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GHG INVENTORIES AND DRIVERS & BARRIERS TO CLIMATE ACTION: AN ANALYSIS OF BRAZILIAN CITIES

Porto Alegre

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Tese apresentada ao Programa de Pós-Graduação em Administração da Escola de Administração da Universidade Federal do Rio Grande do Sul como requisito parcial para obtenção de título de doutor em administração.

Área de Concentração: Inovação, Tecnologia e Sustentabilidade

Orientador: Prof. Luis Felipe Nascimento

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I have had many examples in my family of people with great dedication to their studies. My parents, my grandfather, my brothers, various uncles, aunts and cousins. Somehow, all of them influenced my academic evolution. I am extremely grateful for the positive influence they have had in my life.

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ABSTRACT

Cities are considered core of the global climate change mitigation and strategic low-carbon development and city-level study is a trend for climate change responses studies. The literature review identified three gaps that guided this research: (I) There is lack of consistent and comparable greenhouse gas (GHG) emissions data at the city level; (II) it is necessary to analyze enabling factors that lead to effective urban climate governance and (III) there is a geographical bias of empirical climate governance studies focused on cities from Global North and developed countries realities. To address these gaps, considering the reality of Global South, this thesis had the general objectives of to analyze (I) the quality and gaps of GHG inventories and (II) the main drivers and barriers to climate agenda strengthening in Brazilian cities. Four manuscripts were developed to reach this objective. The first analyzed the differences among the main existing GHG accounting methodologies for cities and identified gaps in carbon inventories of twenty-four Brazilian cities. The second paper compared GHG emissions results of forty-seven Brazilian cities, applying different GHG accounting methodologies. It highlighted characteristics, similarities, and differences of these methodologies, showing how they can impact GHG results. The third and fourth articles discussed about the climate agenda advance in the city of Recife in Brazil. The third paper is a city profile which discusses how geographical characteristics and the historical urbanization process of the city have contributed to the climate risks and vulnerabilities. It evidences factors that can decisively assist cities to strength the climate agenda, mainly in developing or less developed countries. The fourth paper is a case study which discusses the climate actions adopted in Recife and it examines the main drivers and barriers to their effective implementation, comparing to examples from literature. The main important findings are: (I) There are two main types of GHG reporting gaps: incompleteness and lack of transparency which hinder the accuracy, assessment of results and comparability between cities; (II) to analyze GHG reports and to compare results, it is essential to identify methodology, base year, emission sources included, global warming potential, and calculation methods, information which are not transparent in several reports; (III) the drivers to climate action identified include having committed leadership, being part of a multinational network of cities and multilevel governance which supports existing theory, as well as identified climate risks, much in contrast to other European cases; (IV) It is fundamental to institutionalize the climate agenda in the local government to avoid political interferences, which was considered a primary barrier. The thesis provides insights for academics and policymakers on how develop broader, completer, and more transparent GHG inventories and it evidences precautions that should be taken when analyzing a city GHG report. It also evidences factors that can decisively assist cities to strength the climate agenda, mainly in developing or less developed countries, providing insights to academics and policymakers on low carbon strategies for cities. Moreover, it suggests steps that can assist cities to adopt climate actions, particularly in developing or less developed countries.

KEYWORDS:

Climate Action; Climate Governance; Carbon accounting; GHG inventories; Brazilian Cities.

SUMMARY

1. INTRODUCTION

Cities are home to more than half of the world population and are responsible for three quarters of global energy consumption and greenhouse gas (GHG) emissions (Gouldson et al., 2016). The literature review showed that the interest of scholars by cities strategies to climate change has increased considerably during the last decade. However, recent studies highlighted that some knowledge gaps remain in this field (Mi et al., 2019; Van der Heijden, 2019) which guided this research: (I) There is a lack of consistent and comparable GHG emissions data at the city level (Mi et al, 2019); (II) There is a need of analyzing the enabling factors that lead to effective urban climate governance (Van der Heijden, 2019) and (III) there is geographical bias of empirical climate governance studies focused on cities from Global North and developed countries realities (Van der Heijden, 2019; Li et al., 2017b; Castán Broto & Bulkeley, 2012).

GHG inventory is the first step for climate actions at local level. It evidences city main emission sources and where local government must undertake mitigation efforts. There are different carbon accounting methodologies and approaches. The literature that debates the benefits and the negative impacts of using a production-based (PBA) or a consumption-based approach (CBA) is extensive (e.g. Peters, 2008; Dodman, 2009; Harris et al., 2012; Afionis et al., 2017; Lombardi et al., 2017; Sudmant et al., 2018; Andrade et al., 2018; Franzen & Mader, 2018). It shows that these approaches are complementary (Sudmant et al., 2018; Andrade et al., 2018). Both provide important perspectives to analyze city's impact to climate change. However, studies analyzing the quality of GHG reports at city level are rare ((Mi et al., 2019; Mia et al., 2019). It was found just one paper that discusses the shortcomings of cities GHG reports. Also, there are few studies which compare the results of using different GHG accounting methodologies for the same cities and the existing studies (Sudmant et al., 2018; Andrade et al., 2018) compare results from cities located in Global North.

In this context, the thesis defends that: there are two main types of GHG reporting gaps: incompleteness and lack of transparency which hinder the accuracy, assessment of results and comparability between cities GHG reporting and it can limit local climate action plans.

To reach these conclusions, two articles (first and second paper of the thesis) were written in this thesis. They carried out a content analysis of all GHG emission inventories developed by Brazilian cities until July/2021, considering the most recent reports from Brazilian cities.

The first article analyzes the differences among the main existing carbon accounting methodologies for cities and identifies the shortcomings in carbon inventories typically used. Data were collected from the GHG inventories and climate action plans from 24 Brazilian cities using content analysis. Two main types of reporting gaps were identified: incompleteness (Gap 1) and lack of transparency (Gap 2). Seventeen GHG reports presented Gap 1. The study proposes an innovative methodology to analyze the cities GHG inventories shortcomings. It also provides insights for academics and policymakers on how to choose the best methodology and develop more complete inventories and low-carbon plans.

The second paper compares GHG emissions results of forty-seven Brazilian cities, using different methodologies. The paper highlights characteristics, similarities, and differences of these methodologies, showing how they can impact GHG results. It showed, in line with previous literature, that using different carbon accounting approaches will produce different GHG results. It also evidenced that the lack of transparency of GHG reports hinders the accuracy assessment of results and comparability between cities.

These articles contributed to the literature discussing the consistency and comparability of GHG emissions data at the city level. It is proposed actions policy makers can take to overcome these gaps and improve the quality of the cities GHG inventories. It is evidenced that to analyze GHG reports and to compare results, it is essential to identify methodology, base year, emission sources included, global warming potential, and calculation methods, information which are not transparent in several reports.

The literature review also showed that to date, most of the previous studies examining empirical climate governance and the drivers and barriers to climate action have been carried out in the Global North (Van der Heijden, 2019; Mi et al., 2019; Reckien et al., 2018; Romero-Lankao et al., 2018; Castán Broto, 2017; Castán Broto & Bulkeley, 2013). Moreover, these studies tend to connect with an extensive body of authors examining the mitigation and adaptation actions being developed by cities and the reasons for their doing so (Pablo-Romero et al., 2018; Croci et al., 2017; Bulkeley & Castán Broto, 2012; Castán Broto & Bulkeley, 2013; Bulkeley & Kern, 2006). However, it is reasonable to consider that there is no unique path to achieve a low-carbon city.

There are diverse pathways that can be followed to achieve climate governance, and they may differ between cities located in countries in the Global North and those located in the Global South (Van der Heijden, 2019). Yet, there is a profound gap in the environmental governance literature when it comes to examining the climate actions adopted by cities in the Global South, particularly with respect to understanding the drivers of, and barriers to, such actions in these cities. More studies on climate action, and the associated barriers and drivers to policy development and implementation in cities of the Global South are needed what also constitutes a literature gap of this thesis.

To address this literature gap, two manuscripts were written (third and fourth paper of the thesis). Both explore the city of Recife case in Brazil, where the climate agenda has significantly advanced in recent years. Evidence triangulation was developed using documentary research, interviews, and observation.

The city of Recife was chosen given that: (I) in 2020 the city was considered by a relevant international institution (CDP, 2021) to be among the world's leading cities when it comes to climate actions; (II) the city is located in a developing country, thereby addressing a gap in the literature, (III) the city has been considered by the IPCC (2014a; 2021) to be among the most vulnerable cities in the world to climate change, (IV) the city was the first in Brazil to recognize the climate emergency and set targets to neutralize GHG emissions by 2050, in accordance to Paris Agreement and (V) the city has advanced considerably in the climate agenda in recent years with the development of several studies and effective actions to mitigate and adapt to climate change.

The thesis argues that having committed leadership, being part of a multinational network of cities, multilevel governance and climate risks are fundamental drivers to cities climate action. In the other side, political interference in one of the main barriers in the context of Brazilian cities.

The structure of this thesis follows definitions from PPGA/UFRGS Coordinating Committee Resolution 02/2018 which recommends the format to be followed for the thesis composed by articles compilation. Following this introductory chapter, contextualization is presented, where a synthesis of the literature review about GHG accounting approaches and methodologies in cities and drivers and barriers for local climate action are presented. Next, the research problems, objectives and methodology of each article are detailed. In the following chapter, the four articles that composes the thesis are presented, articulated with the specific objectives set out in the first chapter. In the third chapter, the conclusions, limitations, and suggestions for future studies are discussed.

1.1 Research Problem and Objectives

Developing a GHG emissions inventory is the first step in climate action planning. The literature review showed that the quality of city emission inventories has been little debated in academia. And that gaps in these inventories can affect the effectiveness of local climate action plans, as well as the analysis and comparability of the results of these reports.

The literature review also showed that to date, most of the previous studies examining empirical climate governance and the drivers and barriers to climate action have been carried out in the Global North (Van der Heijden, 2019; Mi et al., 2019; Castán Broto & Bulkeley, 2013; Van der Heijden, 2019; Reckien et al., 2018; Romero-Lankao et al., 2018; Castán Broto, 2017).

Literature shows that more studies on climate action, and the associated barriers and drivers to policy development and implementation in cities of the Global South are needed (Van der Heijden, 2019; Mi et al., 2019; Castán Broto & Bulkeley, 2013; Van der Heijden, 2019; Reckien et al., 2018; Romero-Lankao et al., 2018; Castán Broto, 2017).

In this context, aiming to discuss the reality of cities in the global South, this thesis sought as a **central problem** to identify the approaches and methodologies used in the

Brazilian cities GHG inventories, classifying the existing gaps, and understanding the drivers and barriers to climate action in Brazilian cities.

The **general objective** of the thesis is to analyze (I) the quality and gaps of GHG inventories and (II) the main drivers and barriers to climate agenda strengthening in Brazilian cities.

This thesis has five specific objectives:

1) To contribute to the literature in comparing the different GHG methodologies for cities in terms of coverage, efforts, and usage.
2) To identify the main shortcomings of the GHG inventories in terms of quality and gaps by assessing the inventories developed by Brazilian cities.
3) To propose actions policy makers can take to overcome these gaps and improve the quality of the cities GHG inventories.
4) To identify drivers and barriers for climate actions adopted by Brazilian cities.
5) To suggest a pathway to guide policymakers toward climate agenda strengthening in cities, particularly in developing and less developed countries.

To meet specific objectives 1, 2 and 3, all the most recent GHG emission inventories published by Brazilian cities that have already developed this action were used as a field of analysis. To address objectives 4 and 5, a case study was developed in the city of Recife.

1.2 Articles Connections

In order to fulfill the general and specific objectives, this thesis was structured in four articles. Articles 1 and 2 were developed to address specific objectives 1, 2 and 3 and articles 3 and 4 to address specific objectives 4 and 5.

The first article analyzed the differences among the main existing GHG accounting methodologies for cities and identified gaps in carbon inventories of twenty-four Brazilian cities published up to March/2019. The second paper compared GHG emissions results of forty-seven Brazilian cities reported by these cities up to June/2021 and data published by System for Estimating Greenhouse Gas Emissions (SEEG) (from the Portuguese: "Sistema de Estimativas de Emissões e Remoções de Gases de Efeito Estufa"). These publications applied different GHG accounting methodologies.

Article 1 was published by the Journal of Cleaner Production in 2019 (Baltar de Souza Leão et al., 2020) and it had received seven citations by international journals papers until September/2021. Manuscript 2 was submitted to Mitigation and Adaptation Strategies for Global Change journal in August/2021 and it is under analysis.

Brazilian cities experience was chosen because the country is one of the world's largest economies, most populous of Latin America and one of the top ten highest GHG emitters in the world (Carbon Brief, 2018) providing a good case to examine the kind of methodologies used by cities and the shortcomings of their reports. It is a highly urbanized country with more than 85% of its population living in cities. The understanding of how Brazilian cities measure GHG emissions and their GHG reports gaps can bring lessons to improve the way cities report GHG information and increase the quality of climate action plans.

To address specific objectives 4 and 5, articles 3 and 4 explore Recife case due to (I) the city vulnerability to climate change and (II) the fact that the climate agenda has significantly advanced in recent years which made the climate actions adopted by the city worldwide recognized .

The third paper is already published by “Cities” (Baltar de Souza Leão et al., 2021) and it has one international citation until September/2021. It is a city profile which discusses factors that can decisively assist cities to strength the climate agenda, mainly in developing or less developed countries. It was the first city profile published by the journal “Cities” to address the relationship between the impacts of urban evolution in a Latin American city and the threats imposed by climate change. It was also the first city profile of a Brazilian City published by this journal.

The fourth paper is a single case study which deeply examine in the Recife and analyzes climate actions already adopted by Recife and main drivers and barriers to climate agenda advance in the city. It is submitted to Mitigation and Adaptation Strategies for Global Change journal, and it is under analysis.

Figure 1 below shows the articles connection with the thesis objectives:

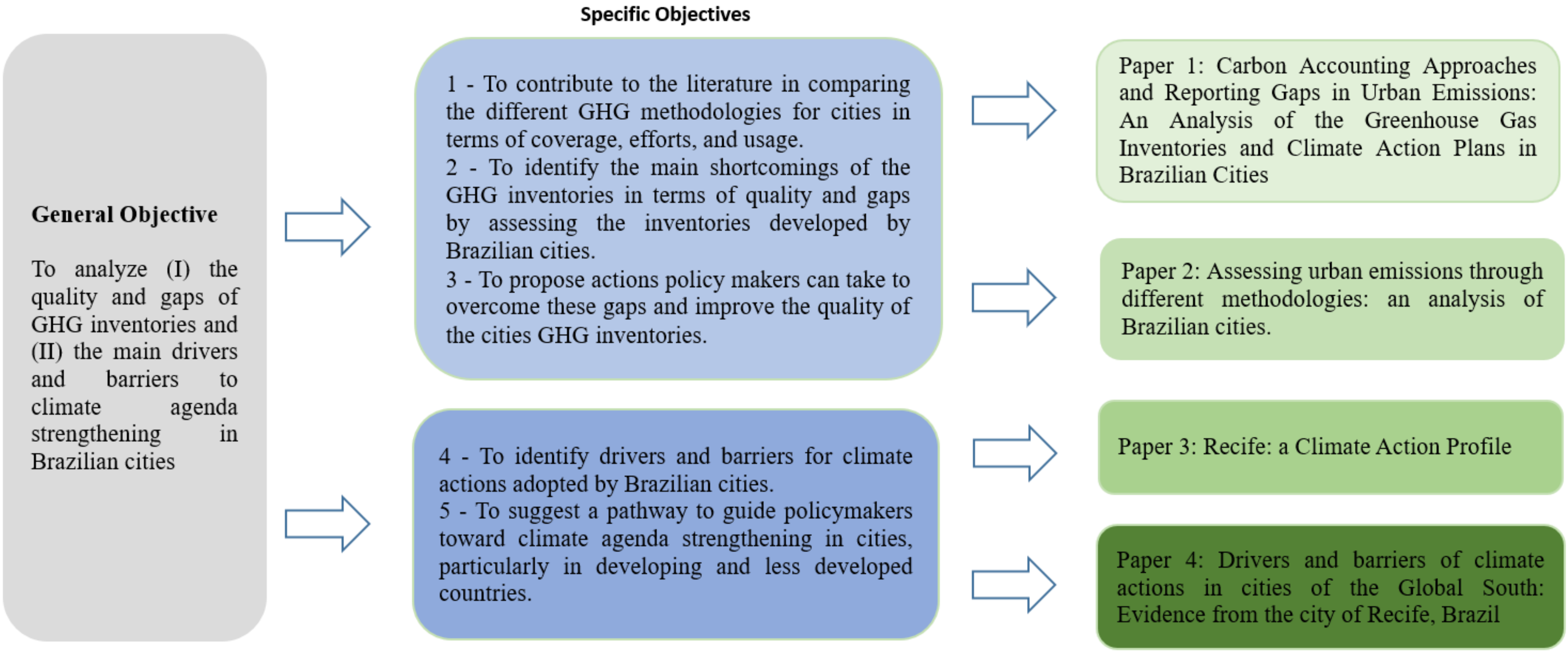

Figure 1: Articles connection with thesis objectives

1.3 Method

At this section, the method used by each manuscript is presented. Therefore, each sub-section will present the method adopted for each paper and the reasons for each option.

1.3.1 Article 1

Article 1 was written between 2019 and 2020. In 2020, it was published by published by Journal of Cleaner Production[1]. It followed a content analysis approach. Content analysis is set techniques of communication analysis that uses systematic and objective procedures to describe the content of messages (Bardin, 2009).

GHG inventories and climate action plans developed by Brazilian cities published up to April/2019 were the documents analyzed. Even though no questionnaire was applied, Latin American Secretariat of Local Government for Sustainability (ICLEI), one of the world most important international cities network, was contacted by phone and e-mail. The objective was to collect all GHG inventories of its members cities in Brazil.

ICLEI shared all GHG reports developed with its support. Once these reports were analyzed, the Carbon Disclosure Project - Latin America (CDP Latin America), another important worldwide city network, was also contacted to collect data submitted by Brazilian cities to CDP Cities and States & Region - Latin America Program. CDP is a platform where cities can report their emissions inventories. The manager of the CDP Latin America provided access to answers that had been provided by Brazilian cities to CDP. Through this platform, researchers could find more detailed information about the GHG accounting of Brazilian cities and emission reduction plans. All information

[1] https://doi.org/10.1016/j.jclepro.2019.118930

provided by Brazilian cities to the public platform Carbonn Climate Registry[2] was also collected and analyzed.

From eighteen GHG inventories[3], twelve were open to the public. Two reports were shared by ICLEI (Porto Alegre and Betim). Three (Vitória, Niterói and Goiânia) were obtained through CDP and one (Duque de Caxias) was publicly available at the beginning of the research, but not anymore. All five climate action plans analyzed are publicly available.

It was performed a content analysis of all GHG inventories and climate action plans developed by Brazilian cities. Documents selected attends to Bardin criteria (Bardin, 2009) of exhaustiveness, representativeness, homogeneity, and relevance.

Based on the information from (I) GHG inventories, (II) answers from Brazilian cities to CDP and (III) data supplied from Brazilian cities to Carbonn Climate Registry, it was possible to develop a frequency and quantitative (Bardin, 2009) analysis of: (I) carbon accounting approach followed by each Brazilian city and (II) sectors and emission sources included in GHG reports.

Finally, using GPC methodology principles, gaps identified in Brazilian GHG Reports were classified and codified in two main categories: (I) Incompleteness and (II) Lack of Transparency. Morse (2008) says that a category comprises and describes a collection of similar data sorted into the same place. To get these two main categories, Paper 1 analyzed gaps identified in each GHG Report. Following an inductive approach, also called data driven (Schreier, 2012), patterns were found, and these categories were

[2] http://carbonn.org/
[3] One GHG Report comprises 7 cities of ABC Region in São Paulo.

defined. Low levels of abstraction and interpretation (Graneheim et al., 2017) were assumed to define the categories.

1.3.2 Article 2

Article 2 compared the results of the GHG emission inventories of forty-seven Brazilian cities, using two different methodologies and data collection methods. Brazilian cities emission inventories were collected using two data sources: (1) the most recent GHG emission inventories of all Brazilian cities that individually carried out and published this report up to July/2021 and (2) the results of the GHG emission inventories published by the "System for Estimating Greenhouse Gas Emissions" (SEEG) for the same cities and same year.

Data collection from the cities' inventories was carried out over the internet, through websites of cities' environmental departments and international networks of cities, such as ICLEI – Local Governments for Sustainability and CDP – Carbon Disclosure Project. The SEEG database is public, available on its website. Forty-seven (47) inventories developed and reported individually by Brazilian cities were identified. For these cities, SEEG data were also collected.

A content analysis of both sources was carried out to identify: (I) methodology used; (II) total GHG emission; (III) emission by sector; (IV) emission sources included and (V) GWP used for calculation.

Total GHG emissions results and GHG emissions by sector results were compared. An analysis of the variations considering the literature review was carried out. Finally, gaps and limitations of each GHG inventory approach were identified.

1.3.3 Articles 3 and 4

Articles 3 is a city profile of Recife which discusses drivers that can help to strengthen the climate agenda, mainly in developing or less developed countries. This article follows the “Cities” specifications for city profiles articles. As noted earlier, this manuscript was published in 2021.

For its elaboration, article 3 used findings and elements generated by the methodological procedures adopted by article 4, which is a case study of the city of Recife, which analyzes in depth climate actions already adopted by Recife and main drivers and barriers to climate agenda advance in the city.

Articles 3 and 4 are exploratory study. They take a case study approach to generate insights on the climate change response of a city in the global south and the associated drivers and barriers to climate action. According to Yin (2001), a single case study is eminently justified when it either represents (a) a crucial test of existing theory, (b) a rare or exclusive circumstance, or (c) a typical or representative case, or serves a (d) revealing or (e) longitudinal purpose. In these studies, the single case study approach was adopted to generate detailed findings that are invited to be further tested in future studies. The city of Recife was chosen given characteristics presented in section 2.4.

As recommended by Eisenhardt & Graebner (2007) and Yin (2001), multiple sources of information were sought to carry out the case study. Data collection involved: (I) a document and content analysis, (II) interviews, and (III) observations to obtain results from a variety of data sources through triangulation.

Regarding the document analysis, special attention was given to the targets, measures, and requirements established by climate policies and plans. These documents provided elements to design the interview script (see Annex 1) and to confirm information obtained from interviews.

Topics	Documents
Recife GHG inventories	Recife (2015c); Recife (2017); ICLEI (2020).
Recife Climate Action Plans	Recife (2016); ICLEI (2020).
Analysis of Risks and Climate Vulnerabilities and Adaptation Strategy of Recife Municipality.	Recife (2019a).
Laws and Decrees related to Climate Change	Recife (2013); Recife (2014); Recife (2015a); Recife (2015b); Recife (2019b); Recife (2019c); Recife (2020).
Data and studies on urban planning and climate change	Sanear (2014); Recife (2018); TomTom (2020); IBGE, (2020a); IBGE (2020b); IBGE (2020c); CDP (2021).

Table 1: Documents submitted for Content Analysis.

Fifteen interviews with key informants were conducted between August,2020 and September,2020. The institutions and people were selected based on their direct involvement with city's climate governance. All interviews were carried out online and recorded. Interviewee profiles are presented in Table 2.

