106.458	632.350	959.746	121.505	520.262	601.390	112.233	143.710
	Wastewater	624.260	256.881	164	-	177.630	62.108	-	168.349	18.935
	Total waste	*2.330.830*	*2.363.339*	*632.514*	*959.746*	*299.135*	*582.370*	*601.390*	*280.581*	*162.645*
AFOLU	Land use	Removal	5.781	-	-	-	Removal	-	-	Removal
	Livestock	10.110	431	-	-	-	-	-	-	21.819
	Agriculture	10.120	1.946	-	-	-	-	-	-	3.802
	Total AFOLU	*20.220*	*8.158*	*2.153*	-	-	-	-	-	*25.621*
IPPU	Industrial processes	2.286.590	30.204	-	-	-	-	-	-	-
	Product use	68.740	56.914	-	-	-	-	-		-
	Substitutes for ozone depletion substances	-	272.000	-	-	-	-	-	-	-
	Total IPPU	*2.355.330*	*359.118*	-	-	-	-	-	-	-
Total emissions (tCO_2e)		*22.648.800*	*15.144.890*	*4.125.853*	*3.827.521*	*3.698.964*	*3.184.997*	*3.120.426*	*1.105.964*	*1.102.954*
Emissions per capita (tCO_2e/hab.)		3.58	1.37	2.29	1.49	1.27	1.32	1.56	2.26	1.9
Population (millions)		6.32	11	1.8	2.55	2.90	2.41	1.54	0.49	0.59
PIB (billions R$)		242	389	43	37	39	32.7	33	22	19

Source: The authors, using Brazilian GHG inventories and data from IBGE – Instituto Brasileiro de Geografia e Estatística

Table 5 confirms the transport sector as the villain of urban CO_2e emissions. It is the largest emitter for almost all cities above. Land transportation (includes on-road, railways and off-road) is the largest contributor, accounting for approximately 92% of São Paulo transport emissions. Rio de Janeiro is the only city in the table above in which the transport sector is not the largest emitter. The high emissions of the Salvador waterway sector and the high emissions from aviation in Rio de Janeiro are noteworthy. The aviation emissions of Curitiba include the volumes of gasoline and aviation kerosene used at the Bacacheri Airport (within the border) and the volume of aviation kerosene used at the Curitiba International Airport (belonging to the metropolitan region). Londrina accounts for the emissions of domestic flights at Jose Richa Airport. The inventory of Sorocaba does not segregate emissions from the transportation sector.

In the AFOLU sector, only Curitiba, Rio de Janeiro and São Paulo account for emissions of all sub-sectors. Sorocaba presents the highest value due to livestock emissions. In Belo Horizonte and Rio de Janeiro, negative emissions were obtained for the land use sector, meaning that CO_2 capture by urban vegetation exceeds GHG emissions of the same sector, generating a positive CO_2 balance (removal). Only São Paulo and Rio de Janeiro estimated the emissions of the IPPU sector, being those of Rio superior to those of São Paulo, which can be justified by the high industrial activity in the region, such as the Manguinhos oil refinery.

Figure 1 Percentage of the contribution of inventoried sectors in Brazilian municipalities



Source: The authors, using Brazilian GHG inventories.

In Figure 1, it is possible to observe the percentage of emissions by sector. Transport sector contribution ranges from 74% of the emissions in Salvador to 30% of emissions in Rio de Janeiro. Only in Rio these emissions fall below 55%. In this same municipality, the stationary energy sector (including fugitive emissions) emits 49%. For other municipalities, the second place alternates between the waste sector (Fortaleza – 25%, Londrina – 25%, Recife – 19%, Belo Horizonte – 18%, Curitiba – 15%,) and stationary energy (São Paulo – 21%, Salvador – 18%, Sorocaba – 26%). Londrina and Fortaleza are the cities with the greatest contributions from the waste sector while in Salvador, it represents only 8% of total emissions. AFOLU emits 2% of the emissions of Sorocaba, showing inexpressive percentage in the other three municipalities where this sector was accounted (Curitiba, São Paulo, Rio de Janeiro). IPPU sector emissions were estimated only in São Paulo and Rio, with contributions of 2% and 10%, respectively.

Analysing the evolution of the emissions over the years, the Rio de Janeiro's inventory compares values from 2005 (11,615 $GgCO_2e$) to 2012 (22,649 $GgCO_2e$) and shows an increase of almost 95% in 7 years. The energy sector (stationary and transportation) has been identified as the main responsible for this rise, as a response to factors such as: GDP growth, increased use of thermoelectric power plants, growth in the use of individual transport modes and gasoline consumption due to subsidies, and the crisis in ethanol production (Rio de Janeiro, 2013). It was also identified a reduction in emissions from the AFOLU sector, as a consequence of reforestation programs and reduction of deforestation. In São Paulo, a small decrease of 1.4% in emissions was observed in a 7-year period, between 2009 (15.144 $GgCO_2e$) and 2003 (15,115 $GgCO_2e$). According to the inventory, this was the result of a national increase in the use of thermoelectric power plants in 2003. The emissions of Curitiba grew 17%, from 2008 (3.52 $GgCO_2e$) to 2013 (4.13 $GgCO_2e$).

Some inventories report future emissions scenarios using diverse methods. The estimation model adopted by Rio de Janeiro and São Paulo considers three scenarios of emissions. Table 6 displays projections for the inertial type scenario, which considers there are no new mitigatory actions implemented. Some values have been approximated from supplied graphs.

Table 6 Emissions Scenarios of Brazilian municipalities

Municipality	*Future emission projection*	*Emissions from latest inventory*
São Paulo	22 mil $GgCO_2e$ by 2021	15.145 $GgCO_2e$ in 2009
	33 mil $GgCO_2e$ by 2040	
Rio de Janeiro	15.967 $GgCO_2e$ by 2020	22.649 $GgCO_2e$ in 2012
	18.261 $GgCO_2e$ by 2025	
Sorocaba	1.240 $GgCO_2e$ by 2020	1.102 $GgCO_2e$ in 2012
	1.390 $GgCO_2e$ by 2025	
Recife	4.662 $GgCO_2e$ by 2020	3.120 $GgCO_2e$ in 2012
	8.375 $GgCO_2e$ by 2030	
Fortaleza	5.500 $GgCO_2e$ em 2022	3.827 $GgCO_2e$ in 2012
	7.300 $GgCO_2e$ em 2030	

Source: The authors, using data from Brazilian GHG inventories

Comparing the projected emissions to the estimated emissions in the latest inventories, it is possible to conclude that a 47% increase in emissions is expected for São Paulo between 2009 and 2021, a 12 years period. For Rio de Janeiro, the projections were made in the second inventory, based on emissions of 2005. It was expected 15.967 $GgCO_2e$ by 2020, but the latest inventory shows that in 2012 the emissions had already exceeded this value, eight years ahead of schedule. Sorocaba's inventory predicts an increase of 28% between the years 2012 and 2020. Recife estimates a 49% increase between 2012 and 2020, and Fortaleza 44% between 2012 and 2022.

Table 7 Comparing characteristics and information reported by Brazilian municipal GHG inventories

Characteristics of emissions report	*Belo Horizonte*	*Curitiba 1st*	*Curitiba 2nd*	*Fortaleza*	*Londrina*	*Recife*	*Rio de Janeiro 1st*	*Rio de Janeiro 2nd*	*Rio de Janeiro 3rd*	*Salvador*	*São Paulo 1st*	*São Paulo 2nd*	*Sorocaba*
General description of the reporting methodology applied	X	X	X	X	X	X	X	X	X	X	X	X	X
Definition of the inventoried gases	X	X	X	X		X	X	X	X	X	X	X	X
Description of calculation methods for each inventoried sector	X	X					X		X		X	X	X
Presentation of socioeconomic and environmental data (population, population density, GDP, area)	X			X			X	X		X	X	X	X
Identification of the inventory boundary	X	X	X	X	X	X	X	X	X	X		X	X
Completeness (inclusion of all major sectors/sub-sectors suggested by the methodology)								X	X		X	X	
Identification of emission sources and activity data	X	X				X	X		X	X	X	X	X
Identification of emission factors	X						X		X		X	X	X
Identification of reporting limitations and justification of unaccounted emissions	X	X	X	X	X		X			X	X	X	X
Summary table with emissions of each sector and sub-sector for the inventoried year		X				X	X	X	X	X			
Table with emissions by scope (when applying GPC methodology)	IPCC	IPCC	X		IPCC	X	IPCC	IPCC	X	X	IPCC	IPCC	IPCC
Table with emissions by fuel type	X						X				X	X	X
Suggestions for improvements to upcoming inventories			X				X					X	
Uncertainty assessment							X	X	X			X	X
Emissions development based on inventories from previous years								X	X			X	
Future scenarios				X		X		X	X			X	X
Executive summary	X	X											X
Implementation through the bidding process	X				X		X	X	X		X	X	
Implementation through agreements between institutions and the local government			X	X		X				X			