Name	Institution	Role	Brief Description	Interview Date	Duration
Alessandra Carvalho (I#1)	Secretary of Environment and Sustainability (SMAS)	Chief of Urban Afforestation	Chief of Urban Afforestation since 2017. She has worked for SMAS since 2011. She coordinates tree planting at the city.	27/08/2020	28 minutes
Ana Gama (I#2)	Secretary of Urban Development and Housing of Pernambuco State	Manager of Environmental Studies and Programs	She represents its Secretary at GECLIMA. She was activelly involved in the Waste Metropolitan Plan elaboration. She has a PhD where studied the Waste Sector and its climate impacts at the Metropolitan Region of Recife (RMR).	10/08/2020	1 hour and 03 minutes.
André Arruda (I#3)	Recife Agency for Innovation and Strategy (ARIES)	Innovation Analyst and Coordinator of Recife 500 anos Project	He coordinates the Project Recife 500 Anos. This project establishes scenarios and targets for the city using 2037 as target year. He is MsC in Prospective Urban Scenario and is actively involved with Aries since its conception in 2015.	13/08/2020	44 minutes
Antônio Valdo (I#4)	EMLURB – Company of Maintenance and Urban Cleaning of Recife	CEO assessor	He has worked for public service in Recife for the last 40 years.He coordinated the Recife Drainage Plan. He is also actively involved at adaptation actions to combat the increase of sea level at the city.	17/08/2020	48 minutes
Igor Albuquerque (I#5)	ICLEI – Local Governments for Sustainability (South America)	Project Manager	Igor has worked for Iclei since 2011. From 2011 to 2019, he was South America Climate Change Manager. From 2019, he became Iclei Project Manager. His work with Recife started in 2013 with Urban Leds Project. He coordinated several projects and partnerships in the city as GHG inventories; the first climate action plan; the vulnerability and risks analysis; actions to mobilize Society, among others.	31/08/2020	1 hour and 10 minutes
Isadora Freire (I#6)	Recife Agency for Innovation and Strategy (ARIES)	Analyst and Coordinator of Project CITinova	She coordinates the project CITinova. This project was financed by GEF (Global Environmental Facility) and it involves three main focus: Urban Planning; Investment of Pilot Projects and Knowledge Platafom. Isadora is also	13/08/2020	53 minutes

Name	Institution	Role	Brief Description	Interview Date	Duration
			actively involved with adaptation actions planning in the city.		
Keila Ferreira (I#7)	Secretary of Civil Defense	General Manager of Social Attention	She has worked at Public Service in Recife for the last 20 years. She has worked for Civil Defense Secretary for 14 years. She is member of GECLIMA and is actively involved in the Climate Action Plan and Vulnerability and Risks Analysis elaboration. She also coordinates several adaptation actions in the city. Mainly related to vulnerable people.	11/08/2020	55 minutes
Leta Vieira (I#8)	Pelópidas Silveira Institute of the City (ICPS)	General Manager of Sustainability and Urban Resilience	Leta is one of the focal points of the city at international networks as ICLEI and CDP. Before joining ICPS, she was Chief of Low Carbon Policy and Climate at SMAS. She is one of the coordinators in the city of the following actions: (I) Vulnerability and Risks Analysis; (II) GHG Inventory from 2015 to 2017; (III) Update of Climate Action Plan among several other actions related to the climate agenda.	11/08/2020	1 hour 01 minute
Luiz Gustavo (I#9)	Secretary of Environment and Sustainability (SMAS)	Manager of Environmental Policies	He is one of the focal points of the city at international networks as ICLEI and CDP. He coordinated with Leta the GHG inventories of 2016 and 2017 and the update of the Climate Action Plan. He is responsible for reporting GHG and climate information to international plataforms as CDP and Carbonn Climate registry.	06/08/2020	1 hour 48 minutes
Luiz Roberto (I#10)	Secretary of Environment and Sustainability (SMAS)	Former Chief of Low Carbon Policies and Climate	He coordinated the first GHG inventory of the city (Base year 2012). He also worked at the GHG inventory from 2013 to 2015. He was actively involved at the elaboration of the first Climate Action Plan of the city. He also participated at the elaboration of the City Climate Change and Sustainability Law. Luiz Roberto	05/08/2020	1 hour 54 minutes

Name	Institution	Role	Brief Description	Interview Date	Duration
			also worked as independent consultant at the Vulnerability and Risks Analysis elaboration.		
Maurício Guerra (I#11)	Secretary of Environment and Sustainability (SMAS)	Former Environmental Executive Secretary	He worked at SMAS from 2008 to 2019. From 2010 to 2015, he was director of Environmental Policies and from 2015 to 2019, Executive Secretary of Climate Change and Sustainability of the City. He helped to design SMAS concepts and structure. During his work at the secretariat, he participated and led several projects related to climate change and sustainability. He led the city entrance in international networks as ICLEI and CDP. He coordinated the GHG inventories from 2012 to 2015 and the first climate action plan. He also led the discussions over the City Climate Change and Sustainability Law.	07/08/2020	1 hour 48 minutes
Raquel Meneses (I#12)	Parque Capibaribe Project	Executive Coordinator of Parque Capibaribe Project	Architect and Urbanist, she is the executive coordinator of Parque Capibaribe Project since 2016. She is also UFPE Researcher (PhD in progress) at INCITI/UFPE (Laboratory of Research and Innovation for Cities).	20/08/2020	1 hour and 09 minutes
Taciana Maria (I#13)	CTTU – Company of Traffic and Urban Transportation	CEO	Taciana is CEO of CTTU since 2013. She led and participate of several projects to improve urban mobility at the city. As example: Bike Lanes; Bus Lanes; Pedestrianism; Traffic light and road network optimization and Education campaigns on mobility enhancement. She is involved in the city Mobility Plan development.	27/08/2020	26 minutes
Tiago Henrique (I#14)	Pelópidas Silveira Institute of the City (ICPS)	Geoprocessing and analysis manager	He has worked at ICPS since 2011. He was responsible to map green area existing in the city. He and his team also proposed a green index by neighborhoods. He developed a work that identified heat islands in the city. This diagnosis was a input to Aforestation Program elaborated by SMAS. He is a PhD and is directly involved in	27/08/2020	1 hour 11 minutes

Name	Institution	Role	Brief Description	Interview Date	Duration
			climate change discussions in the city as a member of GECLIMA.		
Ubirajara Ferreira (I#15)	Pelópidas Silveira Institute of the City (ICPS)	Urban Development Analyst	Before joining ICPS, Ubirajara coordinated the development of Aforestation Plan at SMAS. He worked at SMAS between 2008 and 2019. In 2008, he coordinated the Building Standard Law elaboration. At ICPS, he got involved with the Building Standard Law review and discussions about the Land Use Law that is now under discussion in the city.	19/08/2020	25 minutes

Table 2: Interviewee Profiles

To verify the information obtained in interviews, participant observation was also carried out, whereby this PhD candidate participated in six online meetings between the stakeholders of the city and an international climate network that occurred between March,2020 and December,2020. Local stakeholders and representatives of one multinational city climate network participated in these meetings to discuss and contribute to the elaboration of Recife local climate action plan (LCAP) (ICLEI, 2020). During these meetings, the authors of this study observed climate actions, drivers, and barriers to their implementation.

Meetings	Date	Subject	Participants
O#1	03/06/2020	Presentation of GHG Emissions Scenarios and Preliminary Action Plan.	Representatives from Local Government, *ICLEI*, Universities, the private sector, and local NGOs.
O#2	05/06/2020	Discussion of the concept of green areas and targets to be defined.	Representatives from Local Government, *ICLEI*, and Universities.
O#3	26/06/2020	Discussion on targets related to green areas.	Representatives from Local Government, *ICLEI*, and Universities.
O#4	20/08/2020	Workshop to collect opinions from youth of the city on climate actions.	Representatives from Local Government, *ICLEI*, and the youth community.
O#5	14/10/2020	Workshop to validate the Climate Action Plan	Representatives from Local Government and *ICLEI*.
O#6	15/12/2020	Presentation of the Local Climate Action Plan	Representatives from Local Government, *ICLEI*, Universities, the private sector, and local NGOs.

Table 3: Overview of Participant Observation in Institutional Meetings

In the results and discussion section of the article 4, the acronyms “I#” and “O#” stand for interviews and observations, respectively.

2. SINTHESIS OF THE LITERATURE REVIEW

The second chapter of the thesis is divided into two parts that aim to academically contextualize, delimit, and present the theme of the thesis that will be presented in the following chapter.

In the first part, a synthesis of the literature review is presented. Initially, the different approaches and methodologies for GHG emissions accounting are addressed. Subsequently, the theoretical discussion on the main drivers and barriers for climate action at the local level is presented.

2.1 Carbon Accounting Approaches and Methodologies

There are different GHG accounting methodologies to measure GHG emissions from cities. And these methodologies can use different carbon accounting approaches. This section will discuss first different carbon accounting approaches and after the main methodologies used for GHG measurement at city-scale.

2.1.1 Production-Based Approach X Consumption-Based Approach

Existing GHG carbon accounting methodologies have two basic distinct approaches: the production-based approach (PBA) and the consumption-based approach (CBA). While the former allocates GHG emissions to where they are generated in the production processes, the latter allocates the emissions to the final consumer.

Lombardi et al. (2017) defines PBA as the methodology that includes all emissions from economic activities by resident companies and households. It assigns responsibility for emissions at the point where the emissions are produced. Alternately, CBA measures the carbon emissions associated with the final consumption of goods and services. GHG emissions are calculated by subtracting the emissions associated with exported goods and services from PBA and adding those generated to produce imported goods and services (Grasso, 2016; 2017; Andrade et al., 2018; Sudmant et al., 2018). The CBA accounts for emissions generated from the consumption of goods and services within an area regardless of where emissions from production of such goods and services have happened (Dahal & Niemelä, 2017). This method includes emission sources that are beyond the boundary of the city (Lombardi et al., 2017).

Recently, several studies have discussed the impact of these approaches on city-level carbon inventories (e.g. c). Studies show that approach chosen can significantly impact GHG inventory results (Sudmant et al., 2018; Athanassiadis et al., 2018). Studies found divergent results of GHG emissions inventories of New York, Paris, and Shanghai (Ibrahim et al., 2012) when applying different approaches. Other efforts also reached the same conclusion for London and Madrid (Andrade et al., 2018), Hong Kong (Harris et al. 2012) and 45 urban areas in China, the U.K., and the U.S. (Sudmant et al., 2018).

Although the PBA is the most used approach by cities around the world, several authors defend using CBA methodology. Both approaches have positive and negative aspects (see in Table 4). The key advantages of CBA include (I) eliminating carbon leakage, (II) covering more emissions, (III) consistency between consumption and environmental impacts and (IV) increasing mitigation options (Peters, 2008; Afinois et al., 2017; Andrade et al., 2018).

Authors agree, however, that it is technically more difficult and uncertain to use CBA instead of PBA (Peters, 2008; Grasso, 2016; Franzen & Mader, 2018; Sudmant et al., 2018). CBA method requires more complex calculations, assumptions, and estimations (Peters, 2008; Dodman, 2009; Afionis et al., 2017), while the PBA is much closer to the statistical sources. PBA includes domestic activities and is more consistent with the concept of gross domestic product (GDP) (Peters, 2008). However, using just PBA can guide to ineffective mitigation policies once the emissions coverage is focused on what it is emitted within the territory. This neglect emissions related to consumption of imported products and goods, and it is a motivation for carbon leakage. Ibrahim (et al., 2012), Lombardi et al. (2017), Andrade et al. (2018) and Athanassiadis et al. (2018) agree that a combination of these methods can be used. The two accounting approaches are not competing; rather, they are complementary. This combination would measure GHGs within city boundaries, plus indirect emissions deriving from infrastructure and non-infrastructure supply chains that serve the entire community.

GHG Accounting Approach	Advantages	Disadvantages	References
PBA	-Established reporting and widespread use. - Information used is closer to statistical sources. - Straightforward calculations. - Less uncertainty. -Consistency with political and environmental boundaries. - Government has more easily the authority to implement policies over the emissions.	- Coverage of only emissions generated inside the territory. - Lack consideration of emissions related to imported products and goods. - Motivation for carbon leakage. - Guiding ineffective mitigation policies.	Peters (2008); Dodman (2009); Grasso (2016); Afionis et al. (2017); Franzen & Mader (2018)
CBA	- Elimination of carbon leakage. - Coverage of emissions related to (I) imported products, materials, goods, and services and (II) logistics. -Consistency between consumption and environmental impacts. - Responsibility and fairness over consumption. - More precise diagnosis about the main emission sources of the cities. - Highlighting the impacts of a consumption lifestyle.	- Increase uncertainties. - Technical complexity. - Wider range of goods and services across the economy and across the borders should be considered. - Mitigation options can require political decisions outside the administrative boundaries and political influence.	Peters (2008); Dodman (2009); Larsen & Hertwich (2010); Grasso (2016); Afionis et al. (2017); Franzen & Mader (2018); Sudmant et al. (2018); Andrade et al. (2018)

Table 4: Main Advantages and Disadvantages of Each GHG Accounting Approach

Source: Developed by the author

2.1.2 GHG Estimation Methodologies

According to Jonas et al. (2019), GHG emissions are rarely measured directly. To assist countries in compiling comprehensive emission inventories and conducting quantitative uncertainty analyses under the United Nations Framework Convention on Climate Change (UNFCCC), the Intergovernmental Panel on Climate Change (IPCC) developed standardized methodologies to enable adequate accounting of national, natural, and human-induced GHG sources and sinks.

IPCC method (2006) is an internationally agreed methodologies intended for use by countries to estimate greenhouse gas inventories to report to the UNFCCC. It is the Panel recommendation for national GHG inventories.

IPCC (2006) provides detailed guidance on emission and removal categories, calculation formulae, data collection methods, default emission factors, and uncertainty management. It requires GHG emissions reporting from sectors and subsectors that takes place within a territory. It follows a PBA, assigning responsibility for emissions at the point where the emissions are produced (Lombardi et al, 2017). Despite recommended for National Inventories, IPCC methodology is also applied at city level.

The most common method to estimate GHG emissions is to combine information on the extent to which a human activity takes place (called activity data or AD) with coefficients which quantify the emissions or removals per unit activity. These are called emission factors (EF). The basic equation is therefore:

Math Formulae 1: $\text{GHG Emissions} = \Sigma\ AD_i \times EF_i$ for each activity i

GHG emission and removal estimates are divided into main sectors which are groupings of related processes, sources, and sinks, as presented at table 5.

Sectors	Sub-Sectors
1-Energy	1.A. Fuel Combustion Activities 1.B. Fugitive emissions from fuels 1.C. Carbon Dioxide Transport and Storage.
2-IPPU[4]	2.A. Mineral Industry 2.B. Chemical Industry 2.C. Metal Industry 2.D. Non-Energy Products from Fuels and Solvents Use 2.E. Electronics Industry 2.F. Product Uses as Substitutes for Ozone Depleting Substances 2.G. Other Product Manufacture and Use
3-AFOLU[5]	3.A. Livestock 3.B. Land 3.C. Aggregate sources and non-CO2 emission sources on land.
4-Waste	4.A. Solid Waste Disposal 4.B. Biological Treatment of Solid Waste 4.C. Incineration and Open Burning of Waste 4.D. Wastewater Treatment and Discharge. 4.E. Other

Table 5: Main sectors and subsectors– IPCC Methodology

Source: Elaborated by the author based on IPCC (2006).

Another methodology commonly used by cities to estimate GHG emissions is the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC). It was developed by a partnership between the World Resources Institute (WRI), the Local Governments for Sustainability (ICLEI) and the Cities Climate Leadership Group (C40) in 2014 (WRI, 2014).

The GPC requires cities to measure and disclose a GHG inventory using both production and consumption activities within the city boundary. A geographic boundary that identifies the spatial dimension or physical perimeter of the inventory's boundary

[4] Industrial Processes and Product Use.
[5] Agriculture, Forestry and Other Land Use

shall be defined. The GPC is designed to account for city GHG emissions within a single reporting year, covering a continuous period of 12 months. Ideally, it should align to either a calendar year or a financial year. GPC recommends that city GHG emissions be classified into six main sectors and sub-sectors presented at table 6.

Sectors	**Sub-Sectors**
I-Stationary Energy	I.1. Residential Buildings I.2. Commercial and institutional buildings and facilities I.3. Manufacturing industries and construction. I.4. Energy industries I.5. Agriculture, forestry, and fishing activities I.6. Non-specified sources I.7. Fugitive emissions from mining, processing, storage and transportation of coal I.8. Fugitive emissions from oil and natural gas systems
II-Transport	II.1. On Road Transportation II.2. Railways II.3. Water Transport II.4. Aviation II.5. Off-Road Transportation
III-Waste	III.1. Solid waste disposal III.2. Biological Treatment of Waste III.3. Incineration and open burning III.4. Wastewater treatment and discharge
IV-IPPU	IV.I. Industrial Processes IV.II. Product Use
V-AFOLU	V.I. Livestock V.II. Land V.III. Other Agriculture
VI-Other Scope 3	Any other emissions occurring outside the geographic boundary as a result of city activities

Table 6: Main sectors and subsectors– GPC Methodology

Source: Elaborated by the author based on WRI (2014).

Activities taking place within a city can generate GHG emissions that occur inside the city boundary as well as outside the city boundary. To distinguish between these, the GPC groups emissions into three categories based on where they occur: scope 1, scope 2 or scope 3 emissions (WRI, 2014), as follows:

- Scope 1: GHG emissions from sources located within the city boundary.
- Scope 2: GHG emissions from using grid-supplied electricity, heat, steam and/or cooling within the city boundary.
- Scope 3: All other GHG emissions that occur outside the city boundary.

The GPC distinguishes between emissions that physically occur within the city (scope 1) from those that occur outside the city but are driven by activities taking place within the city's boundaries (scope 3), and from those that occur from the use of electricity, steam, and/or heating/cooling supplied by grids which may or may not cross city boundaries (scope 2). Scope 1 emissions are the traditional emission accounted following PBA. It may also be termed "territorial" emissions because they are produced solely within the territory defined by the geographic boundary (WRI, 2014).

Providing scopes 2 and 3, GPC includes emission sources that are beyond the boundary of the city (e.g: electricity consumed from a grid; waste disposal out-boundary). It opens the possibility of accounting and reporting emissions from consumption of goods and services within an area regardless of they have happened (Dahal & Niemelä, 2017; Lombardi et al., 2017). Therefore, GPC offers the possibility to combine PBA and CBA. Cities can expand this possibility reporting other scope 3 emissions.

IPCC and GPC methodologies (IPCC, 2006; WRI, 2014) follow the same accounting and reporting principles as follows:

- Transparency: The inventory should present clear documentation about activity data, emission sources, emission factors, and accounting methodologies. The information should be sufficient to allow individuals outside of the inventory process to use the same source data (WRI, 2014).
- Completeness: All required emissions sources within the inventory boundary shall be estimated. Any exclusion of emission sources shall be justified and clearly explained.
- Consistency: Approach, emissions sources, approach, boundary, and methodology shall be consistent over time, enabling meaningful documentation of emission changes over time, trend analysis, and comparisons. Any deviation shall be disclosed and justified.
- Accuracy: The inventory shall not systematically overstate or understate actual GHG emissions. This means making all endeavors to remove bias from the inventory estimates.

There is only one principle of each methodology that is not expressly provided for in another. IPCC establish the principle of comparability that says that the GHG inventory shall be reported in a way that allows it to be compared with GHG inventories of other territories. And GPC provides the principle of relevance, which says that the reported GHG emissions shall appropriately reflect emissions occurring because of activities and consumption patterns of the city.

There are other recently developed methodologies, such as PAS 2070:2013 (PAS 2070) (Andrade et al., 2018). PAS 2070 specifies requirements for the assessment of the GHG emissions of a city using two distinct methodologies: (I) a direct plus supply chain (PAS 2070-DPSC) methodology and (II) a CBA methodology (PAS 2070-CB).

PAS 2070-DPSC includes PBA emissions plus emissions associated with the largest supply chains serving the cities, including water supply, food and drink, and construction materials, specifically cement and steel. PAS 2070-CB captures lifecycle GHG emissions for all goods and services consumed by the city. The PAS 2070-CB methodology sets out an approach to calculate the GHG emissions linked to global and national supply chains with the use of environmentally extended input output (EEIO) matrices. Table 7 shows characteristics of carbon accounting methodologies.

Characteristics	**Carbon Accounting Methodologies**			
	IPCC	**GPC**	**PAS 2070-DPSC**	**PAS 2070-CB**
Carbon Accounting Approach	PBA	PBA	PBA + largest supply chains	CBA
Sectors	Energy (including Transportation), Waste, IPPU and AFOLU	Stationary Energy; Transportation; Waste; IPPU; AFOLU and Other emissions out-boundary	Stationary Energy; Transportation; Waste; IPPU; AFOLU and Goods and Services	Food and Drink; Utility Services; Household; Transport Services; Private Services; Other Good and Services

Table 7: Characteristics of carbon accounting methodologies

Source: Developed by the author

Emission data are fundamental for guiding climate change mitigation research and actions. Despite these accounting and reporting principles, uncertainties of GHG inventories are high. Although several papers provide methods to improve the comprehensiveness and accuracy of carbon accounting in cities, there are still uncertainties in these inventories. Furthermore, little effort has been made to identify and classify the gaps in a comprehensive manner based on the existing inventories and plans. This fact influences not just the comparability of cities GHG reports. It can also impact the understanding of city emissions and may limit public policies to combat climate change (Harris et al., 2012).

Mi et al. (2019) argue that efforts are needed to reduce those uncertainties. Li et al. (2017b) mentioned problems in the Chinese cities inventories as incompleteness due to data unavailability, reporting problems and inconsistencies between the framework and the contents of the inventories. Andrade et al. (2018) also mention important sources of uncertainties associated to the Madrid's GHG emissions inventory as lack of disaggregated and high-quality data at a local scale. The lack of consistent and comparable GHG emissions data at the city level is highlighted as one of the four remaining gaps in the urban climate actions research area highlighted by Mi et al. (2019).

The only study found that explores the quality of GHG disclosures by cities is Mia et al. (2019). This paper highlights that prior studies predominantly focused on corporate-level GHG disclosure and that there has been limited research, exploring cities' GHG disclosure. The manuscript analyzes GHG disclosure of 42 cities published on Carbon Disclosure Project (CDP) platform through the expectation gap framework.

Mia et al. (2019) uses the following characteristics to assess the quality of CDP cities disclosure data: completeness, consistency, timeliness, accuracy, reliability and comparability. Therefore, parameters used are very aligned with principles suggested by GPC Methodology (WRI, 2014). This paper is focused on reports of cities from C-40 international network (that comprises only Mega Cities) and just discusses data provided by CDP. Details of cities GHG reports documents are not analyzed.

Authors highlighted that there is a lack of empirical research investigating disclosures at the regional or community level, mainly with a detailed examination of emissions information that is already disclosed by cities. Kennedy et al. (2012) also found that Berlin, Boston, Greater Toronto, London, New York City and Seattle are not counting all emission sources and despite progress. Further improvements in city GHG inventorying procedures are needed.

No paper was found in the international databases discussing the quality of GHG reports from Latin America cities what brings the questions: how GHG reports are being developed in Latin America? Which carbon accounting approaches methodologies have been used? Do they also present gaps?

2.2 Climate Actions, Drivers and, Barriers to Climate Change

2.2.1 Climate Actions

Climate actions adopted by cities can follow one of two main strategies: mitigation or adaptation. Mitigation actions are directed toward attacking the root causes of climate change and have been defined as "[…] anthropogenic interventions to reduce the sources or enhance the sinks of greenhouse gases (GHG)" (IPCC, 2014a). Adaptation actions, in turn, aim to reduce local vulnerability to climate change and have been defined as "[…] adjustments in natural or human systems in response to actual or expected climate change and its effects" (IPCC, 2014a).

There are some studies that try to understand which mitigation and adaptation actions are being developed by cities to combat climate change. Pablo-Romero et al. (2018) used the database from the Covenant of Mayors to study 4,741 benchmark actions of nearly 1,300 European cities. The Covenant of Mayors was launched in 2008. It was a voluntary agreement by which cities and regions voluntarily commit to reducing their CO_2 emissions beyond the EU 20% target. This study showed that the greatest number of actions implemented by cities are related to municipal buildings (26%), public lighting (18%) and local electricity production (17%). The most CO_2 emissions reducing actions are also related to municipal buildings, and public lighting. Energy efficiency in the public lighting sector and photovoltaics in the local electricity production sector are notably the two areas of intervention with more benchmark actions undertaken.

Cities tends to look for measures where they can save financial resources in energy costs by reducing energy use (energy saving measures). Thus, in cities with modest budgets, lower-cost actions with high efficiency are promoted. This fact may explain the high percentage of energy efficiency measures linked to public lighting. The Light Emitting Diode (LED) is emerging as the most energy efficient technology for lighting applications, while its decreasing cost makes the investments viable for many cities. However, an exception to this general rule is related to the actions associated with the photovoltaic area. In this case, there are many signatories that carried out these actions, but they have a relatively high cost. Transport actions have higher cost per actions. Nevertheless, among these actions, those related to a modal shift to walking and cycling has relatively lower cost of CO_2 emissions reductions. It is also worth noting the high number of actions related to a modal shift to the walking and cycling area in the transport sector.

Croci et al. (2017) also analyzed the emission reduction strategies of European cities trying to understand the most relevant sectors, subsectors, actions, and policy levers to mitigate climate change. The study analyzed 124 European cities with more than 100,000 inhabitants which delivered a Sustainable Energy Action Plan (SEAP) by February 2014. Buildings and Transport under public management control (municipal buildings, public transport, municipal fleet, and public lighting) stood out as the sectors where cities intend to deliver the largest emission reductions. Energy efficiency in the building sector and a transition from private transport to public and cleaner transport modes, were actions that provided highest share of GHG emission reductions.

Castán Broto & Bulkeley (2012) and Bulkeley & Castán Broto (2012) analyzed 627 urban climate change experiments in a sample of 100 global cities. According to them, climate change initiatives are a global and relatively recent phenomenon. These studies showed that climate change measures tend to focus on energy and that municipalities have a critical role in experimentation, leading 66% of urban climate change experiments. However, the data also reveal that, alongside city governments, other actors may be playing a key role in climate change experimentation such as private and civil society actors. Bulkeley & Kern (2006) carried out six case studies in Leicester, Kirklees and Southampton in the UK and Heidelberg, Munich and Frankfurt am Main in Germany, they also found that city actions are also concentrated in the energy sphere (in the energy management of municipal properties)

Despite the focus on energy sector, within the broad category of mitigation, cities can adopt multiple climate actions. Table 8 presents examples of mitigation actions identified in the literature (Pietrapertosa et al., 2019; Pablo-Romero et al., 2018; Croci et al., 2017; WRI, 2014; Castán Broto & Bulkeley, 2013; Bulkeley & Kern, 2006).

The IPCC (2014b) defined three categories of adaptation actions: (I) Structural/Physical (STR), (II) Social (SOC), and (III) Institutional (INST), and provided examples of adaptation strategies. Table 9 summarizes the main adaptation actions identified in the literature.

Mitigation[6]		
Energy[7]	**Transport**[8]	**Waste**[9]
• Energy efficiency • Energy certification labelling • Smart grid infrastructure • District heating/cooling plant • Use of renewable energy • Renewable energy pilot projects • Energy efficiency schemes for municipal buildings • High energy efficiency standards in new buildings • Purchasing green energy by public buildings • Energy/carbon taxes • Eco-house pilot projects • Strategic planning to enhance energy conservation • Planning guidance on energy efficiency and renewable energy projects • Contracts to guarantee renewable energy installations • Campaigns for energy efficiency • Provision of advice on energy efficiency to businesses and citizens • Grants for energy efficiency and/or renewable energy measures • Guidance for architects and developers on energy efficiency and/or renewables	• Implementation of new low-carbon transport infrastructure • Public fleet replacement • Bike Lanes • Electric vehicles • Transport mobility planning/regulation • Traffic light optimization • Integrating ticketing and charging • Road network optimization • Improvement of logistic and freight transport • Fuel switching and enhancing energy efficiency at existing fleet • Car sharing/pooling • Reducing the need to travel through planning policies • Mobility management for public employees • Pedestrianization • Workplace levies and road-user charging • Road pricing congestion charge • Park zoning and pricing • Policies to reduce car use • Education campaigns on mobility enhancement; • Quality partnerships with public transport providers.	• Enable methane capture and/or combustion from landfill sites • Waste prevention, recycling, and reuse within the local authority • Provision of sites for recycling, composting and 'waste to energy' facilities • Procurement of recycled goods • Recycling, composting, reuse schemes • Campaigns to reduce, reuse, and recycle waste • Promote use of recycled products • Sustainable consumption campaigns • Wastewater treatment for the entire population • Enable methane combustion from wastewater treatment • Green technologies for wastewater treatment

Table 8: Main mitigation actions identified in the literature[10]

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[6] Pietrapertosa et al. (2019); Pablo-Romero et al., 2018; WRI, 2014; Castán Broto & Bulkeley, 2013.

[7] Pietrapertosa et al., 2019; Pablo-Romero et al., 2018; Croci et al., 2017; WRI, 2014; Castán Broto & Bulkeley, 2013; Bulkeley & Kern, 2006.

[8] Pietrapertosa et al., 2019; Pablo-Romero et al., 2018; Croci et al., 2017; WRI, 2014; Castán Broto & Bulkeley, 2013; Bulkeley & Kern, 2006.

[9] Pietrapertosa et al., 2019; Pablo-Romero et al., 2018; Croci et al., 2017; WRI, 2014; Castán Broto & Bulkeley, 2013; Bulkeley & Kern, 2006.

[10] The 2006 IPCC Guidelines for National GHG Emission Inventories considers four sectors: Energy, Waste, Industrial Processes and Product Use (IPPU), and Agriculture, Forestry and Land Use (AFOLU). Actions related to IPPU were considered in the Energy Sector given that these measures are generally related to Energy efficiency. The AFOLU sector was considered in the Adaptation category due to its overlapping benefits with climate change adaptation measures. In the IPCC methodology, Transport is included in the Energy Sector. However, in the Global Protocol for Community-Scale GHG emissions (GPC), which is the methodology predominantly used by cities to calculate GHG inventories, Transport is

Source: Table based on Pietrapertosa et al., 2019; Pablo-Romero et al., 2018; Croci et al., 2017; WRI, 2014; Castán Broto & Bulkeley, 2013; Bulkeley & Kern, 2006.

Category	Examples of specific adaptation strategies
Engineered and built environment (STR)	• Sea walls and coastal protection structures • Flood levees and culverts • Water storage and pumps • Sewage works • Improved drainage • Beach nourishment • Flood and cyclone shelters • Building codes • Storm and wastewater management • Transport and road infrastructure adaptation
Technological (STR)	• New crop and animal varieties • Genetic techniques • Efficient irrigation • Water saving technologies, including rainwater harvesting • Conservation agriculture • Food storage and preservation facilities • Hazard mapping and monitoring technology • Early warning systems • Building insulation • Mechanical and passive cooling • Renewable energy technologies • Second-generation biofuels
Ecosystem-based (STR)	• Ecological restoration • Increasing biological diversity • Afforestation and reforestation • Conservation and replanting of mangrove forests • Bushfire reduction and prescribed fire • Green infrastructure (e.g., shade trees, green roofs) • Controlling overfishing • Fisheries co-management • Ecological corridors • Ex situ conservation and seed banks
Services (STR)	• Social safety nets and social protection • Food banks and distribution of food surpluses • Municipal services, including water and sanitation • Vaccination programs • Essential public health services, including reproductive health services and enhanced emergency medical services
Educational (SOC)	• Awareness raising and integrating into education • Gender equity in education

a specific sector. Most city GHG inventories only measure GHG emissions from Stationary Energy, Transport, and Waste (as it will be shown by Article 1 of this thesis). Therefore, table 1 presents mitigation actions in these three sectors.

Category	Examples of specific adaptation strategies
	• Sharing local and traditional knowledge including integrating into adaptation planning • Participatory action research and social learning • Community surveys • Knowledge-sharing and learning platforms • Research networks and communication through media
Informational (SOC)	• Hazard and vulnerability mapping • Early warning and response systems, including health early warning systems • Systematic monitoring and remote sensing • Climate services, including improved forecasts • Downscaling climate scenarios • Longitudinal data sets • Integrating indigenous climate observations • Community-based adaptation plans
Behavioral (SOC)	• Household preparation and evacuation planning • Retreat and migration • Soil and water conservation • Changing livestock and aquaculture practices • Crop rotation • Changing cropping practices, patterns, and planting dates • Silvicultural options • Reliance on social networks
Economic (INST)	• Financial incentives, including taxes and subsidies • Insurance, including index-based weather insurance schemes • Catastrophe bonds • Revolving funds • Payments for ecosystem services • Water tariffs • Savings groups • Microfinance • Disaster contingency funds
Laws and regulations (INST)	• Zoning laws • Building standards • Water regulations and agreements • Laws to support disaster risk reduction • Protected areas • Marine protected areas • Fishing quotas • Patent pools and technology transfer
Government policies and programs (INST)	• National and regional adaptation plans, including mainstreaming climate change • Sub-national and local adaptation plans • Municipal water management programs • Disaster planning and preparedness • City-level plans, district-level plans, and sector plans, which may include integrated water resource management, landscape, and watershed management

Category	Examples of specific adaptation strategies
	• Integrated coastal zone management, adaptive management, ecosystem-based management, sustainable forest management, fisheries management, and community-based adaptation

Table 9: Main adaptation categories identified in the literature[11]

Previous studies shows that climate action is being implemented mainly by European cities (Pablo-Romero et al., 2018; Croci et al., 2017; Castán Broto & Bulkeley, 2013; Bulkeley & Kern, 2006). But what are the drivers to act? And which barriers can hinder climate actions?

2.2.2 Drivers and Barriers for Climate Action

According to Reckien et al. (2015), drivers for climate action are activities, processes or patterns that produce positive incentives for climate action (Reckien et al., 2015). These factors that contribute toward climate change mitigation and adaptation actions are known as drivers of climate action. Sometimes also classified in the literature as enabling factors (Van der Heijden, 2019).

Several authors have previously discussed the drivers of climate action in the cities (Van der Heijden, 2019; Reckien et al., 2018; Romero-Lankao et al., 2018; Reckien et al., 2015; Castán Broto, 2017; Aylett, 2015). Some of them have highlighted the need to examine and discuss these drivers in more depth and under different circumstances. For example, Van der Heijden (2019) pointed to a lack of knowledge on the enabling factors that lead to effective urban climate governance. Reckien et al. (2018) called attention to the drivers of Local Climate Plans (LCPs) and concluded that they need to be further

[11] The IPCC Guidelines for National GHG Emissions Inventories (2006) consider four sectors: Energy, Waste, Industrial Processes and Product Use (IPPU), and Agriculture, Forestry and Land Use (AFOLU). Actions related to Industrial Processes and Buildings were considered in the Energy Sector given that these measures are generally related to Energy efficiency. The AFOLU sector was considered in the Adaptation category due to its overlapping benefits with climate change adaptation measures.

explored, especially in countries lacking national climate action legislation, such as Brazil. Romero-Lankao et al. (2018) highlighted a need for research that supports urban climate action under different local conditions.

For Reckien et al. (2018) city size, the existence of national legislation requiring climate actions, and being part of international networks influence local climate plans development. This result confirms previous research developed by Reckien et al. (2015) and matches to Van der Heijden (2019). Reckien et al. (2018) also found that climate change planning in European cities is often determined by local organizational capacity rather than proactive anticipation of future need in agreement with Reckien et al. (2015). Climate risk was not found as a driver for action by European cities. According to this study, it is predominantly large and prosperous cities that engage in climate planning, while vulnerable cities and those at risk of severe climate impacts in the future are less active.

The main findings of Reckien et al. (2018) are:

- (I) **The existence of national regulation has a significant impact on local climate planning**. Countries with national climate legislation, such as Denmark, France, Slovakia, and the United Kingdom, are found to have nearly twice as many urban mitigation plans, and five times more likely to produce urban adaptation plans, than countries without such legislation.
- (II) In countries where autonomous LCPs are rare and cities are not required by national legislation to develop plans, **international networks, raise the awareness, build the capacity and**, often through EU-funded projects, provide the expertise and the funding necessary to develop LCPs.

- (III) **Size matters**. About 80% of the cities above 1 million inhabitants have mitigation and/or an adaptation plan.
- **(**IV) the drivers of LCPs in countries without national legislation to develop LCPs need further exploration.

Van der Heijden (2019) analyzed 260 papers published from 2009 to 2018. These publications identify a set of enabling factors as necessary (but not sufficient) for effective urban climate action. It concludes that there is a broad consensus in the literature that these enabling factors work in conjunction, and that there are likely to be different trajectories or pathways of interacting factors that lead to effective urban climate governance.

The most important of these enabling factors highlighted by Van der Heijden (2019) are also supported by other authors as Romero – Lankao et al. (2018), Castán Broto (2017), Aylett (2015), and Bulkeley & Kern (2006), as follows:

- **A supportive political and legal context:** The extent to which cities and those within them can govern climate action depends on, and is affected by, the regional and national political and legal context in which they are embedded.
- **Autonomy**: The effect to which cities and those within them can govern climate action also depends on their autonomy for taking urban climate action and governing local affairs. Romero – Lankao et al. (2018) agree with this view saying that urban transformations depend on who has power to act.
- **Access to funding for climate action:** The extent to which cities have access to funding for climate action is generally considered another condition that is relevant for urban climate governance. National financial support for local initiatives is often limited, and cities generally cannot acquire money in the

same ways as national governments: they lack creditworthiness in international financial markets, they do not have the authority to borrow funds independently, and they face restrictive requirements for bidding and procurement.

- **Vertical coordination**: literature (Romero-Lankao et al., 2018; Castán Broto, 2017; Bulkeley & Kern, 2006) understands that successful cities do not act in isolation. Being embedded in multi-level networks that ensure vertical coordination between a city government, the regional government, and the national government is considered key in creating a supportive context for urban governance for climate action. It is then argued that climate action is linked to local, regional, national, and international actors and issues, and needs support from, and an understanding of, all these levels to be effective.
- **Horizontal coordination:** In a similar vein, horizontal coordination is also considered a relevant condition in urban climate governance trajectories that spur on climate action. Coordination across different departments, agencies and organizations within a city is considered relevant. A dedicated climate action body, agency, or working group at city level may then help traditionally organized departments to break out of these siloes and achieve synergies. Aylett (2015) is more focused on this coordination when analyzing institutional networks of governance that local governments are creating to carry out their work on climate change adaptation.
- **Being part of capacity-building networks**: Evidence has emerged that participation in city networks positively influences urban climate governance at city level. Collaboration between governmental and non-governmental actors and the participation of a wide range of stakeholders will improve the

outcomes of urban climate governance. This factor was highlighted by several authors (as Reckien et al., 2018; Castán Broto, 2017; Bulkeley & Kern, 2006)

- **Presence of a local climate champion:** Mayors and other urban political leaders are often looked upon as precondition for effective urban climate governance. Vocal, charismatic, and experienced city leaders may be able to find connections with other cities and build networks that reach beyond national borders.

A summary of the main potential drivers for climate action identified in the literature, which mainly includes studies of cities located in developed countries is presented in Table 10.

Driver	**Description**	**References**
Access to funding for climate action	• Some cities suffer from a lack of creditworthiness in international financial markets and limited national financial support. • Cities do not have the autonomy to borrow funds and face restrictions when it comes to bidding and procurement. • According to the literature, access to funding for climate action is relevant to urban climate governance.	Van der Heijden (2019); Castán Broto (2017); Aylett, (2015), Bulkeley & Kern (2006).
Committed leadership	• Political will and commitment among city mayors and other urban political leaders are both considered to be essential elements of effective urban climate governance. • Climate engaged leaders are more likely to seek connections with other cities and establish networks beyond national borders.	Van der Heijden (2019); Reckien et al. (2015); Castán Broto (2017); Bulkeley & Kern (2006).
Member of one or more international networks	• Being part of one or more city networks positively influences urban climate governance at the city level. • Climate networks foster capacity building, information exchange and access to financial and political resources.	Van der Heijden (2019); Reckien et al. (2018); Castán Broto (2017); Bulkeley & Kern (2006).

Driver	Description	References
Multilevel Governance	• Local governments of cities that successfully implement climate actions do not do so in isolation, but rather count on other urban actors to also lead and deliver climate actions. • Multilevel climate governance is key to creating a supportive context for climate action. • Both vertical coordination, between cities and their regional and national governments, and horizontal coordination, across different local government departments and, when possible, a dedicated city-level climate action agency or working group, are considered fundamental to effective climate governance at the local level	Van der Heijden (2019); Reckien et al. (2015); Romero-Lankao et al. (2018); Castán Broto (2017); Bulkeley & Kern (2006).
A supportive political and legal context	• The extent to which cities and their residents can govern climate action depends on, and is affected by, the regional and national political and legal contexts in which they are embedded.	Van der Heijden (2019); Reckien et al. (2015; 2018); Castán Broto (2017).
Autonomy	• The city must have the power to act and the autonomy to take urban climate action.	Van der Heijden (2019); Romero-Lankao et al. (2018).
Climate risk[12]	• Climate risk or climate vulnerability is the propensity or pre-disposition to be adversely affected by climate change. It is related to the degree of past, current, or future susceptibility of people or systems to climate change.	Reckien et al. (2015; 2018); Castán Broto (2017).

Table 10: The most important drivers of climate action identified in previous literature

While drivers can accelerate local climate action, their absence can become a barrier for climate agenda development in cities. Reckien et al. (2015) defines barriers as obstacles that can be overcome with concerted effort, creative management, change of thinking, prioritization, and related shifts in resources, land uses, and institutions.

[12]It is cited in the literature. However, Reckien et al. (2015) found that this is not an important driver for European cities.

Different barriers can affect the ability of local governments to design and implement local climate strategies. Overcoming obstacles requires sufficient political will, social support, resources, and effort

Some studies have discussed specific barriers to local climate action. Aylett (2015) analyzed 236 ICLEI member cities worldwide and found the main barriers: a lack of funding for implementation; competing priorities, such as health, housing, sanitation, and economic growth; a lack of funding to hire sufficient staff; a lack of staff time; difficulty factoring climate change into infrastructure budgeting procedures and challenges resulting from a political focus on short-term goals. In the area of information and awareness, the most significant challenges were: (I) a lack of understanding of how local governments can address the issue of climate change and (II) of the local impacts and relevance of the issue.

Reckien et al. (2015) took a statistical approach to analyze 200 large and medium-sized cities across 11 European countries. According to them, less is known about the influence of socio-economic factors on local climate change planning and policy. However, this study found unemployment rate as one significant barrier to climate action along with warmer summers, proximity to the coast and projected exposure to future climate impacts.

Romero-Lankao (2007) showed that climate policymaking in Mexico City has been constrained by some institutional factors, as (I) lack sufficient and adequate personnel with the technical knowledge to monitor emissions and see that standards are met; (II) authorities' lack of both a culture of cooperation and a common and broadly shared metropolitan vision; and (III) the intergovernmental inability to: (a) ensure participation of key actors; (b) provide stable rules and financial provisions to assure intergovernmental collaboration; and (c) allocate responsibilities and provide sufficient authority to coordinating organizations. The IPCC (2014) highlighted institutional, legal, financial, and cultural barriers, as well as administrative and political ones as an obstacle to climate action.

The main barriers to climate action identified in the literature are presented in Table 11.

Barrier	Definition	References
Lack of funding	• A lack of funding is considered one of the most important barriers to climate action. • In a context of scarce resources, competing priorities, such as healthcare, housing, sanitation, public security, and economic growth, can challenge climate action.	Van der Heijden (2019); Castán Broto (2017); Aylett (2015); Reckien et al. (2015); Bulkeley & Kern (2006).
Lack of local political leadership	• Weak leadership can undermine the capacity and willingness to implement effective climate actions. • The focus of political leaders on short term goals is also considered to be important barrier to climate action.	Aylett (2015); Reckien et al. (2015).
Lack of horizontal coordination among municipal agencies/departments and vertical coordination between local and sub-national and national level governments.	• Among the literature, the difficulty to mainstream climate change into existing departmental functions and implement policies that require collaboration between siloed local government agencies has been recognized as a barrier to climate action. • When it comes to certain key policy areas in which local governments lack jurisdiction over, they are required to cooperate with sub-national and national level governments. The intergovernmental inability and incapacity to cooperate at the vertical	Van der Heijden (2019); Reckien et al. (2018); Romero-Lankao et al. (2018); Castán Broto (2017); Aylett (2015); Romero-Lankao (2007); Bulkeley & Kern (2006).

Barrier	Definition	References
	level has been identified in previous studies to be an important barrier to climate action.	
Lack of information on the likely local impacts of climate change	• Some cities have no knowledge of the likely local impacts of climate change. Thus, they do not plan or take actions to mitigate and adapt to it. This lack of information has also been identified in the literature as a barrier to climate action.	Castán Broto (2017); Reckien et al. (2015); Aylett (2015).

Table 11: Most common barriers to local climate action, as identified in previous literature.

Academic studies about drivers and barriers to climate change consider mostly the reality of global North cities. Searching for studies focusing specifically on Latin America reality, few exceptions were found on international databases (e.g. Romero Lankao. 2017; Macedo & Jacobi, 2019). Romero Lankao (2007) explored institutional factors which has constrained policymaking in Mexico City. Macedo & Jacobi (2019) assessed the role of subnational governments and networks using concepts from International Relations discipline (Multiple Level Governance; Paradiplomacy). Authors used two Brazilian cities as case studies (Belo Horizonte and São Paulo) and found that policy implementation is still in its early stages, and GHG emissions inventories so far do not provide evidence of their effectiveness in terms of GHG reductions for these cities.

3. THESIS ARTICLES

This section presents the four articles that compose the thesis. Articles are presented exactly as they were either published (papers 1 and 3) or submitted to journals (papers 2 and 4). Therefore, the numbering of the tables and sections of the articles preserves the publication numbering. Otherwise, it would require texts adaptation. The bibliographic references of each article are presented in each Section to maintain the completeness of each article.

3.1 Article 1: Carbon accounting approaches and reporting gaps in urban emissions: an analysis of the greenhouse gas inventories and climate action plans in Brazilian cities

Carbon accounting approaches and reporting gaps in urban emissions: an analysis of the greenhouse gas inventories and climate action plans in Brazilian cities

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Abstract

This paper analyzes the differences among the main existing carbon accounting methodologies for cities and identifies the shortcomings in carbon inventories typically used. Data were collected from the GHG inventories and climate action plans from 24 Brazilian cities using content analysis. All cities developed their GHG inventories using Production-Based Approach (PBA), adding at least electricity and waste emissions that occurred out-boundaries. Several gaps were identified in the cities' greenhouse (GHG) emissions inventories that consequently impacted their climate action plans. Two main types of reporting gaps were identified: incompleteness (Gap 1) and lack of transparency (Gap 2). Seventeen GHG reports presented Gap 1. Brazilian cities' GHG reports do not appropriately reflect emissions occurring as a result of activities and consumption patterns of the city. Twenty reports presented Gap 2 with no transparency about assumptions, input data, source of input data, emission factors, calculation methods or accounting limitations. Sixteen cities measured only (I) stationary energy, including electricity imported by the grid; (II) transport; and (III) waste. Four cities reported also Industrial Process and Product Use (IPPU) emissions and seven, reported Agriculture, Forestry and other Land Use (AFOLU) emissions/removals. Brazilian cities did not measure GHG emissions related to consumption of foods, beverages and imports of manufactured products. As a result, no climate action plan considers actions towards sustainable consumption. The study provides insights for academics and policymakers on how to choose the best methodology and develop more complete inventories and low-carbon plans.

Key Words: Carbon accounting for cities; Carbon accounting approaches; Consumption-based carbon accounting; Production-based carbon accounting; GHG emissions inventories gaps, Climate action plans.

1. Introduction

Several studies show that the approach used in the accounting of Greenhouse Gases (GHG) can significantly impact the results of the GHG inventory in cities (e.g. Sudmant et al., 2018; Andrade et al., 2018). Depending on the carbon accounting approach adopted, some GHG emission sources may be neglected or underestimated. Thus, the accounting method shapes the provision of the information, and consequently may limit public policies to combat climate change (Harris et al., 2012).

Existing studies have suggested that, depending on the economic profile of the city, the results of consumption-based emissions inventories (CBA) can be much larger than those of production-based approach (PBA) inventories (e.g. Sudmant et al., 2018; Andrade et al., 2018). There are authors that support the use of CBA approach (Dodman, 2009; Harris et al., 2012; Lombardi et al., 2017; Andrade et al., 2018), while others argue that PBA should continue to be the standard given the uncertainties, technical difficulties and lack of data required to reliably use the CBA approach (Peters, 2008; Afionis et al., 2017; Franzen & Mader, 2018).

Several authors discuss the impact of the carbon accounting approach on GHG results (e.g. Dodman, 2009; Harris et al., 2012; Lombardi et al., 2017; Sudmant et al., 2018; Andrade et al., 2018). Some recent research also proposes methods to improve the comprehensiveness and accuracy of carbon accounting for cities (Li et al., 2017a; Liao et al., 2017; Shan et al., 2017; Cai et al., 2018; Ottelin et al. 2018; Mi et al. 2019).

Emissions data based on inventories are foundations of climate change mitigation research and actions. However, studies focusing on the quality analysis of cities GHG reports are rare. It was not found in the literature any paper that specifically analyzes the gaps of the cities GHG accounting reports (hereafter referred as "gaps") and their climate action plans.

According to Li et al. (2017b), research and practices related to city-level GHG inventories are relatively limited, especially in developing countries. Castán Broto & Bulkeley (2012) and Van der Heijden (2019) also mention that existing literature about cities responses to climate change is focused on individual case studies or small set of cities in more economically developed countries.

Brazil is one of the world's largest economies and one of the top ten highest GHG emitters in the world (Carbon Brief, 2018) providing a good case to examine the kind of methodologies used by cities and the shortcomings of their reports. It is a highly urbanized country with more than 85% of its population living in cities. Twenty-four Brazilian cities have already developed GHG inventories representing 27.4% of Brazilian GDP and almost 20% of Brazilian population (more than 40 million people). The understanding of how Brazilian cities measure GHG emissions and their GHG reports gaps can bring lessons to improve the way cities collect GHG information and increase the quality of climate action plans.

This paper has some objectives both to fill the gaps in the scientific literature and provide useful guidance for practice. Firstly, it intends to contribute to the literature in comparing the different GHG methodologies for cities in terms of coverage, efforts and usage. Secondly, the study identifies the main shortcomings of the GHG inventories in terms of quality and gaps (Mi et al., 2019; Mia et al., 2019) by assessing the inventories developed by Brazilian cities. Thirdly, the study analyzes how cities in the most populous country and largest economy of Latin America are combating climate change. Finally, the paper proposes some actions policy makers can take in order to overcome these gaps and improve the quality of the cities GHG inventories and climate plans contributing to the academic efforts to reduce uncertainties in cities emission inventories (Mi et al., 2019). This helps to broaden the scope of existing examples, mostly from developed countries as pointed out by the literature (Castán Broto & Bulkeley, 2012). The research also advances the way they can develop broader and more complete GHG inventories that may lead to more effective low-carbon plans, as well as make the city population aware of the importance of their production and consumption choices in relation to the climate.

2. Materials & Methods

A literature review was carried out and empirical data were obtained from documents issued by Brazilian cities and other secondary sources in 2018 and 2019. Even though no questionnaire was applied, the authors contacted the Latin American Secretariat of Local Government for Sustainability (ICLEI) by phone and e-mail to collect all GHG inventories of its members cities in Brazil in 2018.

Brazil is a good case to advance the literature on carbon inventories in cities in order to overcome the bias of previous studies towards developed countries (Castán Broto & Bulkeley, 2012). As a developing country, Brazil is one of the world's leading GHG emitter and the most populous and largest economy of Latin America.

ICLEI shared all GHG reports of Brazilian cities that developed their GHG inventory with ICLEI support. Once the reports were analyzed, the researchers contacted the Carbon Disclosure Project (CDP) - Latin America to collect data Brazilian cities submitted to CDP Cities and States & Region - Latin America. CDP is a platform cities can report their emissions inventories. The manager of the CDP Cities and States & Region - Latin America provided access to answers that had been provided by Brazilian cities to CDP. Through this platform, researchers could find more detailed information about the GHG accounting of Brazilian cities and emission reduction plans. All information provided by Brazilian cities to the public platform Carbonn Climate Registry[13] was also collected and analyzed.