Source: The authors, using Brazilian GHG inventories

As for the data sources to calculate Brazilian municipal emissions, the approach used is mostly top-down, using national or regional data, which indicates the absence of satisfactory municipal databases. The emission factors are mostly standardised, obtained through IPCC or the Brazilian national inventory. Therefore, the level of methodological complexity of the calculations is in general tier 1, some inventories manage to achieve a tier 2 level (tier 3 is the most detailed method). The cities of São Paulo, Sorocaba, Rio de Janeiro and Belo Horizonte estimated the uncertainty attributed to the mathematical model applied and the energy sector is the one presenting the most reliable emission values.

The quality of the inventory is linked not only to the reliability of the data but also to the type of information provided in order to become a useful tool. Table 7 compares the inventories regarding the information reported and other characteristics, highlighting divergences and gaps in the reporting of GHG emissions.

Many of these aspects shown in Table 7 are essential to provide transparent inventories, like the description of the methodology, inventoried gases, calculation methods, identification of emission sources, activity data and emission factors. Such characteristics make inventories replicable, allowing a complete understanding of the information reported. Not many inventories provide that. In Table 7 it is also possible to observe that few inventories can be considered to have achieved completeness. Most gaps are found in those reported through GPC methodology (Fortaleza, Londrina, Recife, Salvador). Features as: a summary, emissions development based on previous years and future emissions scenarios can be useful for decision-makers since they go beyond the annual inventory and deliver a bigger picture of GHG emissions.

Thereby, from variables presented in Table 7, those considered relevant to produce satisfactory Brazilian municipal GHG inventories were selected. Satisfactory means a report with minimum quality to allow the understanding of the accounted emissions, to facilitate comparison, and with the potential to be used as a tool for discussing public policies and other actions to tackle climate change. These reporting quality criteria take into account the principles defined by the IPCC for the preparation of inventories. Thus, Table 8 shows the suggested criteria for reporting good quality Brazilian municipal GHG inventories.

Table 8 Suggested reference criteria for the reporting of Brazilian municipal GHG inventories

1	Description of reporting methodology applied and inventoried gases
2	Description of calculation methods for each inventoried sector
3	Identification of the inventory boundary
4	Completeness (inclusion of all major sectors/sub-sectors suggested by the methodology)
5	Identification of emission sources and activity data
6	Identification of emission factors
7	Summary table with annual emissions by sectors/sub-sectors/scopes.
8	Uncertainty assessment
9	Emissions development based on inventories from previous years
10	Suggestions for improvements to upcoming inventories
11	Future emission scenarios

Source: The authors, using Brazilian GHG inventories, IPCC (2006) and GPC (2014) guidelines.

The inclusions of uncertainty assessment and of suggestions are both important to the upcoming inventories. They make gaps transparent, helping to define priorities for quality improvement. Although the inclusion of future scenarios may extend beyond the role of the inventory as a tool for diagnosis, it is important to understand how the maintenance of the current levels of emissions impact in the future.

5 Conclusions

Climate change has become a global crisis and evidence demands more effective actions to control the emission of greenhouse gases. It is essential that cities account and monitor their GHG emissions. The evolution of Brazilian municipal inventories is still slow. Considering the amount of 5570 municipalities, the number of local GHG inventories published is not significant. Only Rio de Janeiro, São Paulo and Curitiba have updated their inventories. The future emission scenarios show a significant, and perhaps alarming, increase in GHG emissions in a short period of time.