From 18 GHG inventories[14], 12 are open to the public. Two reports were shared by ICLEI with researchers (Porto Alegre and Betim). Three (Vitória, Niterói and Goiânia) were obtained through CDP and one (Duque de Caxias) was publicly available at the beginning of the research, but not anymore. All five climate action plans analyzed are publicly available.

The research team then carried out a content analysis of all GHG inventories and climate action plans developed by Brazilian cities. Based on the information from (I) the GHG inventories, (II) answers from Brazilian cities to CDP and (III) data supplied from Brazilian cities to Carbonn Climate Registry, it was possible to identify: (I) Carbon accounting approach followed by each Brazilian city and (II) sectors and emission sources included in GHG reports. Finally, we identified the gaps and limitations of each GHG inventory and classified the different kinds of gaps.

3. Theory: Literature Review of Carbon Accounting in Cities

3.1 PBA versus CBA

Existing GHG carbon accounting methodologies have two basic distinct approaches: the production-based approach (PBA) and the consumption-based approach

[13] http://carbonn.org/
[14] ABC Region GHG Report comprises 7 cities.

(CBA). While the former allocates GHG emissions to where they are generated in the production processes, the latter allocates the emissions to the final consumer.

Several studies show that the GHG accounting approach can significantly impact its GHG inventory results (Sudmant et al., 2018; Athanassiadis et al., 2018). Studies applying different approaches to GHG emissions inventories of New York, Paris and Shanghai found divergent results (Ibrahim et al., 2012). Other efforts also reached the same conclusion for London and Madrid (Andrade et al., 2018), Hong Kong (Harris et al. 2012) and 45 urban areas in China, the U.K. and the U.S. (Sudmant et al., 2018). Recently, several studies have discussed the impact of these methodologies on city-level carbon inventories and sub-national climate action plans (e.g. Larsen & Hertwich, 2010*;*Harris et al., 2012; Dahal & Niemala, 2017; Sudmant et al., 2018; Andrade et al., 2018; Athanassiadis et al., 2018).

Lombardi et al. (2017) define PBA as the methodology that includes all emissions from economic activities by resident companies and households. The PBA considers embodied emissions derived from the export city's activities. It assigns responsibility for emissions at the point where the emissions are produced.

Alternately, CBA measures the carbon emissions associated with the final consumption of goods and services. GHG emissions are calculated by subtracting the emissions associated with exported goods and services from PBA and adding those generated to produce imported goods and services (Grasso, 2016; 2017; Andrade et al., 2018; Sudmant et al., 2018). The CBA consists of emissions generated from the consumption of goods and services within an area regardless of where emissions from production of such goods and services have happened (Dahal & Niemelä, 2017). Therefore, this method includes emission sources that are beyond the boundary of the city

(Lombardi et al., 2017). Example of estimations using CBA approach include Ottelin et al. (2018) and Liao et al. (2017). The first mapped consumption-based household carbon footprints to estimate carbon emissions of urban zones within Helsinki Metropolitan Area. The latter used an input-output model to measure the economic contribution of sectors and households to CO_2 emissions of Beijing.

Although the PBA is the most commonly used approach by cities around the world, several authors defend the CBA methodology. Both approaches have positive and negative aspects (see in Table 1). The key advantages of CBA include (I) eliminating carbon leakage, (II) covering more emissions, (III) consistency between consumption and environmental impacts and (IV) increasing mitigation options (Peters, 2008; Afinois et al., 2017; Andrade et al., 2018). Several authors agree that it is technically more difficult and uncertain to use CBA instead of PBA (Peters, 2008; Grasso, 2016; Franzen & Mader, 2018; Sudmant et al., 2018). CBA method requires more complex calculations, assumptions, and estimations (Peters, 2008; Dodman, 2009; Afionis et al., 2017), while the PBA is much closer to the statistical sources. It includes domestic activities and is more consistent with the concept of gross domestic product (GDP) (Peters, 2008).

However, the two methodologies are not competing; rather, they are complementary. Ibrahim (et al., 2012), Lombardi et al. (2017), Andrade et al. (2018) and Athanassiadis et al. (2018) agree that a combination of these methods can be used. This combination would measure GHGs within city boundaries, plus indirect emissions deriving from infrastructure and non-infrastructure supply chains that serve the entire community.

Table 1: Main Advantages and Disadvantages of Each GHG Accounting Approach

GHG Accounting Approach	**Advantages**	**Disadvantages**	**References**
PBA	-Established reporting and widespread use; - Information used is closer to statistical sources; - Straightforward calculations; - Less uncertainty; -Consistency with political and environmental boundaries; - Government has more easily the authority to implement policies over the emissions.	- Coverage of only emissions generated inside the territory; - Lack consideration of emissions related to imported products and goods; - Motivation for carbon leakage; - Guiding ineffective mitigation policies.	Peters (2008); Dodman (2009); Grasso (2016); Afionis et al. (2017); Franzen & Mader (2018)
CBA	- Elimination of carbon leakage; - Coverage of emissions related to (I) imported products, materials, goods and services and (II) logistics of consumed products, materials and goods; -Consistency between consumption and environmental impacts; - Responsibility and fairness over consumption; - More precise diagnosis about the main emission sources of the cities; - Highlighting the impacts of a consumption lifestyle.	- Increase uncertainties; - Technical complexity; - Wider range of goods and services across the economy and across the borders should be considered; - Mitigation options can require political decisions outside the administrative boundaries and political influence.	Peters (2008); Dodman (2009); Larsen & Hertwich (2010); Grasso (2016); Afionis et al. (2017); Franzen & Mader (2018); Sudmant et al. (2018); Andrade et al. (2018)

Source: Developed by the authors

Some recent publications have proposed ways for constructing GHG emissions for cities using a combination of both approaches. Shan et al. (2017) proposes a PBA approach that estimates GHG emissions from Chinese cities through energy balance table. Li et al. (2017a) suggests a PBA approach by using sampling surveys, enterprise GHG reports and the spatial distributions. Cai et al. (2018) estimated emissions, using a PBA approach, establishing high spatial resolution dataset of CO_2 emissions of 286 Chinese prefecture-level cities in 2012.

Uncertainties of GHG inventories are high. Mi et al. (2019) argue that efforts are needed to reduce those uncertainties. Li et al. (2017b) mentioned problems in the Chinese cities inventories as incompleteness due to data unavailability, reporting problems and inconsistencies between the framework and the contents of the inventories. Andrade et al. (2018) mentions important sources of uncertainties associated to the Madrid's GHG emissions inventory as lack of disaggregated and high-quality data at a local scale.

Emission data are fundamental for guiding climate change mitigation research and actions. Although several papers provide methods to improve the comprehensiveness and accuracy of carbon accounting in cities, there are still uncertainties in these inventories. However, little effort has been made to identify and classify the gaps in a comprehensive manner based on the existing inventories and plans. The lack of consistent and comparable GHG emissions data at the city level is one of the four remaining gaps in the urban climate actions research area (Mi et al., 2019).

The only study found that explores the quality of GHG disclosures by cities is Mia et al. (2019). Their paper highlights that prior studies predominantly focused on corporate-level GHG disclosure and that there has been limited research, exploring cities' GHG disclosure. The manuscript then analyzes GHG disclosure of 42 cities published on CDP platform through the expectation gap framework. This paper is focused on reports of cities from C-40 international network and just discusses data provided by CDP. Details of cities GHG reports documents are not analyzed.

Castán Broto & Bulkeley (2012) says that research about cities responses to climate change has mainly focused on case studies or small sets of cities with a focus on members of specific transnational networks or early city pioneers. Van der Heijden (2019) also concluded that the empirical urban climate governance literature is still dominated by studies (and scholars) from the Global North, and it is still dominated by single-n and small-n studies. This fact has created a geographical bias towards cities in more economically developed countries.

3.2 Frameworks and Protocols

All GHG quantification protocols for cities derive their approaches and methodologies from 2006 IPCC guidelines (Andrade et al., 2018), which is based on the PBA approach. This methodology measures GHG emissions combining information of economic activity (called activity data, AD) (e.g., electricity and fossil fuel consumed) with coefficients that quantify the related emissions or removals per unit of activity (called emission factors, EF). GHG emissions are, therefore, calculated as follows:

Math Formulae 1: GHG Emissions = $\Sigma\, AD_i \times EF_i$ *for each activity i.*

This method requires the reporting of direct emissions from sectors and subsectors and can also be applied at districts within the city's boundaries. Emission sources are generally classified into four sectors: (i) energy, (ii) industrial process and product use (IPPU), (iii) waste, and (iv) agriculture, forestry, and other land use (AFOLU).

Cities have become the object of recently developed methodologies, such as PAS 2070:2013 (PAS 2070) (Andrade et al., 2018). PAS 2070 specifies requirements for the assessment of the GHG emissions of a city using two distinct methodologies: (I) a direct plus supply chain (PAS 2070-DPSC) methodology and (II) a CBA methodology (PAS 2070-CB).

PAS 2070-DPSC includes PBA emissions plus emissions associated with the largest supply chains serving the cities, including water supply, food and drink, and construction materials, specifically cement and steel. PAS 2070-CB captures lifecycle GHG emissions for all goods and services consumed by the city. The PAS 2070-CB methodology sets out an approach to calculate the GHG emissions linked to global and national supply chains with the use of environmentally extended input output (EEIO) matrices.

Another protocol is the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC), developed by a partnership between the World Resources Institute (WRI), the Local Governments for Sustainability (ICLEI) and the Cities Climate Leadership Group (C40) in 2014. The GPC requires cities to measure and disclose a GHG inventory using both production and consumption activities within the city boundary. It includes some emissions released outside the city boundary. It categorizes all emissions into 3 “scopes”, depending on where they physically occur (WRI, 2014), as follows:

- Scope 1: GHG emissions from sources located within the city boundary.
- Scope 2: GHG emissions from using grid-supplied electricity, heat, steam and/or cooling within the city boundary.
- Scope 3: All other GHG emissions that occur outside the city boundary.

GHG emissions from city activities shall be classified into six main sectors according to the GPC: (I) Stationary Energy; (II) Transportation; (III) Waste; (IV) Industrial Processes and Product Use (IPPU); (V) Agriculture, Forest and other Land Use (AFOLU) and (VI) Any other emissions occurring outside the geographic boundary as a result of city activities may be reported separately (WRI, 2014). These sectors are broken down by subsectors. Table 2 summarizes main carbon accounting protocols.

Table 2: Characteristics of carbon accounting frameworks

Characteristics	**Carbon Accounting Frameworks**			
	IPCC	**GPC**	**PAS 2070-DPSC**	**PAS 2070-CB**
Carbon Accounting Approach	PBA	PBA	PBA + largest supply chains	CBA
Sectoral division	Energy (including Transportation), Waste, IPPU and AFOLU	Stationary Energy; Transportation; Waste; IPPU; AFOLU and Other emissions out-boundary	Stationary Energy; Transportation; Waste; IPPU; AFOLU and Goods and Services	Food and Drink; Utility Services; Household; Transport Services; Private Services; Other Good and Services
Emission Subdivision by scopes	No	Yes	Yes	No

Source: Developed by the authors

4. Results and Discussions

4.1 Reports and Methodologies Used

Twenty-four cities reported their GHG inventories using the Carbonn Climate Registry or CDP databases (17 cities plus the ABC region, see Table 3) by may/2019. These 24 cities represent 27.4% of the Brazilian GDP and account for almost 40 million people, which is 19.7% of the country's population. These cities are located in 12 Brazil states (see figure 1). Twelve cities are capitals of their states (i.e., Vitória, João Pessoa, Palmas, Recife, Goiânia, Fortaleza, Salvador, Porto Alegre, Curitiba, Belo Horizonte, Rio de Janeiro and São Paulo) and seven form the ABC region, which are part of the metropolitan area of the city of São Paulo: Diadema, Mauá, Ribeirão Pires, Rio Grande da Serra, Santo André, São Bernardo do Campo and São Caetano do Sul.

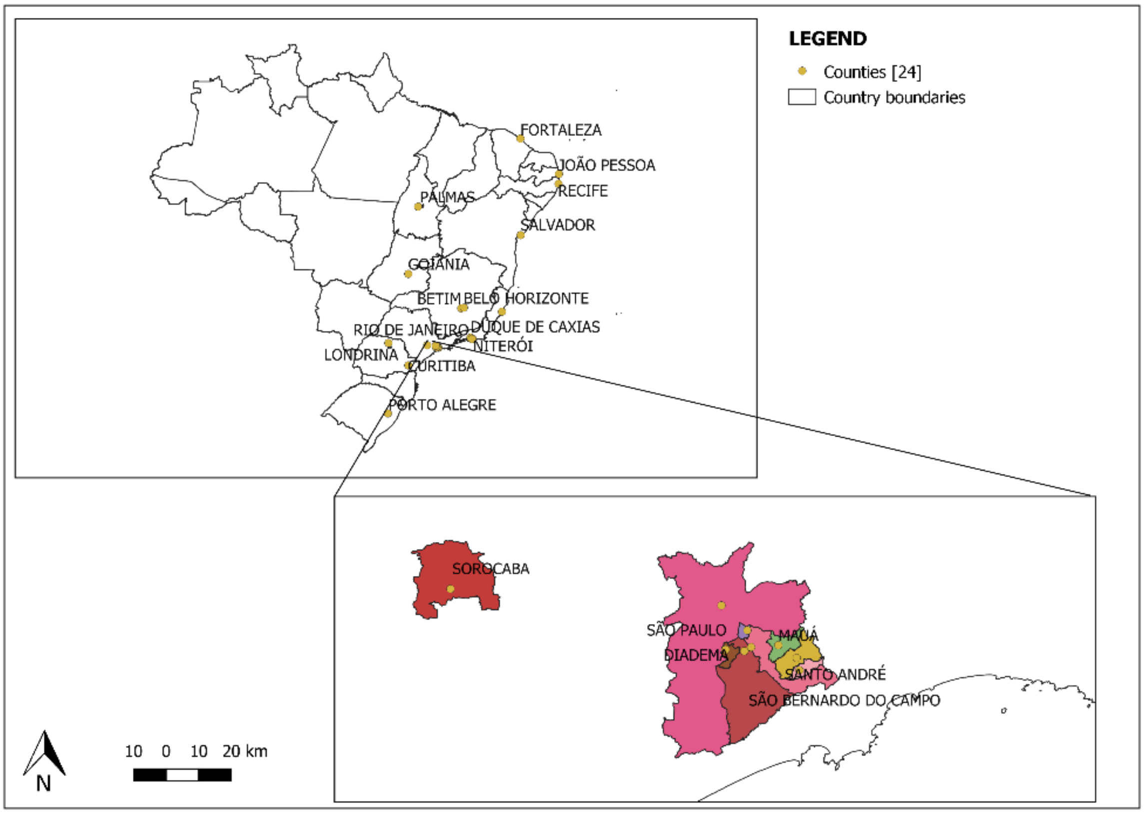

Figure 1 – Brazilian cities that developed the GHG inventory

Source: Developed by the authors

Figure 2 shows the GDP distribution by economic activity in each Brazilian city. There is a predominance of service activities, which vary between 52% and 88% of the GDP. Betim, Mauá and Diadema are the cities where industrial activities have higher GDP shares (48%, 38% and 34%, respectively). Agriculture and livestock are not relevant economic activities for any of the 24 cities.

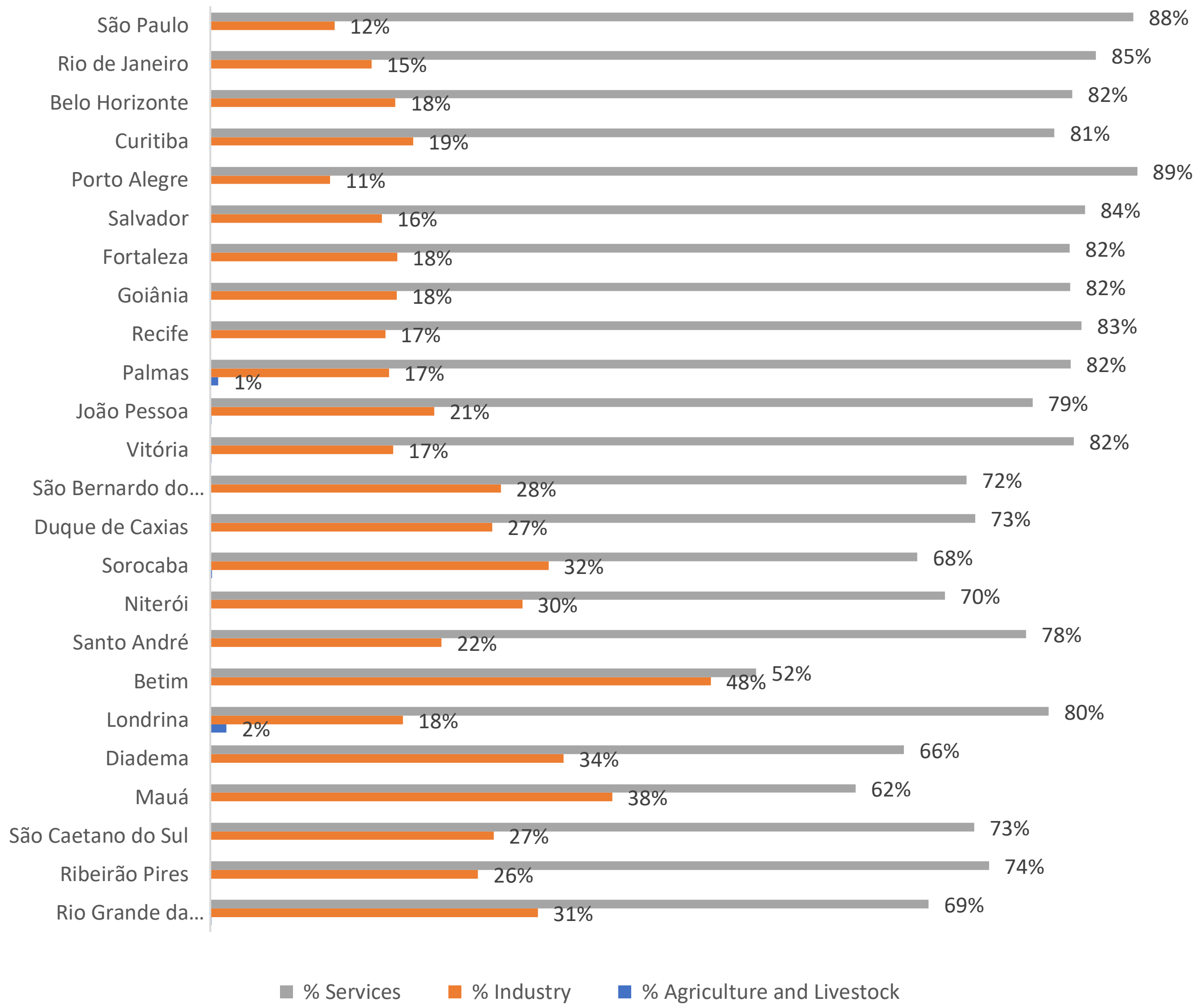

Figure 2 – GDP by Economic Activity (%)

Source: Developed by the authors from data of IBGE (2015)

Table 3 consolidates the accounting year, methodology used and GHG emissions results by scope according to GPC methodology of all cities. Nineteen cities used GPC methodology for their GHG inventories. Rio de Janeiro (Rio de Janeiro, 2015) and Goiânia (Goiânia, 2013) reported their GHG inventories using both GPC and IPCC methodologies.

Results of Belo Horizonte (Belo Horizonte, 2009), São Paulo (São Paulo, 2013) and Sorocaba (Sorocaba, 2014) followed IPCC, thus their emissions are not presented by scope. Londrina did not present their results by scope (Londrina, 2017), though its GHG inventories follow GPC. GHG Inventory Report for the ABC Region does not distribute emissions of each city per scope, just in the aggregate (Consórcio Intermunicipal do Grande ABC, 2017a).

Table 3: GHG Emissions by Scope Per City

City	BaseYear	Methodology	Total Emissions (tCO_2e)	Emissions - Scope 1 (tCO_2e)	Emissions - Scope 2 (tCO_2e)	Emissions - Scope 3 (tCO_2e)
ABC Region	2014	GPC	**9.879.437**	8.451.956	1.227.278	200.202
Belo Horizonte	2007	IPCC	**3.187.983**			
Betim	2013	GPC	**2.250.980**	1.394.960	856.020	
Curitiba	2013	GPC	**4.125.853**	2.686.651	349.791	1.089.411
Duque de Caxias	2014	GPC	**2.264.578**	2.001.034	263.543	244.277
Fortaleza	2012	GPC	**3.827.521**	2.162.866	213.992	1.450.663
Goiânia	2012	GPC and IPCC 2006	**2.686.640**	1.890.800	125.520	670.320
João Pessoa	2014	GPC	**2.837.499**	2.309.846	194.421	333.232
Londrina	2013	GPC	**1.105.964**			
Niterói	2015	GPC	**1.729.602**	1.134.408	164.574	430.620
Palmas	2013	GPC	**646.478**	589.055	36.336	21.087
Porto Alegre	2013	GPC	**2.829.128**	1.917.235	350.704	561.189
Recife	2015	GPC	**3.120.426**	1.687.504	203.869,	1.229.053
Rio de Janeiro	2012	GPC and IPCC 2006	**22.637.140**	19.344.810	1.413.430	1.563.040
Salvador	2013	GPC	**3.698.963**	3.242.166	366.395	90.402
São Paulo	2009	IPCC 2006	**15.115.000**			
Sorocaba	2012	IPCC 2006	**1.108.205**			
Vitória	2015	GPC	**2.798.291**	2.424.305	367.109	6.877

Source: Developed by the authors using data of GHG reports of the cities

4.2 Emission analysis

Content analyses of GHG Reports were carried out and Figure 3 shows the relevance of the scopes for each city. Emissions from scope 1 are the most relevant to all Brazilian cities in this study. Scope 1 covers emissions in-boundary related to stationary energy, transport, waste, IPPU and AFOLU.

All cities reported electricity consumed from the National Interconnected System by industries, residences, commercial and institutional buildings, independently of whether electricity generation occurred in their boundaries. These emissions are reported as scope 2. Most of the cities also reported some indirect emissions, which were mainly emissions related to waste disposal out boundaries and transport (e.g., air travel and maritime freight).

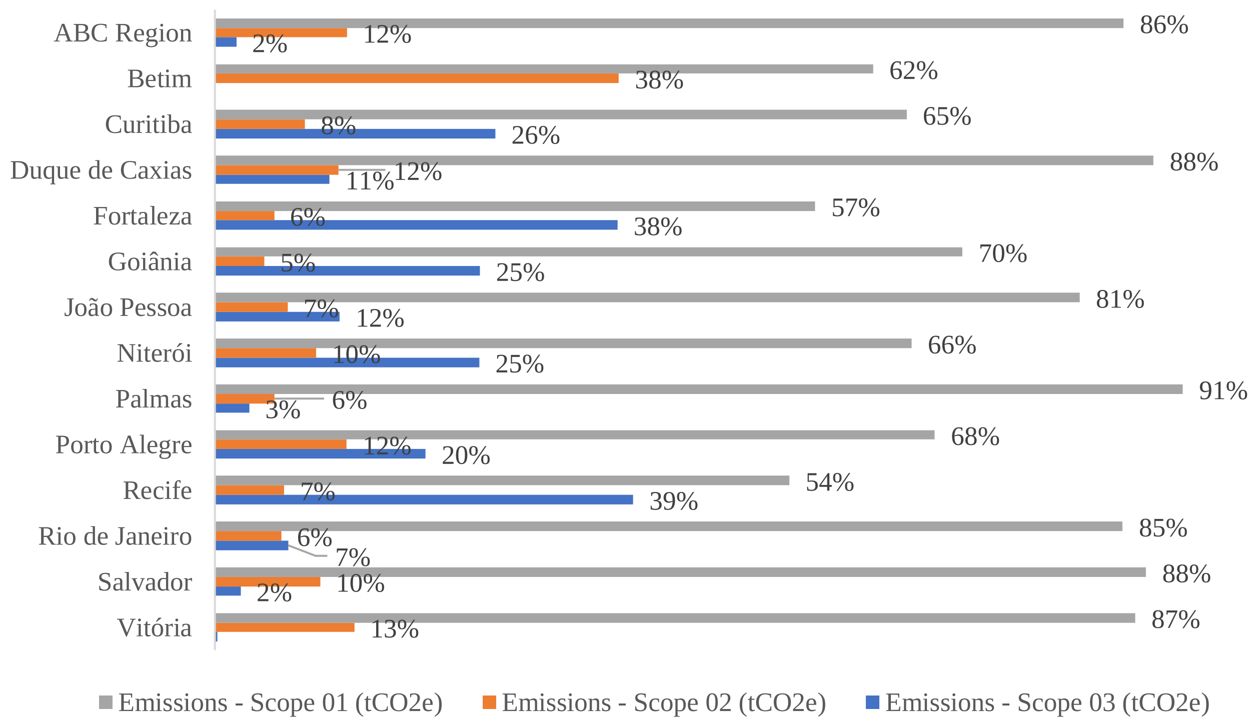

Figure 3 – GHG Emissions by Scope (%)

Source: Developed by the authors using data of GHG reports of the cities

Figure 4 shows GHG emissions by sector. All cities reported emissions related to (I) stationary energy, including electricity imported by the grid; (II) transport; and (III) waste. Sixteen cities reported only these three categories. Some did so because it was their first experience in conducting a GHG inventory (e.g., Recife, Fortaleza, ABC Region, Porto Alegre), while others (e.g., São Paulo) decided to focus on the main relevant emission sources, as suggested by the literature (Damsø et al., 2016; Li et al., 2017b)

Four cities reported IPPU (Duque de Caxias, Rio de Janeiro, São Paulo and Palmas), and seven cities (Duque de Caxias, Curitiba, Goiânia, Palmas, São Paulo, Sorocaba and Rio de Janeiro) reported AFOLU emissions/removals. Emissions related to consumption are just considered by Duque de Caxias (Duque de Caxias, 2016).

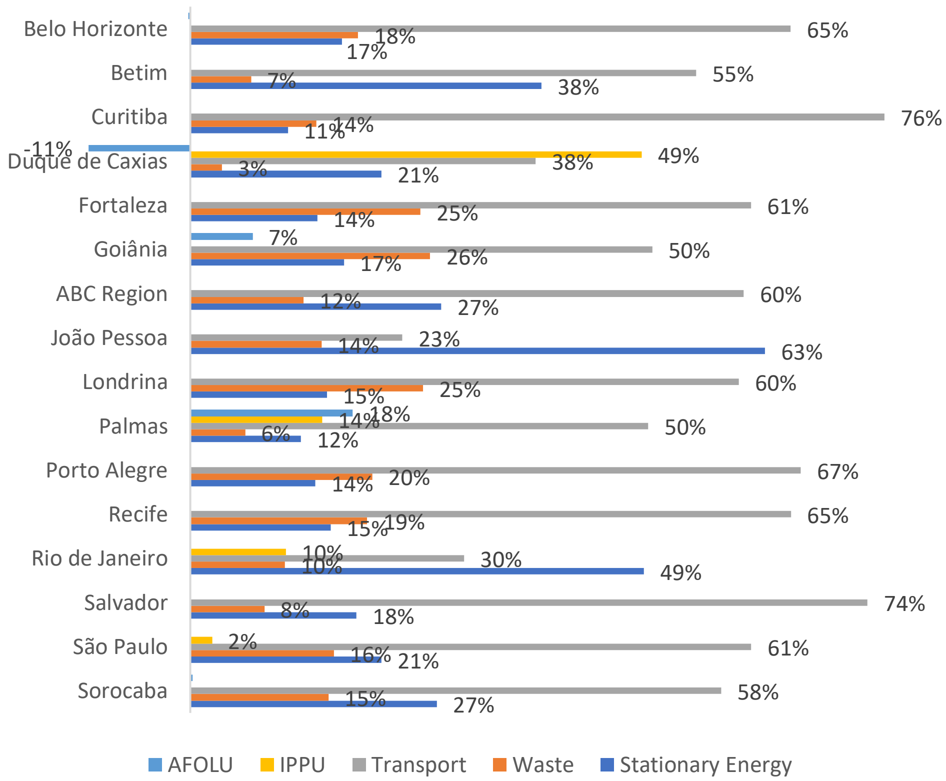

Figure 4 – GHG Emissions by Sector (%).

Source: Developed by the authors using data of GHG reports of the cities

As discussed in 4.2.2, transport is the most relevant GHG emission source. The only exceptions are Duque de Caixas, João Pessoa and Rio de Janeiro. When sub-sectors are analyzed, it can be seen differences between GHG emissions sources accounted by each city in the same sector, as detailed below.

4.2.1 Stationary Energy

Stationary energy includes emissions related to the generation of all energy sources for residential, commercial, and institutional buildings; manufacturing industries and construction, energy industries and agriculture, forestry, and fishing activities (WRI, 2014). There is a certain uniformity of stationary energy emission sources reported by Brazilian cities as showed by table 4.

Figure 5 shows stationary energy emissions for each city and its relevance for each city GHG inventory. Rio de Janeiro presents higher stationary energy emissions. These emissions are mainly related to energy consumption of three thermoelectric plants that generate electricity from fossil fuel (28%), industries (22%), residential buildings (16%) and commercial and institutional buildings (14%) (Rio de Janeiro, 2015).

São Paulo also shows relevant stationary emissions, mainly associated to (I) natural gas and liquified petroleum Gas (LPG) consumed by residential buildings (37%); (II) natural gas consumed by industries (23%) and (III) fuels used to generate electricity (20%) (São Paulo, 2013). Industries (65%) and residential buildings (21%) present the most relevant stationary emissions of the ABC Region. The most important fuels are Electricity (45%), LPG (13%) and Natural Gas (13%) (Consórcio Intermunicipal do Grande ABC, 2017a). João Pessoa presents important stationary emissions due to an oil power plant located in the city (72%) (João Pessoa, 2018) and Betim (Betim, 2016) shows relevant stationary emissions related just to electricity consumption, as discussed in table 4.

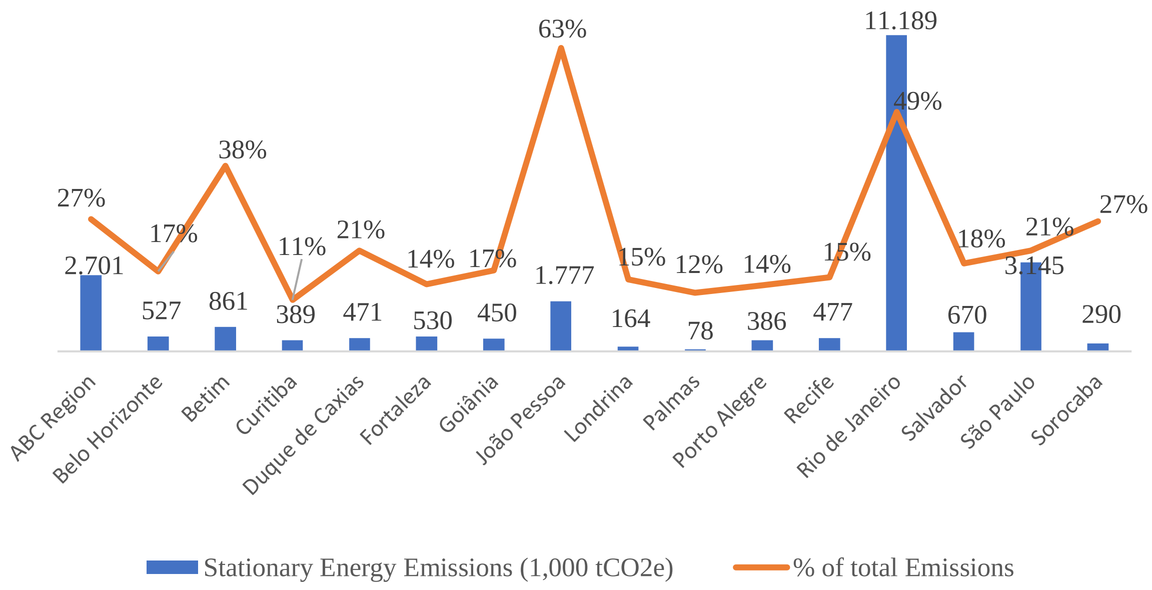

Figure 5 – Stationary Emissions by City (tCO2e).

Source: Developed by the authors using data of GHG reports of the cities

Emissions calculations were based on fuels sold inside the city to generate thermal energy and electricity consumed from the National Grid. When cities followed IPCC Guidelines (Belo Horizonte, 2009; São Paulo, 2013; Sorocaba, 2014; Rio de Janeiro, 2015; Duque de Caxias, 2016), Stationary, and Transportation were considered in the same sub-sector. When GPC was followed, these emissions sources were accounted individually.

4.2.2 Transport

The transport sector included transportation by on-road, off-road, railway, aviation, and waterborne navigation (WRI, 2014). When there was no airport or access to a sea/river, these emissions were not presented (e.g., ABC region Report). However, using a CBA approach, even for cities where there is no airport or port, emissions associated to air travel and maritime transportation of products consumed by its population should be accounted.

In general, these emissions were calculated considering fuels sold inside the cities' boundaries (e.g., Sorocaba, 2014; Recife, 2015; Curitiba, 2016; Consórcio Intermunicipal do Grande ABC, 2017a).

Emissions from transport are the most important GHG source for almost all cities. The only exceptions are (I) Duque de Caixas, where IPPU emissions are the most relevant (Duque de Caxias, 2016), (II) João Pessoa (João Pessoa, 2018) and (III) Rio de Janeiro (Rio de Janeiro,2015), where stationary emissions have the highest numbers. Figure 6 shows transport emissions and its relevance for each GHG inventory.

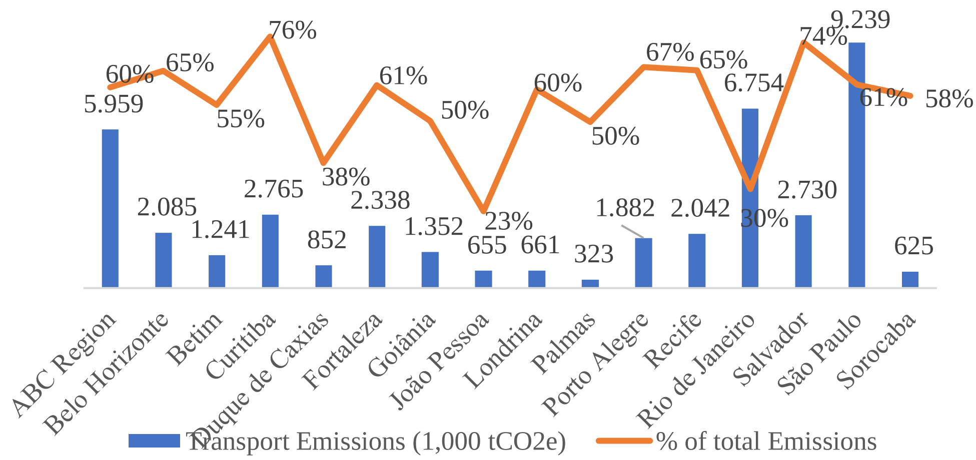

Figure 6 – Transport Emissions by City (tCO_2e).

Source: Developed by the authors using data of GHG reports of the cities

São Paulo, Rio de Janeiro and ABC Region present the highest transport emissions numbers. São Paulo and Rio de Janeiro are the cities with highest population and vehicle fleet. Diesel consumed by trucks are the most important transport emission source in ABC Region (Consórcio Intermunicipal do Grande ABC, 2017a).

4.2.3 IPPU - Industrial Process and Product Use

São Paulo, Rio de Janeiro, Duque de Caxias and Palmas are the only cities that accounted IPPU emissions. In Duque de Caixas (Duque de Caxias, 2016), IPPU emissions are related to emissions from the Duque de Caxias Petroleum Refinery. Emissions from cement and steel production were also considered in this category, although production plants were not located in the city. This city also estimated emissions from using refrigerators, foams, aerosols and air conditioners.

In Rio de Janeiro (Rio de Janeiro, 2015), it was reported leakage emissions presented in glass, methanol and steel production. Emissions related to the use of lubricants and greases were also considered. São Paulo (São Paulo, 2013) also reported emissions leakage occurred due to glass production and lubricants and greases use in addition to the use of substances that cause ozone layer depletion. Palmas (Palmas, 2017) did not detail information about IPPU emissions sources measured. Figure 7 shows IPPU emissions by city.

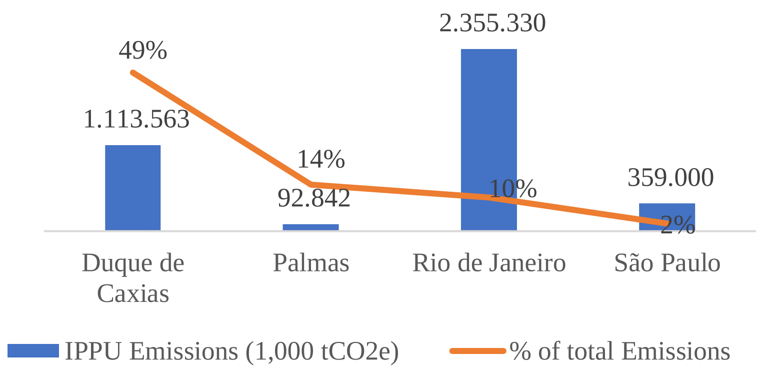

Figure 7 –IPPU Emissions by City (tCO2e).

Source: Developed by the authors using data of GHG reports of the cities

4.2.4 Waste

Waste emissions covered emissions associated with waste management, independent of whether these practices occurred in-boundary or out-boundary (WRI, 2014). All cities measured in-boundary waste emissions. Only three cities – Palmas (Palmas, 2017), Rio de Janeiro (Rio de Janeiro, 2011) and São Paulo (São Paulo, 2013) considered all practices of waste management. The main gap is the biological treatment of waste that was just considered by these cities. Incineration was either not always accounted, thus only nine cities reported, as discussed in table 4. As the largest cities in the group, Rio de Janeiro and São Paulo present the highest emissions from waste as shown in figure 8. Goiânia (Goiânia, 2013), Fortaleza (Fortaleza, 2016a) and Londrina (Londrina, 2017) are the cities where waste emissions are the most relevant.

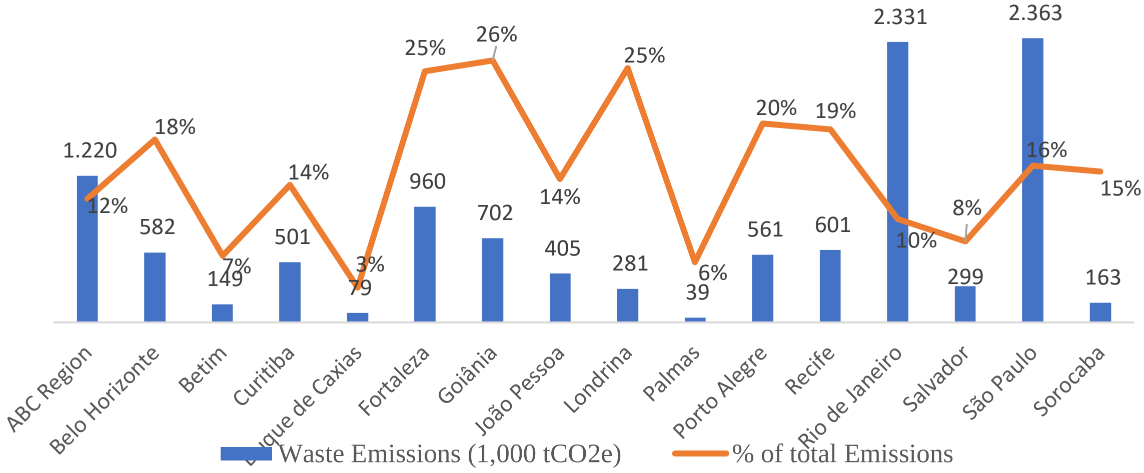

Figure 8 –Waste Emissions by City (tCO2e).

Source: Developed by the authors using data of GHG reports of the cities

4.2.5 AFOLU - Agriculture, Forestry, and Other Land Use

AFOLU emissions and removals included agriculture, forestry and other land use. In Palmas (Palmas, 2017) and Goiania (Goiania, 2013), AFOLU showed some relevance due to urban pressures over green areas and livestock activities. In Duque de Caxias (Duque de Caxias, 2016), the carbon capture by green areas produced relevant carbon removals as presented in figure 9.

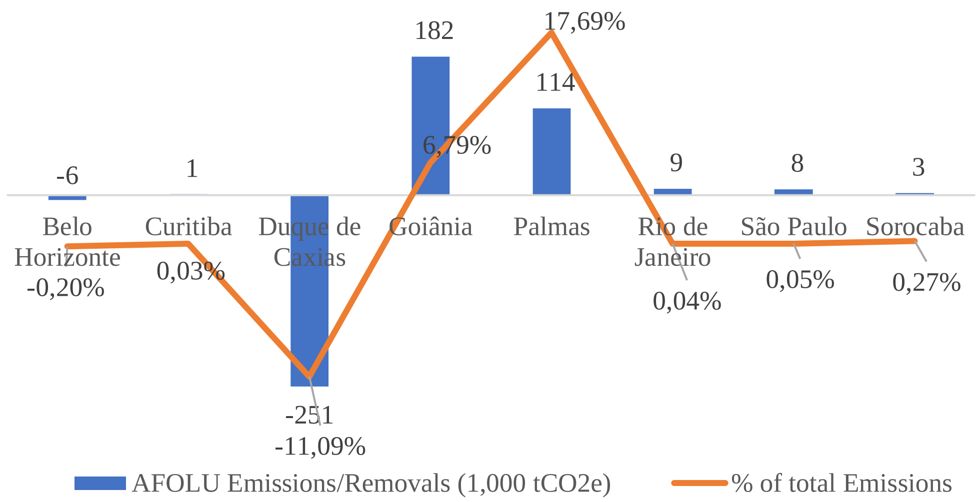

Figure 9 –AFOLU Emissions/Removals by City (tCO2e).

Source: Developed by the authors using data of GHG reports of the cities

4.3 Carbon Accounting Approaches

Brazilian cities are not using CBA approach to develop a GHG inventory. All cities used a PBA approach, adding emissions associated with (1) electricity consumed produced out-boundary; (2) waste emissions generated by the city but disposed at out-boundary sites; and in some cases (3) transport emissions that occurred out-boundary (e.g., air travel, maritime).

This practice is not found in the traditional PBA generally used by cities worldwide. Cities following the PBA usually do not consider these sources, as for example, when Harris et al. (2012) analyzed Hong Kong inventories and Andrade et al. (2018) examined Madrid's GHG emissions.

Brazilian cities did not account emissions associated with food, beverages and manufactured goods consumed by the city but produced out-boundary. The city of Duque de Caxias (Duque de Caxias, 2016) was the only city to measure emissions from cement and steel that was used in the city.

The literature shows that an important share of a city emission can be attributed to the production and transport of imported products and services from outside the city's boundaries, such as food, manufactured products and consumables (Dodman, 2009; Lombardi et al., 2017; Andrade et al., 2018).

The experience of London using PAS 2070-DPSC showed that goods and services comprise an additional 18% of emissions, with food and drink being the major contributor (Greater London Authority, 2014). Andrade et al. (2018) showed that Madrid doubled their total GHG emissions under the PBA when using the PAS 2070-DPSC Standard.

Emissions from the production and transport of imported products and services can be particularly relevant for the Brazilian cities in this study once their economies are mainly based on services. This implies that food, beverages, construction inputs and other manufactured products consumed by the population within the boundaries of those cities are produced elsewhere. Emissions associated with these products have not been accounted by these Brazilian cities.

The Brazilian official statistics institutions do not provide information regarding products bought or sold from other cities/states in Brazil. There is no environmentally extended input output (or EEIO) for Brazilian cities. This fact makes it difficult to develop a CBA inventory. More complex calculations and assumptions would be needed, increasing uncertainties. These findings were highlighted as a disadvantage by several authors (Peters, 2008; Dodman, 2009; Grasso, 2016; Afionis et al., 2017; Franzen & Mader, 2018; Sudmant et al., 2018).

Data obtained from Research of Families Budget developed by IBGE (2009) shows that food, clothing, and personal care consumed by urban population represent from 8.4% to 19.4% of the cities' GDP. Among these items, expenditures related to food have the greatest importance in all cities. As these cities do not present relevant agriculture and industrial activities, it is reasonable to assume that these items come from another city, state, or country. Therefore, emissions related to their production were not accounted in the inventories of the cities.

Although a CBA approach would provide more comprehensive results and a more complete diagnosis of city emissions, many estimates would have to be developed, which could hinder the accuracy of the results. This is aligned with the CBA disadvantages mentioned in the literature (Peters, 2008; Dodman, 2009; Grasso, 2016; Afionis et al., 2017; Franzen & Mader, 2018; Sudmant et al., 2018).

GHG inventories of Brazilian cities have considered some sources of indirect emissions, but there is still a long way to go to achieve the complete application of methods such as the PAS 2070-DPSC. For this application to be possible, it is necessary to improve statistical information at the city level, which is recommended by Andrade et al. (2018).

4.4 Differences and Gaps in the GHG inventories

The gaps identified in Brazilian cities GHG reports can be divided into two main types: incompleteness a lack of transparency.

Gap 1 – Incompleteness: The reported GHG emissions shall appropriately reflect emissions occurring as a result of activities and consumption patterns of the city (WRI, 2014). Cities shall account for all required emissions sources within the inventory boundary. Some GHG inventories did not account GHG emissions of all economic sectors and emissions sources, independently of the carbon accounting approach chosen. For example, in the report of Betim (Betim, 2016), where industrial sector is the most important economic activity, no source of stationary energy neither IPPU were accounted. The report of ABC region (Consórcio Intermunicipal do Grande ABC, 2017a), where more than 2.7 million people live, no emission related to aviation was considered because there is no airport at the region. At these GHG emissions inventories, relevant emission sources may be neglected. Therefore, GHG results can be underestimated. Consequently, results can guide limited actions to combat climate change within the city.

Gap 2 - Lack of Transparency: Data, emission sources, emission factors, and accounting methodologies require adequate documentation and disclosure to enable verification. The information should be enough to allow individuals outside of the inventory process to use the same source data and derive the same results. All exclusions shall be clearly identified, disclosed and justified. Several GHG inventories were not transparent. Some reports did not present input data, emission sources included; emission factors or calculation methodologies (e.g. Betim, Recife, Fortaleza, Porto Alegre, Salvador, São Paulo). The lack of transparency of these GHG inventories limits the reproducibility of their results by a third party . Therefore, it is not feasible to assess the accuracy of the GHG results of these reports.

Both gaps are indirectly mentioned in previous literature. Croci et al. (2017), analyzing mitigation options of 124 European cities, found that GHG inventories of these cities did not cover the same sectors. Mia et al. (2019), analyzing GHG disclosure of 42 mega cities from C-40, also found that GHG inventories were incomplete, once they did not account for all emission sources and GHG, and they present deficiencies regarding transparency.

Seventeen GHG reports presented incompleteness (Gap 1) and twenty presented lack of transparency (Gap 2). Table 4 presents details of each report and a discussion about sectors and sub-sectors considered by each city, highlighting gaps and limitations of each report.

In order to close the gaps identified in the research and seeking to contribute to the efforts, asked by Mi et al. (2019), of reducing uncertainties of cities emission inventories, several initiatives could be easily executed, such as identification of the main economic activities and consumption patterns that could generate large emissions and the presentation of source of inputs. Table 5 summarizes the potential actions to reduce the emissions.

Table 4 – Sectors, Sub-sectors and Gaps of Each Report

City	Sectors and Emission Sources Included in GHG Inventories					Gaps		Discussion about subsectors, gaps and limitations
	Stationary Energy	**Waste**	**Transport**	**IPPU**	**AFOLU**	**1**	**2**	
ABC Region	Residential Buildings Commercial and Institutional Buildings Manufacturing Industries and Construction	Solid waste disposal (SWD) Incineration and open burning of waste Wastewater treatment	On Road Off-Road Railways	N.A.[15]	N.A.	Yes	Yes	GHG Report is transparent about assumptions, emission factors and some limitations of the report. However, input data used for calculation is not presented. GHG results cannot be reproduced. The following sub-sectors were not accounted: • Aviation and Waterborne navigation; • Biological treatment of waste; • One incineration site was not considered due to lack of data; • IPPU and AFOLU emissions
Belo Horizonte	Residential Buildings Commercial and Institutional Buildings	SWD Wastewater treatment	On Road Aviation	N.A.	Land Use	No	No	GHG Report is transparent about emissions sources, calculation methodologies and limitations. However, it does not present input data used. The following sub-sectors were not accounted:

[15] N.A. means Not accounted.