The divergences observed in this study shows that the Brazilian municipal emissions cannot be directly compared. It is necessary to breakdown the sectors to understand and to identify corresponding emissions between the cities and many inventories lack transparency. The production of urban inventories in Brazil requires the set out of a minimum criterion of quality so that the inventory can become a transparent and organised tool, useful to define actions and public policies. Also, the dialogue among cities can help to make inventories compatible.

The most recent inventories (Salvador, Recife, Fortaleza and the latest inventory of Rio de Janeiro) have used the GPC methodology, which indicates a tendency towards standardisation. The GPC methodology provides an interesting framework to report local emissions, but inventories still differ while using it. These different interpretations indicate the need of an agreement among Brazilian cities so that the inventories can be standardised and able to dialogue with one another, at least nationally. In general, the transparency principle has been ignored by GPC inventories. IPCC inventories are, in general, more detailed. It is necessary to find a better balance between the practicality of the GPC methodology and the transparency of IPCC inventories. While the greatest difficulty pointed out by IPCC inventories is the definition of inventory boundary, some GPC inventories point to the absence of satisfactory municipal databases as their biggest challenge. As a consequence, the urban inventories are built on Top-Down method, using national or regional information. AFOLU, IPPU are the most difficult sectors to account, due to the lack of data.

Regarding emissions, the city of Rio de Janeiro is the largest GHG emitter in Brazil, although São Paulo is one of the most populous cities in Latin America. This is mainly due to the combustion of fossil fuels for power generation and industrial processes (IPPU). Rio also shows high values of energy loss through fugitive emissions. On the other side, São Paulo shows slightly higher transport emissions. The emissions of these two cities are at least four times higher than any other city analysed in this study. And together, Rio and São Paulo exceed twice the total amount of the other seven municipalities. Belo Horizonte, Curitiba, Fortaleza, Recife and Salvador exhibit relatively close emission values.

As for the sectors, land transportation is the largest emitter in all cities, except Rio de Janeiro, contributing up to 74% per cent of total emissions in the case of Salvador. Emissions of the waste sector vary and IPPU is considered the least relevant sector, accounted only by the inventories São Paulo and Rio de Janeiro, with a large contribution to the latter. The other inventories notify the lack of either data or relevant industrial activity. The same happens for the AFOLU sector in Recife, Fortaleza and Salvador. These inventories consider the contribution of land use of little importance.

It was not yet possible to establish a relationship between emissions and covariates such as population, GDP or geographical characteristics. The information obtained from the Brazilian municipal inventories seems insufficient to understand the differences between emissions of different cities. These limitations require new researches. Also, more inventories are needed, with more transparency and improved reliability of the information.

References

Albrecht, J., Marcotullio, P., Sarzynski, A., Schulz, N. and Garcia, J. (2013) 'The geography of global urban greenhouse gas emissions: an exploratory analysis', *Climatic Change*, Vol. 121, No. 4, pp.621–634.

Azevedo, T., Junior, C.C., Junior, A.B., Cremer, M.S., Piatto, M., Tsai, D.S., Barreto, P., Martins, H., Sales, M., Galuchi, T., Rodrigues, A., Morgado, R., Ferreira, A.L., Silva, F.B., Viscondi, G.F., Santos, K.C., da Cunha, K.B., Manetti, A., Coluna, I.M.E., de Albuquerque, I.R., Junior, S.W., Leite, C. and Kishinami, R. (2018) 'SEEG initiative estimates of Brazilian greenhouse gas emissions from 1970 to 2015', *Nature*, *Sci. Data*, Vol. 5, No. 180045.

Bader, N. and Bleischwitz, R. (2009) 'Measuring urban greenhouse gas emissions: The challenge of comparability', *Sapiens*, Vol. 2, No. 3, pp.7–21.

Belo Horizonte (2009) *Inventário Municipal de Emissões de Gases de Efeito Estufa*, Relatório Final, Mundus Carbo, Prefeitura Municipal de Belo Horizonte.

Croci, E., Melandri, S. and Molteni, T. (2011) 'Determinants of cities' GHG emissions: a comparison of seven global cities', *International Journal of Climate Change Strategies and Management*, Vol. 3, No. 3, pp.275–301.

Curitiba (2011) *Inventário e Balanço de Emissões de Gases de Efeito Estufa no Município de Curitiba*, Relatório Síntese. Ecowood Assessoria Ambiental.

Curitiba (2016) *2° e 3° Inventários de Emissões de Gases de Efeito Estufa para a Cidade de Curitiba*, Prefeitura Municipal da Cidade de Curitiba.

D'avignon, A., Carloni, F.A., Rovere, E.L. and Dubeaux, C.B.S. (2009) 'Emission inventory: an urban public policy instrument and benchmark', *Energy Policy*, Vol. 38, No. 9, pp.4838–4847.

Dodman, D. (2009) 'Blaming for climate change? An analysis of urban greenhouse gas inventories', *Environment and Urbanization*, Vol. 21, No. 1, pp.185–201.

Fortaleza (2014) *Inventário de Emissões de GEE do Município de Fortaleza*, Urban Leds, Prefeitura de Fortaleza.

GPC (2014) *Global Protocol for Community-Scale Greenhouse Gas Emission Inventories*, World Resources Institute.

Hoornweg, D., Sugar, L. and Gomez, C.L.T. (2011) 'Cities and greenhouse gas emissions: moving forward', *Environment and Urbanization*, Vol. 23, No. 1, pp.207–227.

IPCC (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

Kennedy, C., Hoornweg, D., Sugar, L. and Ibrahim, N. (2012) 'Greenhouse gas emissions from cities: comparison of international inventory frameworks', *Local Environment*, Vol. 17, No. 2, pp.223–241.

Londrina (2017) *Inventário de Gases de Efeito Estufa do Município de Londrina*, Prefeitura Municipal de Londrina.

Recife (2014) *1° Inventário de Emissões de Gases de Efeito Estufa para a Cidade do Recife*, Prefeitura Municipal do Recife.

Rio de Janeiro (2003) *Inventário de Emissões de Gases de Efeito Estufa da Cidade do Rio de Janeiro*, COPPE/UFRJ, Prefeitura Municipal do Rio de Janeiro.

Rio de Janeiro (2011) *Inventário e Cenários de Emissões dos Gases de Efeito Estufa da Cidade do Rio de Janeiro*, COPPE/UFRJ, Prefeitura Municipal do Rio de Janeiro.

Rio de Janeiro (2013) *Inventário das Emissões de Gases de Efeito Estufa da Cidade do Rio de Janeiro em 2012 e Atualização do Plano de Ação Municipal para Redução das Emissões*, COPPE/UFRJ, Prefeitura Municipal do Rio de Janeiro.

Rochedo, P., Soares-Filho, B., Schaeffer, R., Szklo, V.E., Lucena, A., Koberle, A., Davis, J.L., Rajão, R. and Rathmann, R. (2018) 'The threat of political bargaining to climate mitigation in Brazil', *Nature Climate Change*, Vol. 8, pp.695–698 [online] https://www.nature.com/articles/s41558-018-0213-y#article-info.

Salvador (2016) *Inventário de Emissões de Gases de Efeito Estufa da Cidade de Salvador*, Pangea Capital, Prefeitura de Salvador.

São Paulo (2005) *Inventário de Emissões de Gases de Efeito Estufa do Município de São Paulo*, Centro Clima COPPE/UFRJ.

São Paulo (2013) *Inventário de Emissões e Remoções Antrópicas de Gases de Efeito Estufa do Município de São Paulo de 2003 a 2009, com atualização para 2010 e 2011 nos setores Energia e Resíduos*m Instituto Ekos Brasil e Geoklock Consultoria Ambiental.

Sorocaba (2014) *Inventário de Gases do Efeito Estufa do Município de Sorocaba. Relatório Final*, Prefeitura de Sorocaba, In Natura Soluções Ambientais.

Sovacool, B. and Kahn, F. (2016) 'Testing the efficacy of voluntary urban greenhouse gas emissions inventories', *Climatic Change*, Vol. 139, No. 2, pp.141–154.