City	Sectors and Emission Sources Included in GHG Inventories					Gaps		Discussion about subsectors, gaps and limitations
	Stationary Energy	Waste	Transport	IPPU	AFOLU	1	2	
	Manufacturing Industries and Construction Fugitive Emissions from Oil and Natural Gas System							• Waterborne navigation, Railway and Off-Road transportation are not mentioned; • Incineration and Open Burning and Biological treatment; • IPPU; • Livestock.
Betim	Residential Buildings Commercial and Institutional Buildings Manufacturing Industries and Construction Energy Industries Non-Specified Sources	SWD Wastewater treatment	On Road Railways Aviation	N.A.	N.A.	Yes	Yes	GHG Report is not transparent about assumptions, input data, emission factors and limitations. It was identified that GHG results may be underestimated because: • It was considered just electricity in Stationary Energy. Betim has relevant industrial sector and no other stationary energy emission was accounted. This emission source could be relevant once industrial activities represent 48% of the city GDP. • Waterborne navigation and Off-Road transportation were not accounted;

City	Sectors and Emission Sources Included in GHG Inventories					Gaps		Discussion about subsectors, gaps and limitations
	Stationary Energy	Waste	Transport	IPPU	AFOLU	1	2	
								• IPPU, AFOLU and Open Burning and Biological treatment of waste were not considered.
Curitiba	Residential Buildings Commercial and Institutional Buildings Manufacturing Industries and Construction Energy Industries Agriculture, forestry and fishing activities	SWD Wastewater treatment	On Road Off-Road Waterborne Navigation Railways Aviation	N.A.	AFOLU	No	Yes	GHG Report is not transparent about assumptions, input data, emission factors and limitations. Fugitive emissions of HFCs are mentioned but not accounted. Biological treatment of waste was not considered in Waste sub-sector. GHG Report presents result for AFOLU but do not provide additional information about sub-sectores measured.
Duque de Caxias	Residential Buildings Commercial and Institutional Buildings	SWD Wastewater treatment	On Road Off-Road Waterborne Navigation	Industrial Processes (IP) Product Use (PU)	Livestock Land Use and Wood Consumption	No	No	GHG Report is transparent about assumptions, input data, sources of data and emission calculation. One of the most complete GHG inventory among Brazilian cities. Incineration

City	Sectors and Emission Sources Included in GHG Inventories					Gaps		Discussion about subsectors, gaps and limitations
	Stationary Energy	Waste	Transport	IPPU	AFOLU	1	2	
	Manufacturing Industries and Construction Energy Industries		Railways Aviation					and Open Burning and Biological treatment of waste were not considered.
Fortaleza	Residential Buildings Commercial and Institutional Buildings Manufacturing Industries and Construction Energy Industries	SWD Incineration and open burning of waste	On Road Off Road Aviation	N.A.	N.A.	Yes	Yes	GHG Report is not transparent about assumptions, input data, emission factors and limitations. The following sub-sector were not accounted: • Railway; • Biological treatment of waste and wastewater treatment; • IPPU and AFOLU.
Goiânia	Residential Buildings Commercial and Institutional Buildings Manufacturing Industries and Construction	SWD Wastewater treatment	On Road Off Road Aviation	N.A.	Livestock Land Use	Yes	Yes	GHG Report is not transparent about assumptions, input data and emission factors. Report did not consider: • Railway and Waterborne Navigation; • Biological treatment and Incineration;

City	Sectors and Emission Sources Included in GHG Inventories					Gaps		Discussion about subsectors, gaps and limitations
	Stationary Energy	Waste	Transport	IPPU	AFOLU	1	2	
	Energy Industries							• IPPU.
João Pessoa	Residential Buildings Commercial and Institutional Buildings Manufacturing Industries and Construction Energy Industries Non-Specified Sources	SWD Incineration and open burning of waste Wastewater treatment	On Road Off-Road Railways Aviation	N.A.	N.A.	Yes	Yes	GHG Report is transparent about assumptions and emission factors but input data are not presented. Waterborne navigation was not considered due to lack of data. IPPU and AFOLU were not accounted.
Londrina	Residential Buildings Commercial and Institutional Buildings Manufacturing Industries and Construction	SWD Incineration and open burning of waste Wastewater treatment	On Road Off-Road Aviation	N.A.	N.A.	Yes	Yes	GHG Report is transparent about assumptions and input data. However, emission factors and calculation methods are not presented. GHG Report did not account: • Railway and Waterborne; • Biological treatment of waste;

City	Sectors and Emission Sources Included in GHG Inventories					Gaps		Discussion about subsectors, gaps and limitations
	Stationary Energy	Waste	Transport	IPPU	AFOLU	1	2	
	Energy Industries Agriculture, forestry and fishing activities Non-Specified Sources							• IPPU and AFOLU.
Palmas	Residential Buildings Commercial and Institutional Buildings Manufacturing Industries and Construction	SWD Incineration and open burning of waste Biological treatmente of waste Wastewater treatment	On Road Off-Road Waterborne Navigation Railways Aviation	IP PU	Livestock Land Use	No	Yes	Authors have access just to main results of the GHG inventory. It was not possible to assess transparency of the report because the official report is not public.
Porto Alegre	Residential Buildings Commercial and Institutional Buildings	SWD Wastewater treatment	On Road Railways Aviation	N.A.	N.A.	Yes	Yes	GHG Report is not transparent about input data and emission factors. GHG report did not account the following sub-sectors: • Waterborne navigation; • Incineration and biological;

City	Sectors and Emission Sources Included in GHG Inventories					Gaps		Discussion about subsectors, gaps and limitations
	Stationary Energy	Waste	Transport	IPPU	AFOLU	1	2	
	Manufacturing Industries and Construction Energy Industries Agriculture, forestry and fishing activities							• IPPU and AFOLU.
Recife	Residential Buildings Commercial and Institutional Buildings Manufacturing Industries and Construction	SWD Incineration and open burning of waste	On Road Waterborne Navigation Railways Aviation	N.A.	N.A.	Yes	Yes	GHG Report is transparent about assumptions and input data. However, it does not present emission factors. GHG Report did not present: • Biological treatment and wastewater treatment and discharge; • IPPU; • AFOLU.
Rio de Janeiro	Residential Buildings Commercial and	SWD Incineration and open burning of waste	On Road Off-Road Waterborne Navigation	IP PU	Livestock Land Use Agriculture	No	Yes	GHG Report is not transparent about assumptions, input data and emission factors. It is one of the most complete GHG

City	Sectors and Emission Sources Included in GHG Inventories					Gaps		Discussion about subsectors, gaps and limitations
	Stationary Energy	Waste	Transport	IPPU	AFOLU	1	2	
	Institutional Buildings Manufacturing Industries and Construction Energy Industries Fugitive Emissions from Oil and Natural Gas System Agriculture, Forestry and Fishing Activities	Wastewater treatment Biological treatmente of waste in the city	Railways Aviation					inventories among Brazilian cities. Energy sector includes Stationary Energy and Transportation.
Salvador	Residential Buildings Commercial and Institutional Buildings Manufacturing Industries and Construction	SWD Incineration and open burning of waste Wastewater treatment	On Road Waterborne Navigation Aviation	N.A.	N.A.	Yes	Yes	GHG Report is transparent about assumptions and sources of data. However, it does not present input data and emission factors. Biological treatment of waste, IPPU and AFOLU were not accounted.

City	Sectors and Emission Sources Included in GHG Inventories					Gaps		Discussion about subsectors, gaps and limitations
	Stationary Energy	Waste	Transport	IPPU	AFOLU	1	2	
	Energy Industries Agriculture, forestry and fishing activities							
São Paulo	Residential Buildings Commercial and Institutional Buildings Manufacturing Industries and Construction Energy Industries Fugitive Emissions from Oil and Natural Gas System Non-Specified Sources	SWD Incineration and open burning of waste Wastewater treatment Biological treatmente of waste in the city	On Road Off Road Waterborne Navigation Aviation	IP PU	Livestock Land Use Agriculture	No	Yes	GHG Report is not transparent about assumptions, input data and emission factors used for calculation. It does not present Gap 1.

City	Sectors and Emission Sources Included in GHG Inventories					Gaps		Discussion about subsectors, gaps and limitations
	Stationary Energy	Waste	Transport	IPPU	AFOLU	1	2	
Sorocaba	Residential Buildings Commercial and Institutional Buildings Manufacturing Industries and Construction	SWD Wastewater treatment	On Road Off Road Aviation	N.A.	Livestock Land Use Agriculture	Yes	No	GHG Report is transparent about assumptions, input data and emission factors used for calculation. IPPU; incineration and open burning and biological treatment were not considered.
Niterói and Vitória	Authors have access just to answers provided by these cities to CDP (CDP, 2019). GHG Reports are not publicly available. It was just possible to identify emission by sources							

Source: Developed by the authors with data of Cities' GHG Inventory Reports

Table 5 – Actions to overcome the Gaps

Gap 1: Incompleteness	**Gap 2: Lack of transparency**
• To identify main economic activities and consumption patterns of the city; • To identify emission sources considering both approaches PBA and CBA; • To assess the necessary data to emission calculation; • To analyze the feasibility of data collection; • To decide about carbon accounting approach, boundaries sectors and subsectors to be measured; • To use more robust information system that allow an integrated production-consumption approach.	• To identify clearly boundaries, sectors and sub-sectors included in the GHG inventory; • To justify any exclusion; • To present clearly assumptions, input data, source of input data, calculation methodologies and emission factors used for GHG emission calculation; • To describe limitations and uncertainties of the report; • To engage stakeholders on GHG inventory development with a more transparent and participatory process.

Source: Developed by the authors

4.5 Impacts on Climate Action Plans

Belo Horizonte (Belo Horizonte, 2013), Fortaleza (Fortaleza, 2016b), Recife (Recife, 2016), Rio de Janeiro (Rio de Janeiro, 2015) and the ABC region (Consórcio Intermunicipal do Grande ABC, 2017b) have climate action plans approved by the local city councils. The climate action plan of the ABC region was developed with integrated actions for all 7 cities. Other cities that developed GHG inventories are also planning actions to reduce GHG emissions (Carbonn, 2019). However, a structured climate action plan was not approved by local councils yet.

Climate action plans of these cities follow a similar structure. They consider activities in the transport, energy and waste sectors. Fortaleza (Fortaleza, 2016b) and Recife (Recife, 2016) consider a fourth sector that includes actions related to urban development. Belo Horizonte (Belo Horizonte, 2013) also considered actions on sanitation and adaptation to climate change.

In the transport sector, several actions are planned in the climate action plans: improvement of public transport with new equipment (BRTs, VLTs, Metro Lines); infrastructure for bicycles and pedestrians; increase of biofuels in the public fleet and bike and car sharing. For the energy sector, actions on public lighting and building efficiency as well as solar energy use, and incentives for renewable energy have been proposed. Regarding the waste sector, cities seek to reduce waste disposal at landfills. They also plan to implement electricity generation from biogas and increase recycling and composting practices. The sector of urban development considered adaptation actions and activities to promote green areas (e.g., conservation, afforestation and reforestation) and green building. In Belo Horizonte, regarding adaptation the plan intends to: (I) review local rainwater management law; (II) define targets for implantation of permeable and light color floors; (III) improve the monitoring and alert network of extreme weather; and (IV) to establish partnerships to protect and to increase urban vegetation. For sanitation, the plan aims to provide 100% of the population with wastewater treatment and using biogas from wastewater treatment station.

The fact that no city used a CBA approach have an impact on their climate action plans. Reflecting their inventories, no climate action plan considered mitigation actions regarding consumption of goods and manufactured products that were produced out-boundary. Therefore, the climate impact of imported carbon emissions is not considered. This may limit the effectiveness of established local climate policies (Peters, 2008; Harris et al., 2012; Vetné Mózner, 2013; Grasso, 2017; Afionis et al., 2017; Andrade et al. 2018), and an opportunity to engage and encourage more sustainable consumption habits in the local community is lost.

5. Conclusions

Several authors (e.g. Dodman, 2009; Harris et al., 2012; Lombardi et al., 2017; Sudmant et al., 2018; Andrade et al., 2018) discuss the impact of the carbon accounting approach on urban GHG emissions inventories and some recent papers propose methods to improve the comprehensiveness and accuracy of carbon accounting for cities. Through a critical analysis of the literature, this study summarized benefits and disadvantages of using each carbon accounting approach. Although several authors support the adoption of the CBA approach, the disadvantages of this approach are also highlighted by several studies, such as the lack of data available at the local level impacting the accuracy of the results (Peters, 2008; Afionis et al., 2017; Franzen & Mader, 2018).

The research verified that PBA is used by Brazilian cities with the aggregation of indirect emissions of electricity, waste disposed in out-boundary landfills, and emissions from aviation (with few exceptions). Most the cities uses GPC methodology. Five cities use IPCC. Brazilian cities have not accounted for GHG emissions from food, beverages and manufactured products that are consumed by cities and produced out-boundary. Thus, the emissions from all cities may be underestimated in agreement with previous literature (Dodman, 2009; Lombardi et al., 2017; Andrade et al., 2018).

Literature focusing on the quality of these reports are rare (Mia et al., 2019). Two main gaps were identified in Brazilian cities GHG emissions reports: incompleteness and lack of transparency.

Seventeen Brazilian cities presented major incompleteness gap. These cities do not account important sectors and sub-sectors in their GHG reports. Relevant emission sources in some cities, such as stationary energy, may be neglected. Therefore, GHG results can be underestimated.

Twenty GHG reports presented lack of transparency. At these reports, there are no transparency about assumptions, input data, source of input data, emission factors, calculation methods and limitations. Without these types of information, it is difficult to verify the accuracy of the report and make it difficult to replicate the study in future inventories, as well as to make comparisons among cities and changes in carbon emissions over time, which is important for benchmarking and analysis of the effectiveness of actions to mitigate climate change.

The carbon accounting approach chosen, and the gaps identified in our study impact the quality of GHG inventories, and consequently climate mitigation plans do not consider actions to promote sustainable consumption and to change consumption patterns of the population.

In order to overcome these gaps, there are some actions that can improve the quality of the GHG inventories. Using robust information system that allow an integrated production-consumption approach would be a possible solution to help cities to overcome incompleteness gap. Also, developing the GHG inventory with more stakeholder engagement and disclosing clearly boundaries, assumptions, input data, emission sources included, exclusions and limitation would eliminate the lack of transparency gap.

As few Brazilian cities have developed emission inventories and even fewer cities have enacted low-carbon plans as laws, for policy makers there is an opportunity to motivate the development of broader and more complete GHG inventories that may lead to low-carbon plans that involve and make the population aware of the importance of their consumption choices in relation to the climate.

This paper has several contributions to fill the gaps in the scientific literature and provides insights for policy makers. Firstly, this manuscript contributes to the literature in comparing the different GHG methodologies for cities in terms of coverage, efforts and usage. Secondly, there is lack of empirical research that investigates the quality of GHG disclosures at city level as pointed by Mia et al. (2019). By assessing GHG inventories of Brazilian cities, this study identified the main gaps of city emissions inventories. Efforts are necessary to reduce uncertainties of GHG inventories result (Mi et al., 2019) and this manuscript contributes to these efforts.

Thirdly, it provides a detailed study of inventories in a developing country. As Castán Broto & Bulkeley (2012) and Van der Heijden (2019) argue, the literature about city responses to climate change is dominated by economically developed countries. Despite the limitations of the method, this is one of the most complete studies in Latin America.

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[16] The following steps are necessary to find data used by the paper. (I) Access table 1594; (II) Check the following options: “Despesa monetária e não monetária média mensal familiar (Reais); “Total”; “1.Despesa Total”; “2. Despesas Correntes”; “2.1.1Alimentação”; “2.1.2. Habitação”; “2.1.3.Vestuário”; “2.1.4. Transporte”; “2.1.5. Higiene e cuidados pessoais”; “2.1.6. Assistência à saude”; “2.1.7. Educação”; “2.1.8. Recreação e cultura”; “2.1.9. Fumo”; “2.1.10. Serviços pessoais”; “2.1.11. Despesas diversas”; “2.2. Outras despesas correntes”; “Município”. After that, click on “Download” and information about family’s budget expenses for all Brazilian cities will be provided. Cities that are scope of our study must be selected.

[17] The following steps are necessary to find data used by the paper. (I) Access https://sidra.ibge.gov.br/tabela/5938 . After that, check the following options: “Produto Interno Bruto a preços correntes (Mil Reais)”; “Impostos, líquidos de subsídios, sobre produtos a preços correntes (Mil Reais)”; “Valor adicionado bruto a preços correntes total (Mil Reais)”; “Valor adicionado bruto a preços correntes da agropecuária (Mil Reais)”; “Participação do valor adicionado bruto a preços correntes da agropecuária no valor adicionado bruto a preços correntes total (%)”; “Valor adicionado bruto a preços correntes da indústria (Mil Reais)”; “Participação do valor adicionado bruto a preços correntes da indústria no valor adicionado bruto a preços correntes total (%)”; “Valor adicionado bruto a preços correntes dos serviços, exclusive administração, defesa, educação e saúde públicas e seguridade social (Mil Reais)”; “Participação do valor adicionado bruto a preços correntes dos serviços, exclusive administração, defesa, educação e saúde públicas e seguridade social, no valor adicionado bruto a preços correntes total (%)”; “Valor adicionado bruto a preços correntes da administração, defesa, educação e saúde públicas e seguridade social (Mil Reais); “Participação do valor adicionado bruto a preços correntes da administração, defesa, educação e saúde públicas e seguridade social no valor adicionado bruto a

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3.2 Article 2: Assessing urban emissions through different methodologies: an analysis of Brazilian Cities

Assessing urban emissions through different methodologies: an analysis of Brazilian cities.

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Abstract

This paper compares the different methodologies used to measure greenhouse gas (GHG) emissions in forty-seven Brazilian cities. The paper highlights the characteristics, similarities, and differences between these methodologies to show how they can impact GHG results. In line with previous literature, it demonstrates how different carbon accounting approaches produce different GHG results. Furthermore, it demonstrates that the lack of transparency in GHG reports hinders accurate assessments of results and the ability to makes comparisons between cities. When analyzing the GHG inventory of a given city or comparing GHG results among cities, in order to understand variations, it is essential to identify the methodology, base year, emission sources, global warming potential, and calculation methods used to derive results. This paper contributes to the literature discussing the consistency and comparability of GHG emissions data at the city level. It also uses the reality of Brazilian cities, thus addressing a literature gap in climate governance studies, which tend to focus on cities from Global North. This study provides insights to academics and policymakers on how to develop broader, more complete, and more transparent GHG inventories, and evidence precautions that should be taken when analyzing a city's GHG report.

Key Words: Carbon accounting; GHG inventories; Carbon methodologies; City level; Brazilian cities.

1 Introduction

An increasing number of cities have developed their greenhouse gas (GHG) emission inventories (GHG inventory) and climate action plans. A GHG inventory is the first step toward climate action at the local level (Moran et al., 2021). It identifies the main emission sources of a city and where local governments should direct mitigation efforts.

The methodological approach used by any city in their GHG accounting can impact the results (e.g., Sudmant et al., 2018; Andrade et al., 2018; Baltar de Souza Leão et al., 2020). Some GHG emission sources may either be neglected or underestimated, depending on the approach adopted. This is specially challenging when comparing GHG emissions between different cities.

The most common methodologies used among cities to identify their GHG inventory are the IPCC (Intergovernmental Panel on Climate Change) Guidelines (2006) and the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC). The IPCC Guidelines use a Production-Based Approach (PBA), which considers emissions related to what is produced within a given city. The GPC methodology was specifically created to carry out city inventories, and it offers the possibility to measure and disclose GHG inventories using both production and consumption activities within city limits.

There is an extensive body of literature surrounding the benefits and the negative impacts of PBA versus consumption-based approaches (CBA) (e.g., Peters, 2008; Dodman, 2009; Harris et al., 2012; Afionis et al., 2017; Lombardi et al., 2017; Sudmant et al., 2018; Andrade et al., 2018; Franzen & Mader, 2018). Previous literature has also shown these approaches to be complementary (Sudmant et al., 2018; Andrade et al., 2018). Both provide important perspectives when it comes to analyzing the impact of a given city on climate change. However, to date, few studies have compared the results of both approaches within a single city (exceptions include Sudmant et al., 2018 and Andrade et al., 2018).

This paper will compare the GHG emissions results from forty-seven Brazilian cities, using both IPCC and GPC methodologies, which present different scopes and different data collection approaches, i.e., one uses national data to estimate local GHG results, whereas the other uses local data for these estimates.

Mi et al. (2019) detail four remaining gaps in urban climate action research: 1) a lack of consistent and comparable GHG emissions data at the city level, 2) a lack of scientific understanding of the roles that different urban sectors play in mitigating climate change, 3) a lack of scientific understanding of the dynamics between sustainable development and climate change mitigation in cities, and 4) a lack of scientific understanding on how cities choose climate change mitigation strategies and develop local actions.

This study contributes to the literature surrounding the consistency and comparability of GHG emissions data at the city level, thereby addressing the first literature gap highlighted by Mi et al. (2019). It also highlights differences in GHG methodologies and the precautions that should be taken when analyzing the inventory of a given city.

Furthermore, this study also analyzes how cities in Latin America's most populous and wealthiest country are measuring their emissions, and discusses the quality and gaps of these GHG inventories. By addressing the reality of Brazilian cities, this paper also addresses another literature gap pointed out in previous studies, notably that urban climate literature to has mostly focused on examples from the Global North (Van der Heijden, 2019; Castán Broto & Bulkeley, 2012).

2 Literature Review

2.1 IPCC Methodology

According to Jonas et al. (2019), GHG emissions are rarely measured directly. To assist countries in compiling comprehensive emission inventories and conduct quantitative uncertainty analyses under the UNFCCC, the IPCC has put forth standardized methodologies to enable adequate accounting of national, natural, and human-induced GHG sources and sinks.

The IPCC (2006) methodology is an internationally recognized methodology directed toward countries to estimate their greenhouse gas inventories and report these to the United Nations Framework Convention on Climate Change (UNFCCC). It is the Panel recommendation for national GHG inventories.

The IPCC (2006) provides detailed guidance on emission and removal categories, calculation formulae, data collection methods, default emission factors, and management. It requires GHG emissions reporting from sectors and subsectors within a territory. It follows a PBA, thereby assigning responsibility for emissions to the place where they are produced (Lombardi et al, 2017). Although it has been recommended to carry out National Inventories, the IPCC methodology can also be applied at the city level.

The most common method to estimate GHG emissions is to combine information on the extent to which a human activity takes place (called activity data or AD) with coefficients that quantify the emissions or removals per unit of activity. These are called emission factors (EF). The basic equation is therefore:

Equation 1: GHG Emissions = Σ $AD_i \times EF_i$ for each activity i

GHG emission and removal estimates are divided into primary sectors, which are groupings of related processes, sources, and sinks, as presented in table 1.

Sectors	**Sub-Sectors**
1-Energy	1.A. Fuel Combustion Activities 1.B. Fugitive emissions from fuels 1.C. Carbon Dioxide Transport and Storage.
2-IPPU[18]	2.A. Mineral Industry 2.B. Chemical Industry 2.C. Metal Industry 2.D. Non-Energy Products from Fuels and Solvents Use 2.E. Electronics Industry 2.F. Product Uses as Substitutes for Ozone Depleting Substances 2.G. Other Product Manufacture and Use
3-AFOLU[19]	3.A. Livestock 3.B. Land 3.C. Aggregate sources and non-CO2 emission sources on land.
4-Waste	4.A. Solid Waste Disposal 4.B. Biological Treatment of Solid Waste 4.C. Incineration and Open Burning of Waste 4.D. Wastewater Treatment and Discharge. 4.E. Other

Table 1: Main sectors and subsectors– IPCC Methodology

Source: Elaborated by the authors based on IPCC (2006).

Some benefits of the IPCC methodology is that (I) includes publicly available datasets for economic data, such as GDP (Gross Domestic Product); (II) maintains consistency when it comes to respecting political and environmental boundaries; (III)

[18] Industrial Processes and Product Use.
[19] Agriculture, Forestry and Other Land Use

contains straightforward calculations and (V) contains less uncertainty (Baltar de Souza Leão at al., 2020; Franzen & Mader, 2018; Afionis et al., 2017; Grasso, 2016; Dodman, 2009, and Peters, 2008).

However, previous literature (Baltar de Souza Leão at al., 2020; Franzen & Mader, 2018; Afionis et al., 2017; Grasso, 2016; Vetné Mózner, 2013; Dodman, 2009 and Peters, 2008) has highlighted that PBAs can lead to ineffective mitigation policies, given the focus of emissions coverage on what it is emitted within a given territorial boundary. Thus, they neglect emissions related to the consumption of imported products and goods, and provide motivation for carbon leakage.

2.2 GPC Methodology

The Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) methodology was developed by the World Resources Institute (WRI) in partnership with the Local Governments for Sustainability (ICLEI) and the Cities Climate Leadership Group (C40), in 2014 (WRI, 2014).

The GPC methodology requires cities to measure and disclose their GHG inventories based on both production and consumption activities within city limits. Thus, it requires that a geographic boundary be defined to identify the spatial dimension or physical perimeter of the inventory.

The GPC methodology was designed to account for a city's GHG emissions within a single reporting year, over a continuous period of 12 months. Ideally, it should be aligned with either a calendar or financial year. The GPC recommends that GHG emissions from city activities be classified into six main sectors, as well as a number of sub-sectors. These sectors and subsectors are presented at table 2.

Sectors	Sub-Sectors
I-Stationary Energy	I.1. Residential Buildings I.2. Commercial and institutional buildings and facilities I.3. Manufacturing industries and construction. I.4. Energy industries I.5. Agriculture, forestry, and fishing activities I.6. Non-specified sources I.7. Fugitive emissions from mining, processing, storage and transportation of coal I.8. Fugitive emissions from oil and natural gas systems
II-Transport	II.1. On Road Transportation II.2. Railways II.3. Water Transport II.4. Aviation II.5. Off-Road Transportation
III-Waste	III.1. Solid waste disposal III.2. Biological Treatment of Waste III.3. Incineration and open burning III.4. Wastewater treatment and discharge
IV-IPPU	IV.I. Industrial Processes IV.II. Product Use
V-AFOLU	V.I. Livestock V.II. Land V.III. Other Agriculture
VI-Other Scope 3	All emissions that occur outside of city limits but are driven by the consumption of goods/services within city limits.

Table 2: Main sectors and subsectors– GPC Methodology

Source: Elaborated by the authors based on WRI (2014).

Activities that take place within a city can generate GHG emissions both inside and outside city boundaries. To distinguish between these, the GPC groups emissions into three categories according to where they occur: scope 1, scope 2, and scope 3 emissions (WRI, 2014), as follows:

- Scope 1: GHG emissions from sources located within city boundaries.
- Scope 2: GHG emissions from grid-supplied electricity, heat, steam, and/or cooling sources from within city boundaries.
- Scope 3: All emissions that occur outside city boundaries but are driven by the consumption of goods/services within city boundaries.

The GPC distinguishes between three types of emissions: those that physically occur within a given city (scope 1), those that occur outside this same city but are driven by activities that take place within the city's boundaries (scope 3), and those that occur from the use of electricity, steam, and/or heating/cooling supplied by grids which may or may not cross the city's boundaries (scope 2). Scope 1 emissions are the traditional types of emissions accounted for in PBA. These are also referred to as "territorial" emissions because they are produced solely within defined geographic boundaries (WRI, 2014).

Within scopes 2 and 3, the GPC includes emission sources that stem from areas beyond a given city's boundaries (e.g., electricity consumed from a grid; waste disposal out-boundary). Thus, these scopes open the possibility of accounting for and reporting on emissions from the consumption of goods and services within an area regardless of where they were produced (Dahal & Niemelä, 2017; Lombardi et al., 2017). Therefore, the GPC offers the possibility to combine the PBA and CBA approaches. Cities can expand this possibility by reporting on other scope 3 emissions.

Benefits of using a CBA approach include: (I) the possibility to account for more emissions, (II) the ability to maintain consistency between consumption and environmental impacts; (III) the ability to eliminate carbon leakage and (IV) the ability to provide more mitigation options (Peters, 2008; Afinois et al., 2017; Andrade et al., 2018). However, the CBA approach can be more technically difficult and uncertain to use than the PBA approach when several indirect emissions are included (Peters, 2008; Grasso, 2016; Franzen & Mader, 2018; Sudmant et al., 2018). CBA can require more complex calculations, assumptions, and estimations (Peters, 2008; Dodman, 2009; Afionis et al., 2017), whereas PBA is much more aligned to available datasets.

2.3 IPCC X GPC Methodologies: Similarities and Differences

The IPCC and GPC methodologies (IPCC, 2006; WRI, 2014) follow the same accounting and reporting principles as follows:

- Transparency: Inventories should clearly document activity data, emission sources, emission factors, and accounting methodologies. "The information should be sufficient to allow individuals outside of the inventory process to use the same source data" (WRI, 2014).
- Completeness: All sources of emissions required within the inventory boundary should be estimated. Any exclusion of emission sources should be justified and clearly explained.
- Consistency: Approach, sources of emissions, approach, boundary, and methodology should be consistent over time to enable meaningful documentation of emission changes over time, analysis of trends, and comparisons. Any deviation should be disclosed and justified.
- Accuracy: The inventory should not systematically overstate or understate actual GHG emissions. This means taking measures to remove bias from inventory estimates.

Each methodology contains one principle that is not expressly stated in the another. The IPCC establishes the principle of comparability, whereby the GHG inventory should be reported in a way that allows it to be compared with the GHG inventories of other territories. Meanwhile, the GPC establishes the principle of relevance, whereby the reported GHG emissions should appropriately reflect the emissions that actually occur given according to the activities and consumption patterns of a given city.

Both methodologies account for the types of emissions that must currently be reported in national GHG inventories as per the Kyoto Protocol: carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF6), and nitrogen trifluoride (NF3).

When calculating the GHG emissions from a given activity, the quantity of each GHG is multiplied by the global warming potential (GWP) of each gas (IPCC, 2006; WRI, 2014). Given that the IPCC updates the GWP values of each GHG over time, it is important to record in the inventory which GWP is being used. The sectors and sub-sectors that must be accounted for according to the methodologies are basically the same, as shown in Table 3.

IPCC classification		GPC classification	
	Energy		Stationary Energy
1A4b	Residential	I.1	Residential buildings
1A4a	Commercial/institutional	I.2	Commercial and institutional buildings/facilities
1A2	Manufacturing industries and construction	I.3	Manufacturing industries and construction
1A1	Energy industries	I.4	Energy industries
1A4c	Agriculture/forestry/fishing/fish farms	I.5	Agriculture, forestry and fishing activities
1A5a	Non-specified	I.6	Non-specified sources
1B1	Solid fuels (fugitive emissions)	I.7	Fugitive emissions from mining, processing, storage, and transportation of coal
1B2	Oil and natural gas (fugitive emissions)	I.8	Fugitive emissions from oil and natural gas systems
			Transportation
1A3b	Road transportation	II.1	On-road transportation
1A3c	Railways	II.2	Railways
1A3d	Water-borne navigation	II.3	Water transport
1A3a	Civil aviation	II.4	Aviation
1A3e	Other transportation	II.5	Off-road transportation
4	Waste		Waste
4A	Solid waste disposal	III.1	Solid waste disposal
4B	Biological treatment of solid waste	III.2	Biological treatment of waste
4C	Incineration and open burning of waste	III.3	Incineration and open burning
4D	Wastewater treatment and discharge	III.4	Wastewater treatment and discharge
2	IPPU		IPPU
2A	Mineral industry	IV.1	Industrial processes
2B	Chemical industry		
2C	Metal industry		
2E	Electronics industry		
2D	Non-energy products from fuels and solvent use	IV.2	Product use
2F	Product uses as substitutes for ozone depleting substances		
2G	Other product manufacture and use		
2H	Other		
3	AFOLU		AFOLU
3A	Livestock	V.1	Livestock
3B	Land	V.2	Land
3C	Aggregate sources and non-CO_2 emissions sources on land	V.3	Other agriculture
3D	Other		

Table 3: Comparison of emission sources sectors and sub-sectors

Source: elaborated by authors based on WRI (2014)

A key difference between both methodologies has to do with the possibilities that the GPC offers to account for emissions that take place outside territorial boundaries, i.e., those in scopes 2 and 3. These emissions may account for a larger percentage in a city and should not be neglected, as has been pointed in several previous studies (Baltar de Souza Leão et al., 2020; Andrade et al., 2018; Sudmant et al., 2018; Athanassiadis et al., 2018).

Another important issue that must be analyzed is how activity data is collected. In general, national inventories are collected based on national data. To develop a city GHG inventory, local input data may not be readily available. Therefore, city level inventories can require more efforts to collect the necessary data to carry out GHG emissions estimates. (WRI, 2014).

3 Materials & Methods

This paper uses two different methodologies and data collection methods to compare the GHG emission inventory results of forty-seven Brazilian cities. These 47 Brazilian cities were chosen because they were the only municipalities to have self-reported their GHG emission inventories up to June, 2021.

The emission inventories of these Brazilian cities were collected from two data sources: (1) the most recent GHG emission inventories self-reported by Brazilian cities, and (2) the results of the GHG emission inventories published by the "System for Estimating Greenhouse Gas Emissions (SEEG) (from the Portuguese: "Sistema de Estimativas de Emissões e Remoções de Gases de Efeito Estufa") for the same cities and same years. All tables and graphs generated in the Results section were also referenced from these two sources.

SEEG is an initiative of the Non-Governmental Organization (NGO) Climate Observatory that comprises annual estimates of greenhouse gas (GHG) emissions for Brazil, analytical documents on the evolution of emissions and an internet portal that provides the system's methods and data. Estimates of GHG Emissions and Removals follow IPCC guidelines (2006). To estimate the emissions of each state and city in the country, SEEG uses national GHG data from the Brazilian National Inventories of Anthropogenic Greenhouse Gas Emissions and Removals, prepared by the Brazilian

Ministry of Science, Technology, and Innovation (MCTI), and data from government reports, institutes, research centers, sector entities, and non-governmental organizations. The methodology used by SEEG was published in 2018 (De Azevedo et al., 2018). The SEEG database is publicly available on its website[20].

Among the 47 cities studied, all self-reported GHG emission inventories followed the GPC methodology, With the exception of Brasília, which used the IPCC methodology. The most recent year for each GHG report varied between 2010 and 2019. The inventories used local data as input data for calculations. Two self-reported inventories estimated emissions of metropolitan regions. However, these reports also identified emissions for each city in these metropolitan regions.

Self -reported GHG inventories were collected through systematic online search, from the websites of the environmental departments in each city, and from international networks of cities, such as ICLEI – Local Governments for Sustainability and CDP – Carbon Disclosure Project.

The research team then carried out a content analysis of both sources to identify: (I) the methodology used; (II) the total GHG emissions; (III) emissions by sector; (IV) emission sources included, and (V) the GWP used in calculations.

Content analysis was carried out for all forty-seven (47) self-reported inventories. SEEG data were also collected for these cities. After an initial comparison of results and identification of significant deviations, it was noticed that not all city inventories used the same Global Warming Potential (GWP) to calculate Greenhouse Gases (GHG) which directly impacted the results achieved. SEEG calculation use the GWP published by the IPCC's Fifth Assessment Report (AR5) (IPCC, 2014) (e.g., CH4 – 28; N2O – 265).

[20] https://seeg.eco.br/

However, some inventories released by cities used AR5 GWP, published by IPCC's Fourth Assessment Reports (AR4) (e.g., CH4 – 25; N2O - 298) (IPCC, 2007), and some did not identify which GWP was used.

Table 4 identifies the forty-seven Brazilian cities that self-reported GHG emissions, the year inventoried, the reference used to calculate GWP and total GHG emissions, according to the GPC and SEEG methodologies:

City	**Year**	**GWP**	**Total Emissions (tCO2e) - GPC (A)**	**Total Emissions (tCO2e) - SEEG (B)**
Americana	2016	AR5	535.805,43	790.150,87
Arthur Nogueira	2016	AR5	81.854,96	119.181,59
Belo Horizonte	2019	AR4	4.160.083,00	4.885.254,39
Betim	2017	AR5	1.914.253,00	3.553.903,08
Brasília	2012	Not specified	7.740.430,00	11.010.289,20
Campinas	2016	AR5	2.663.901,41	3.846.325,80
Canoas	2018	AR4	4.057.643,00	3.396.918,77
Contagem	2018	AR4	1.409.363,22	2.372.735,35
Cosmópolis	2016	AR5	91.629,33	200.702,15
Curitiba	2016	AR4	3.505.045,00	5.413.925,00
Diadema	2014	AR5	1.711.271,00	854.686,79
Duque de Caxias	2014	AR4	2.508.854,00	8.052.116,72
Eng. Coelho	2016	AR5	41.247,18	63.556,49
Fortaleza	2018	AR5	4.523.015,00	5.735.418,37
Goiânia	2010	AR4	2.686.640,00	3.087.598,90
Holambra	2016	AR5	65.603,82	71.310,03
Hortolândia	2016	AR5	238.036,00	397.309,33
Indaituba	2016	AR5	460.918,93	603.435,34
Itatiba	2016	AR5	291.212,63	439.588,36
Jaguariúna	2016	AR5	658.661,21	217.927,92
João Pessoa	2014	AR5	2.837.499,00	3.093.639,73
Londrina	2013	AR5	1.105.964,46	1.745.607,71
Mauá	2014	AR5	1.839.408,00	804.530,67
Monte Mor	2016	AR5	124.320,64	149.958,81
Morungaba	2016	AR5	48.729,86	42.724,63
Niterói	2015	Not specified	1.664.419,12	1.857.908,97

City	Year	GWP	Total Emissions (tCO2e) - GPC (A)	Total Emissions (tCO2e) - SEEG (B)
Nova Odessa	2016	AR5	151.754,49	194.874,19
Palmas	2013	Not specified	646.478,00	919.829,69
Paulínia	2016	AR5	3.993.286,76	4.908.802,88
Pedreira	2016	AR5	107.637,58	134.934,28
Porto Alegre	2013	AR4	2.829.128,00	4.337.359,64
Recife	2017	AR4	3.043.609,00	4.078.189,15
Ribeirão Pires	2014	AR5	747.535,00	265.508,66
Rio de Janeiro	2017	AR5	20.561.900,00	12.307.439,29
Rio Grande da Serra	2014	AR5	161.151,00	47.683,25
Salvador	2018	AR4	3.023.094,00	4.855.175,36
Santa Bárbara d'Oeste	2016	AR5	264.889,94	521.677,53
Santo André	2014	AR5	4.727.848,00	1.850.657,92
Santo Antônio de Posse	2016	AR5	92.484,68	127.631,40
São Bernardo do Campo	2014	AR5	5.307.154,00	2.312.171,19
São Caetano do Sul	2014	AR5	1.343.536,00	424.188,51
São Paulo	2017	AR5	15.418.071,00	18.874.179,33
Serra Talhada	2019	AR4	94.042,44	209.683,50
Sorocaba	2017	AR5	1.492.422,00	1.631.167,29
Sumaré	2016	AR5	597.164,69	879.557,48
Valinhos	2016	AR5	302.905,39	469.135,79
Vinhedo	2016	AR5	196.619,54	248.396,36

Table 4: Total Emissions (tCO2e) GPC x SEEG

The research team tried to reproduce GHG results from reports that used AR4 GWP in AR5 basis. However, due to a lack of transparency about input data used to calculate GHG emissions (Baltar de Souza Leão et al., 2020), GHG results could not be reproduced. It was not possible to convert values for the same base. Therefore, to analyze results, 34 GHG Inventories that used AR5 GWP were considered. Thirteen cities that either used AR4 or did not identify GWP were excluded from the detailed analysis.

All 34 self-reported GHG inventories accounted for emissions from Stationary Energy, Transport and Waste. Twenty reported AFOLU emissions, and five accounted for IPPU emissions. No GHG inventory reported other scope 3 indirect emissions.

SEEG did not estimate IPPU emissions for cities that self-reported this emission source. Therefore, to analyze the difference between these two emission datasets, IPPU emissions were not considered. In the energy sector, there is an important difference between the GPC and IPCC methodologies.

In the GPC methodology, electricity produced outside the city but consumed within its limits is estimated in addition to stationary energy emissions. In the IPCC methodology, which is adopted by SEEG, only energy inputs burned within the municipality are accounted for. Therefore, to compare the results of the two datasets, the GPC energy emissions sector discounts emissions from electricity consumption produced outside of city limits (scope 2 emissions). Figure 1 presents the number of reports in the analysis.

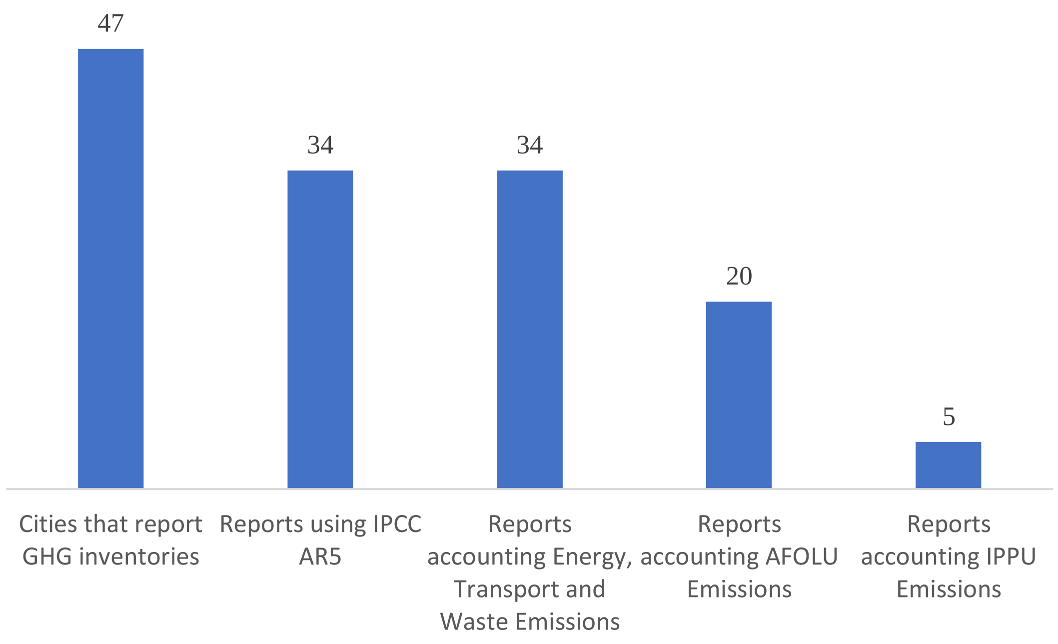

Figure 1: Number of self-reported GHG inventories in this paper

Figure 2 shows the location of all 34 cities analyzed. These thirty-four sample cities accounted for 14.3% of the population in Brazil in 2021 and 22% of the country's GDP (Gross Domestic Product), according to IBGE (2021). there is a concentration in cities located in the state of São Paulo, the most developed and industrialized state in the country.

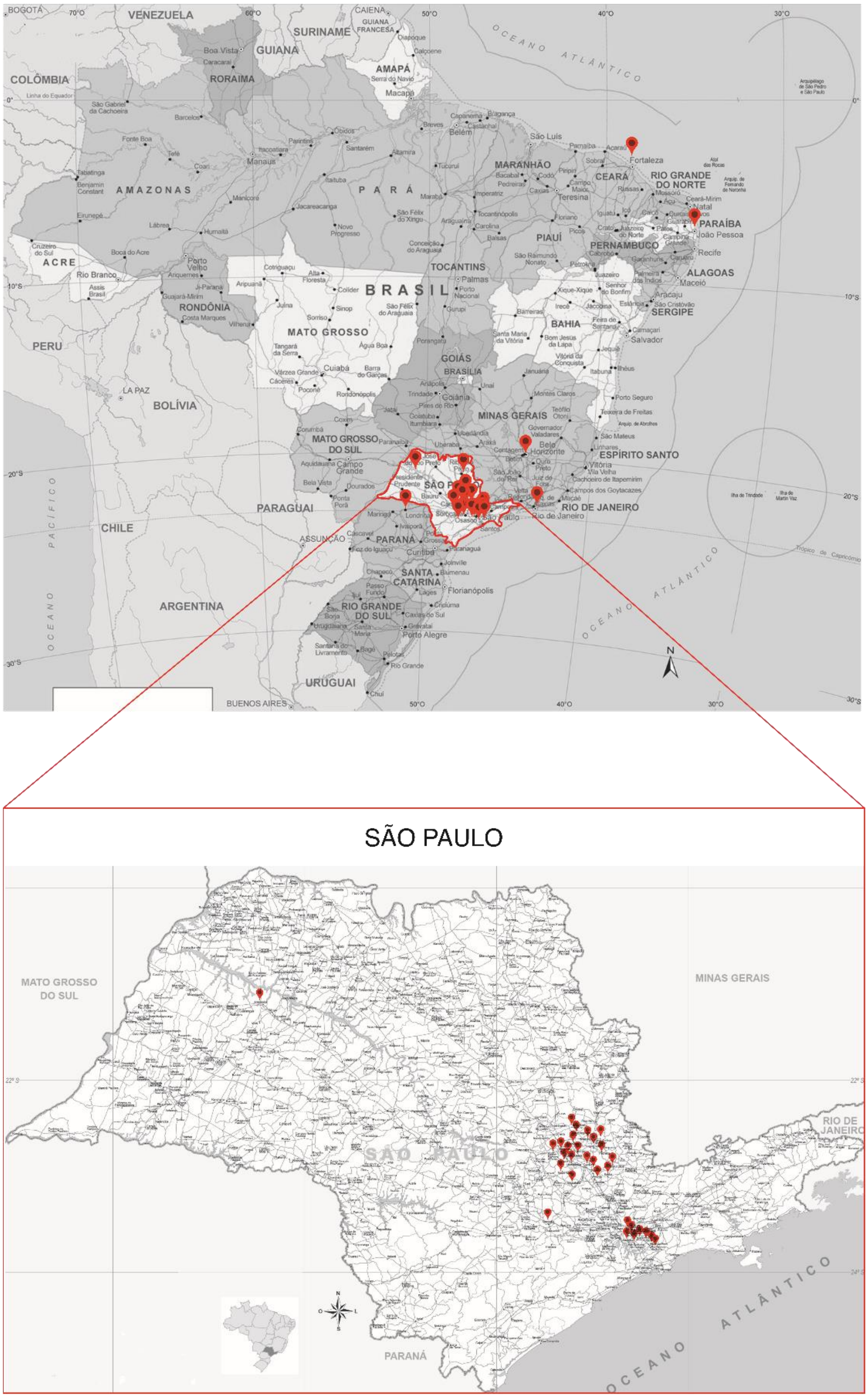

Figure 2: Cities location included in the analysis (In Brazil and in São Paulo state)

GHG emissions results were compared by sector. An analysis of the variations was carried out, considering the literature review. Finally, gaps and limitations of each GHG inventory method were identified.

4 Results

The mean relative difference (MRD) between the two emissions datasets was found to be 8.5% (GPC > SEEG; calculated as [(GPC / SEEG) - 1]), with a mean absolute (unsigned) relative difference (MARD) of 31%. Figure 3 provides the individual city relative differences for total emissions. It should be noted that one of the Metropolitan regions that self-reported its GHG inventory (which comprises the following cities: Diadema, Mauá, Ribeirão Pires, Rio Grande da Serra, Santo André, São Bernardo do Campo and São Caetano do Sul) does not specify scope 2 emissions per city. It only accounts for the entire Metropolitan Region. Therefore, these cities were analyzed together.

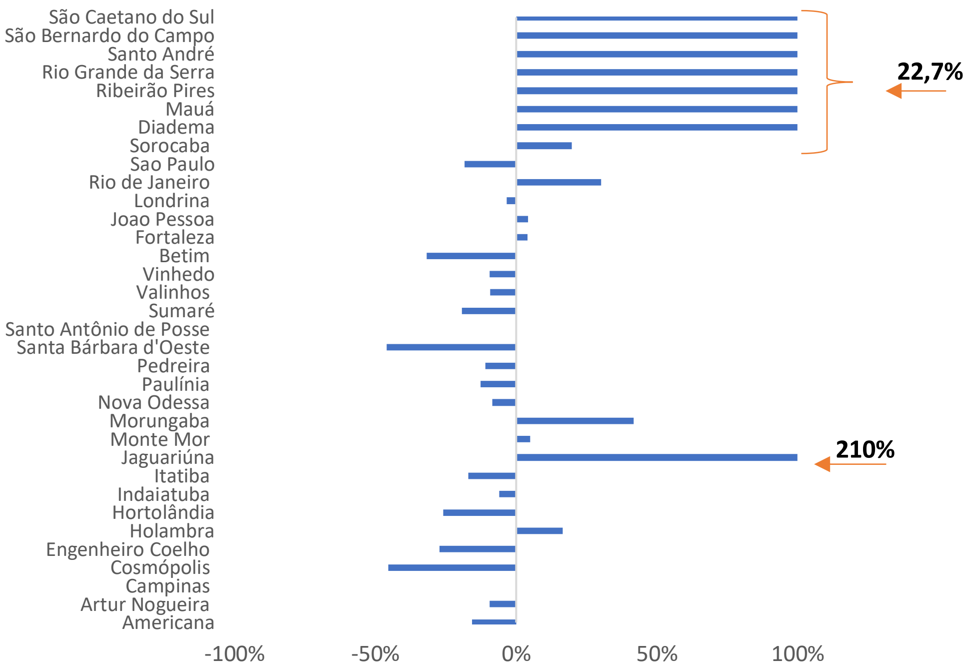

Figure 3: Relative difference (RD) of emissions between GPC self-reported and GHG emission inventories and SEEG emission inventories. Scale capped at 100%. The mean excluded IPPU and scope 2 emissions from GPC results. RD was calculated as follows: [(GPC / SEEG) - 1]).

Table 5 presents the relative difference between the self-reported GHG inventories and SEEG results of sector based individual city emissions.

Table 5: Relative difference of sector-based individual city emissions - GPC x SEEG

City	Energy RD - (%)	Transport RD - (%)	Waste RD (%)	AFOLU RD (%)
Americana	7%	9%	-99%	35%
Artur Nogueira	29%	8%	-82%	51%
Campinas	17%	30%	-73%	81%
Cosmópolis	-40%	-25%	-98%	-25%
Engenheiro Coelho	56%	12%	-100%	-38%
Holambra	137%	-2%	-71%	62%
Hortolândia	12%	7%	-85%	
Indaiatuba	11%	4%	-42%	11%
Itatiba	-1%	3%	-98%	8%
Jaguariúna	7%	6%	1953%	0,2%
Monte Mor	215%	9%	-65%	-7%
Morungaba	50%	8%	-66%	262%
Nova Odessa	20%	9%	-58%	-35%
Paulínia	-31%	23%	-100,2%	-21%
Pedreira	-9%	8%	-52%	-1%
Santa Bárbara d'Oeste	-61%	5%	-98%	-24%
Santo Antônio de Posse	-1%	9%	-63%	23%
Sumaré	-11%	10%	-97%	21%
Valinhos	7%	7%	-78%	-2530%
Vinhedo	-6%	5%	-59%	131%
Betim	-88%	13%	263%	
Fortaleza	-51%	51%	-31%	
Joao Pessoa	-1%	20%	2%	
Londrina	-73%	12%	10%	
Rio de Janeiro	153%	61%	-42%	-397%
Sao Paulo	13%	-1%	-76%	
Sorocaba	31%	2%	41%	

City	Energy RD - (%)	Transport RD - (%)	Waste RD (%)	AFOLU RD (%)
Diadema	-22%	149%	-25%	
Mauá	-22%	200%	-144%	
Ribeirão Pires	-22%	273%	-12%	
Rio Grande da Serra	-22%	745%	-35%	
Santo André	-22%	222%	115%	
São Bernardo do Campo	-22%	164%	-15%	
São Caetano do Sul	-22%	237%	137%	

The average variation [(GPC / SEEG) - 1] for the energy sector was 7.1%. For some cities, however, RD was significant. Monte Mor (215%), Holambra (137%), Rio de Janeiro (153%) and Betim (88%) presented higher variations. In the Transport sector, the mean variation was 67%. Some cities were found to have significant RDs, such as Diadema (149%), Mauá (199%), São Caetano do Sul (237%) and Rio Grande da Serra (744%). Whereas others were found to have very similar results, such as São Paulo (-1%), Sorocaba (1.6%), Holambra (-1.6%). In the waste sector, the mean variation was 19%. However, several cities presented RDs above 100%, such as Jaguariúna (1953%), Betim (263%), São Caetano do Sul (137%), Santo André (115%), Mauá (-144%), and Paulínia (-100,2%). Only 20 self-reported GHG inventories measured AFOLU emissions/removals. The average RD was 119%, with some cities reporting higher values, such as Valinhos (-2530,0%), Rio de Janeiro (-397,3%), and Morungaba (261,6%).

Among all the cities analyzed, SEEG did not estimate IPPU GHG emissions. However, five cities reported IPPU emissions in their specific inventory reports (Rio de Janeiro, Paulínia, Sumaré, Valinhos and Vinhedo), using the GPC methodology.

5 Discussion

Previous studies, which have mainly focused on the reality of the Global North (Gurney et al., 2021; Sudmant et al., 2018; Athanassiadis et al., 2018; Andrade et al., 2018; Ibrahim et al., 2012) have shown that the methodological and accounting approaches used to carry out GHG inventories can impact their results. Emission sources can either be over or underestimated, and uncertainties should always be analyzed (Jonas et al., 2019).

Transparency regarding the assumptions adopted in GHG reporting, which is a principal of both the GPC (WRI, 2014) and IPCC (2006) methodologies, is essential to enabling the reader and user of GHG inventories to analyze a given city's emissions over time and compare them with the results of other cities. The consistency and comparability of GHG emissions data at the city level is one of four remaining gaps in the area of urban climate actions research, according to Mi et al. (2019).

With respect to Brazilian cities that disclose their GHG inventories using the GPC methodology, the principle of transparency has not been followed. The input data for the calculations are not disclosed by the cities, which hinders the ability to reproduce the calculations made and the possibility to recalculate. When, for example, the GWP of a given report is different from another, if the city's input data and calculation methodologies has not been presented, it makes emissions recalculations unfeasible. This result is in line with the findings of Baltar de Souza Leão et al. (2020) and Mia et al. (2019).

This lack of transparency hinders the ability to draw comparisons from city results and among the methodological approaches. It also makes it impossible to assess the accuracy of GHG results, thus breaching other methodological principles.

Completeness is another principle that has not been followed in the inventories. Among the forty-seven GHG inventories, only 26 reported emissions/removals from the AFOLU sector, and only 9 from IPPU. None of the cities analyzed reported other indirect emissions that may be relevant for large urban centers, such as civil construction inputs and food supply. The low number of cities that reported AFOLU and IPPU emissions indicates that the methodologies used to develop GHG emission inventories in cities are not being followed. In other words, there is a difference between the expectations of the methodology and the reality. This result is also in line with the findings of Gurney et al. (2021), Baltar de Souza Leão et al. (2020), and Mia et al. (2019).

This study also showed that, despite some similarities, the differences in the GPC (WRI, 2014) and IPCC (2006) methodologies are enough to significantly affect the results. The possibility to report emissions from a consumption-based perspective afforded by the GPC leads to significantly different results in the energy and waste sectors, for example.

In the GPC methodology (WRI, 2014), electricity consumption within a city is accounted for in scope 2, even when it is produced outside of city limits. In the IPCC (2006) methodology, this source is not measured. Nevertheless, even when removing electricity consumption, several cities presented significant variation (above 50%). In this sector differences should not be high, given that GHG emissions calculations are based on the fuel consumed by cities to generate energy and this data can be collected from official suppliers in the country, such as the National Oil Agency (ANP).

In the waste sector, the IPCC methodology accounts for emissions where the solid waste decomposition occurs. In the GPC methodology, as per scope 3, the city that generates the waste should account for emissions, even if this occurs outside city limits, which is not possible under the IPCC methodology.

The method used to calculate GHG emissions can also impact GHG results. There are two methodologies that can be used to calculate waste disposal emissions. The IPCC default method and the First Order Decay (FOD).

SEEG uses FOD. Given the lack of transparency, it is not possible to know which calculation method was used in the reports carried out by the cities. The main difference between the two methods, according to the IPCC (2006), is that the FOD method produces a time-dependent emissions profile that better reflects the true pattern of the degradation process over time, whereas the default method assumes that all potential CH4 is released in the year that the waste is disposed of. The default method provides reasonable annual estimates of actual emissions if the amount and composition of waste disposed have been constant or slowly varying over time. However, if the amount or composition of waste disposed of at Solid Waste Disposa Site (SWDS) changes more rapidly over time, the IPCC default method will not provide an accurate overview of this trend.

Data collection for inventories can also impact results. In self-report inventories, when using the GPC methodology, data collection appears to provide greater accuracy because it is collected locally. In the SEEG, national emissions data are disaggregated and allocated among the states and cities of the country (De Azevedo et al., 2018). In the case of the Brazilian cities studied, when comparing results from both methodologies, there are significant variations among GHG results between both methodologies. This was true for several cities and for all the emissions sectors analyzed.

One of the possible explanations is the incompleteness of emission sources accounted for in individual reports due to a lack of access to the information necessary to carry out calculations, as has been shown in previous literature (Li et al., 2017b; Andrade et al., 2018). This lack of data at the local level can impact the accuracy of the results, as highlighted by Gurney et al. (2021), Peters, (2008), Afionis et al. (2017) and Franzen & Mader (2018).

However, this cannot be the only explanation, given that all sectors were shown to have several cases in which GHG results from the GPC methodology were higher than those calculated by the IPCC methodology. Once again, given the lack of transparency in the disclosed inventories, it is not possible to carry out a more in-depth analysis of variations, as it is not possible to analyze the input data and calculation methodologies used for each method.

If the GPC methodology is correctly applied, it also allows emissions related to imported products, materials, and goods and services, and the logistics of consumed products, materials, and goods to be accounted for. Moreover, this method provides: (I) consistency between consumption and environmental impacts; (II) responsibility and fairness over consumption; and (III) the possibility to eliminate carbon leakage (Peters, 2008; Dodman, 2009; Larsen & Hertwich, 2010; Grasso, 2016; Afionis et al., 2017; Franzen & Mader, 2018; Sudmant et al., 2018; Andrade et al., 2018).

However, these reports have work to do when it comes to following methodological principles, such as transparency and completeness. GHG Inventories can be costly for a city and may require a technical team, which is not always available (Morin et al., 2021). Therefore, expanding the development of these inventories to a wide range of cities, especially in developing or less developed countries, is a challenging exercise. The Brazilian case shows that by June/2021 only 47 cities among the more than 5,500 had developed their own GHG emissions inventories. In this sense, the SEEG exercise is important. Using the IPCC (2006) methodology and data from the national inventory, emissions were distributed to all 27 states and 5,568 municipalities in the country.

However, some derivations, such as those performed by SEEG, seem to need further refinement to be closer to local measurements. Methodological approaches with large margins of error can lead to mistaken emissions results and, ultimately, inefficient GHG emissions mitigation actions.

Therefore, an important finding of this study is that it is only possible to compare the results of two different methodologies (GPC x IPCC) and of different data collection techniques if the same emissions sources are accounted for in both methodological approaches, and if there is full transparency about input data and the calculation methods used. Otherwise, methods are essentially incompatible for comparison. There are many uncertainties surrounding GHG inventories (Jonas et al., 2019) and efforts are needed to reduce these uncertainties (Mi et al; 2019) given that emissions data are fundamental to guiding climate change mitigation research and actions. Third party GHG verification is recommended to assure that methodological principles are followed.

6 Conclusion

Previous literature has shown that PBA and CBA analyses are complementary. They provide important perspectives toward analyzing a city's impact on climate change (Sudmant et al., 2018; Andrade et al., 2018), and have positive and negative elements (Peters, 2008; Dodman, 2009; Harris et al., 2012; Afionis et al., 2017; Lombardi et al., 2017; Sudmant et al., 2018; Andrade et al., 2018; Franzen & Mader, 2018).

The IPCC methodology (2006), which uses PBA, and the GPC methodology, which uses a combination of PBA and CBA, are the most used by cities to develop GHG inventories. Although they are similar in terms of the sectors and subsectors measured and their principles, the differences between them can produce significantly different results, as demonstrated by Brazilian cities.

This is an alert to GHG emission inventory users. When analyzing and comparing the results of inventories from different cities, it is essential to identify the methodology that was used to calculate them, and to understand the differences between methods.

For public policy developers, it is also important to understand the methodological differences when starting to plan climate actions. An inventory carried out according to the IPCC methodology, for example, does not provide the resources to fully understand the impacts of a population's consumption, or the impact of imported inputs (from construction and food supply, for example), on GHG emissions.

Furthermore, in line with recent literature (Gurney et al., 2021, Baltar de Souza Leao et al., 2020; Mia et al., 2019), it is evident that cities' GHG inventory reports have not been following the principles of transparency and completeness. Many reports do not present information on assumptions, input data and calculation methods, which, thus, hinders any assessments of data accuracy. This lack of transparency in GHG inventories, along with the deficiencies of a detailed description of how the emissions estimated by SEEG have been allocated in each municipality, make it difficult to analyze in-depth variations. Furthermore, some cities do not account for important sectors and sub-sectors in their GHG reports. Relevant emission sources in some cities may be neglected. Therefore, GHG results can be underestimated.

The criticism of this article is not related to emission quantification methodologies, but rather to the way the methodologies have been used. Improving the way the methodologies are used is needed to increase reporting transparency and completeness. Third party verification of cities' GHG emissions is also recommended.

These uncertainties and deficiencies in cities' emissions inventories impact the quality of GHG inventories. Consequently, they can guide climate action plans that ignore important emissions sources, such as consumption patterns among the population and local businesses.

To overcome these gaps, GHG inventories must (I) clearly disclose the methodology used, as well as assumptions, input data, the emission sources included and excluded, and equations for each emission source, and (II) use information technology to estimate GHG emissions according to an integrated production-consumption approach. This would improve consistency and comparability of GHG emissions data at the city level, which is one of the four remaining gaps in the urban climate actions research area, according to Mi et al. (2019).

Given that few cities in Brazil and in other developing and less developed countries have developed emissions inventories, there is an opportunity for policymakers to develop broader, more complete, and more transparent GHG inventories. This would contribute toward more effective local climate action plans.

This paper contributes toward filling several gaps in the scientific literature and provides insights for policymakers. First, this study contributes to the literature by comparing different GHG methodologies among cities by highlighting their similarities, differences, and the precautions that should be taken when analyzing an inventory. Second, it demonstrates that GHG results can vary significantly when different methodological approaches are used. Third, it also contributes to the efforts to reduce GHG inventories result uncertainties aligned with one of the literature gaps highlighted by Mi et al. (2019) and Mia et al. (2019).

As a limitation, this article is focused on the emission inventories of Brazilian cities. Studies using larger samples of cities from different countries and regions are encouraged. More research is needed to compare GHG emission results at the city-level using different methodological approaches. Studies examining methods to improve the comprehensiveness and accuracy of carbon accounting for cities, including methods to facilitate GHG inventory development using CBA, are urgently needed. Moreover, new research could investigate how GHG reports impact climate action planning in cities and examine whether these actions have contributed toward reducing GHG emissions.

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3.3 Article 3: Recife: A Climate Action Profile

Recife: A Climate Action Profile
https://doi.org/10.1016/j.cities.2021.103270

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Abstract

This paper seeks to present the main drivers for climate agenda advance in the city of Recife in Brazil, discussing how geographical characteristics and the historical urbanization process of the city have contributed to the climate risks and vulnerabilities. A city profile is designed and the literature about drivers to cities actions to climate change are used as theoretical basis. The presence of committed leaders, multilevel governance, being part of multinational cities networks and access to funding are traditional fundamental factors identified in the literature to strength climate agenda in a city which were also found in Recife. The climate risks imposed to cities with lower development level were found as important driver to climate action, unlike what previous studies showed for European cities. The article contributes evidencing factors that can decisively assist cities to strength the climate agenda, mainly in developing or less developed countries. It also provides insights for academics and policymakers about low carbon urban strategies that can be adopted by cities. This is the first city profile to address the relationship between the impacts of urban evolution in a Latin American city and the threats imposed by climate change.

Key Words: Recife; Climate Change; Low Carbon Development; Climate Action; Mitigation; Adaptation.

1 Introduction

Data from the Global Convenant of Mayors for Climate & Energy (2021), the largest global alliance for city climate action, built upon the commitment of over 10,000 local governments, shows that cities across the world are taking actions to fight climate change.

Cities are considered the core of the global climate change mitigation and strategic low-carbon development. However, some studies often find that climate change remains ungoverned in cities and, if it is addressed, it is a complement to urban governance, rather than a key topic.

For many cities, traditional issues such as economic growth, sanitation, housing provision and public security are more urgent areas for governance. There is a gap between political rethoric and real action (Van der Heijden, 2019; Castán Broto, 2017).

The interest of scholars in cities' strategies to respond to climate change has increased considerably during the last decade. There is a consensus in the literature that that there is no single route to a low-carbon city. There are many pathways that can be strongly different for cities located in developed and developing world. (Van der Heijden, 2019; Reckien et al., 2018).

In this context, several studies agree that there is a geographical bias of empirical climate governance studies. Existing literature is focused on cities from Global North and developed countries' realities, evidencing a literature gap (Van der Heijden, 2019; Li et al., 2017; Castán Broto & Bulkeley, 2013).

There is a relevant academic discussion on understanding the factors that enable cities to govern local climate action effectively that has advanced significantly over the past decade. This discussion also has a geographical bias, neglecting the global South (Van der Heijden, 2019; Reckien et al., 2018; Romero-Lankao et al., 2018).

To advance in the literature about cities from developing countries, this paper will present a climate action profile of Recife city in Brazil. This Brazilian city is recognized by IPCC (IPCC, 2007) as one of the most vulnerable cities to climate change in the world, due to geographical characteristics and the process of historic urban occupation. It is the first Brazilian city to recognize the state of climate emergency and to establish the goal to become carbon neutral by 2050.

The Carbon Disclosure Project (CDP) (2021) positions Recife among 88 cities in the World that in 2020 led the fight against the climate crisis. According to CDP (2021), these cities have made major progress since the signing of the Paris Agreement, showing that impactful and urgent action is possible. The figure 1 below positions these 88 cities in the world. There are just six cities in Latin America and two Brazilian cities in this list.

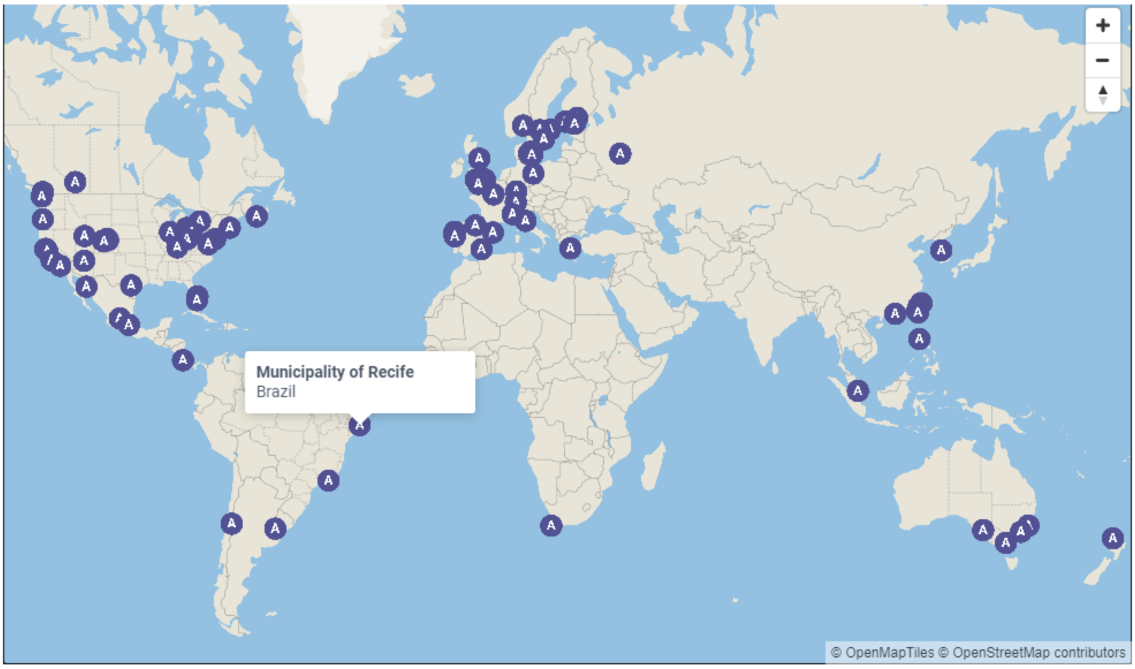

Figure 1: CDP 2020 A List

Source: CDP (2021)

Using the academic debates about the factors that lead cities to effective climate actions, the objective of the article is to discuss the main drivers that contributed to strength the climate agenda in Recife in the last decades and to highlight the importance of specific drivers in the context of developing or less developed countries.

Presenting the historical evolution of the city, the paper also shows how the geographical characteristics and the urbanization process of Recife have contributed to the climate risks to which the city is exposed. In addition, it presents the evolution of climate agenda in the city, highlighting factors that favored low carbon actions adopted and the challenges that the city will have to address in the future.

The article intends to provide information about the low-carbon path adopted by cities located in developing countries, addressing the lack of studies on this reality pointed out in the literature (Van der Heijden, 2019; Li et al., 2017; Castán Broto & Bulkeley, 2013). It also seeks to contribute with insights for academics and policymakers highlighting specific drivers that can help low carbon development in cities that have not yet started this process or are in an initial stage, mainly in developing or less developed countries.

2 Drivers to Climate Action

There are several studies that try to understand the factors that enable city governments to effectively implement local climate action. There is a broad consensus in the literature that these enabling factors work in conjunction (Van der Heijden, 2019). The most important drivers studied by literature are presented at table 1:

Table 1: The most important identified by literature:

Driver	Definition	References
A supportive political and legal context	Regional and national political and legal context influences how local government can develop climate actions	Van der Heijden (2019); Reckien et al. (2015; 2018); Castán Broto (2017).
Autonomy	The city must have the power to act and autonomy for taking urban climate action.	Van der Heijden (2019); Romero-Lankao et al. (2018).
Access to funding for climate action	Access to funding for climate action is considered relevant to urban climate governance. Several cities lack creditworthiness in international financial markets. They do not have the authority to borrow funds independently, and they face restrictive requirements for bidding and procurement.	Van der Heijden (2019); Castán Broto (2017); Aylett, (2015), Bulkeley & Kern (2006).
Multilevel Governance	Local governments are not the only urban actors who can lead and deliver climate action. The understanding of the multilevel nature of climate governance, is considered key in creating a supportive context for climate action. The vertical coordination between a city, regional and national governments and the horizontal coordination across different departments, agencies, and organizations within a city and, when possible, a dedicated climate action agency or working group at city level are also considered fundamental to an effective climate governance at local level.	Van der Heijden (2019); Reckien et al. (2015); Romero-Lankao (2018); Castán Broto (2017); Bulkeley & Kern (2006).
Being part of international networks	Literature shows that being part of city networks positively influences urban climate governance at city. Climate networks foster capacity building, information exchange and, access to financial and political resources.	Van der Heijden (2019); Reckien et al. (2018); Castán Broto (2017); Bulkeley & Kern (2006)

Driver	Definition	References
Presence of a committed leadership	Mayors and other urban political leaders are considered essential for effective urban climate governance. According to Van der Heijden (2019), vocal, charismatic, and experienced city leaders may be able to find connections with other cities and build networks that reach beyond national borders.	Van der Heijden (2019); Reckien et al. (2015); Castán Broto (2017); Bulkeley & Kern (2006).
Climate risk	Climate risk or climate vulnerability is propensity or pre-disposition to be adversely affected by climate change.	Reckien et al. (2015; 2018); Castán Broto (2017)

Another finding of the literature is that there are high levels of policy rhetoric about urban climate governance and the reality of limited activity is still present (Van der Heijden, 2019). Authors (Van der Heijden, 2019; Beermann et al. 2016, Van der Heijden, 2016) says that other agendas as economic development, poverty reduction, sanitation, waste disposal, house providing are more urgent areas for governance.

Although the co-benefits of climate action in cities are highlighted by some studies (Beerman et al., 2016; Gouldson et al., 2015), understanding the relationship between the threats of climate change and the development needs of cities and using this relationship as a driver for strengthening the climate agenda in a municipality is a little explored topic.

3 Recife Geographic Features

Recife is the capital of the state of Pernambuco, located in the Northeast region of Brazil. In 2020, it has an estimated population of 1,653,461 inhabitants, spread over 218.84 km^2, with a high population density of 7,555.47 inhab./km^2 (IBGE, 2020a) concentrated 100% in an urban environment. The metropolitan region of Recife (RMR), formed by 13 other municipalities, constitutes the fifth largest metropolitan contingent in Brazil. The figure 2 shows Recife location in Brazil and in Pernambuco.

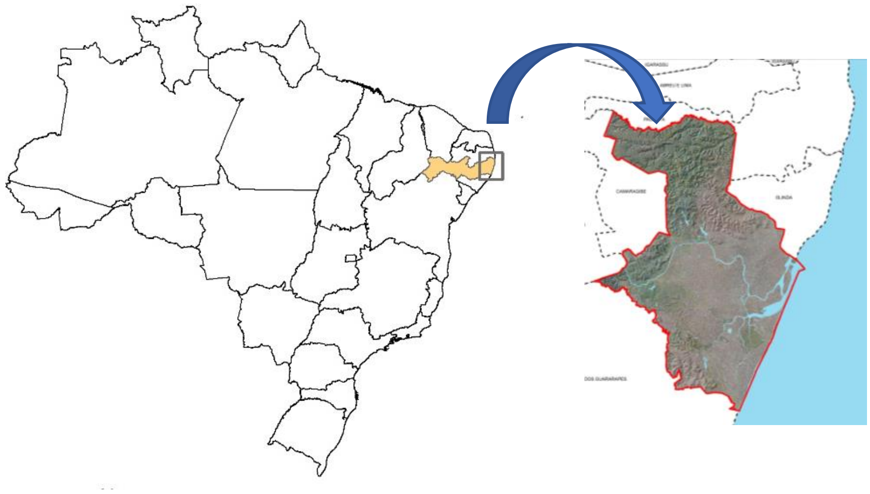

Figure 2 Recife location in Brazil

It is located on the coast of the Atlantic Ocean with an average altitude of 4 meters above sea level. The city, known as “Brazilian Venice”, is cut by four rivers (Capibaribe, Beberibe, Tejipió, Jordão and Jiquiá) and more than 70 canals, artificial drainage elements with 2 meters or more in width (ICLEI, 2020).

The low average altitudes of its territory, the presence of flat areas, the water table close to the surface and outcropping in the rainy season and the influence of sea variation are natural characteristics that hinder the drainage process. Its urbanization process resulted in several areas susceptible to flooding, imposing severe difficulties for drainage and sanitation systems (Recife, 2018).

The climate is humid tropical with a monthly average temperature always above 18 ° C, the average temperature in summer being 30 ° C. The precipitation index is greater than 2,000 millimeters (mm) per year (Recife, 2020a).

Regarding vegetation, there is a predominance of Atlantic forest vegetation, with emphasis on mangroves, a transition ecosystem between terrestrial and marine environments. The largest remnant of Mangroves is the “Parque dos Manguezais” showed at figure 3 below that occupies more than 300 hectares of the city, providing environmental services, such as preventing flooding, the reproduction of typical species and the easing the local thermal sensation.

Figure 3: Mangroves Park (ARIES, 2016)

Recife has a significant preserved green area in its territory. There are 71.6 km^2 of green area, representing 44.3% of its territory and with an index of 46.02 m^2 / inhabitant (Recife, 2018; ARIES, 2016). However, this area is poorly distributed among its more than 90 neighborhoods. Most of them are in private ownership and are not accessible to their population.

4 Urban Occupation Process

4.1 Occupation Start (1537 – 1630)

Occupied by the Portuguese in 1537, Recife is one of the ten oldest cities in Brazil. The city was born from its port, with the function of selling sugar production of the current state of Pernambuco (Leme, 1999; Castro, 1948). Until the 18th century, the flow of goods of the sugar economy for the port was the main driver of its urbanization (ARIES, 2016). An export economy was formed with slave labor imported from Africa.

The arrangement of the Capibaribe, Beberibe and Tejipió river basins guided the occupation, as shown at figure 4. The Capibaribe River is the main body of water that divides the city's territory in half. The estuaries in these basins created the conditions for the plain occupation. The residents' relationship with water resources was totally dependent. The central nucleus of the city at that time was a narrow strip of land, 300 meters long and 80 meters wide where people worked in port activities.

1 – Recife

2 – Olinda Village

3 –Antônio Vaz Island

4 –Jordão River

5 –Tejipió River

6 – Wetlands, current ArrudaChannel

8 –Beberibe River

9 – Sugarcane Plantation Areas

10 – Entrance to Recife Port

Figure 4: Urban Structure in 17th century (Recife, 2018)

4.2 The Dutch Occupation (1630 – 1654)

In 1630, the Dutch invaded Recife to control the production and commercialization of Brazilian sugar in the European market. During the Dutch occupation, there was an accelerated process of urbanization of the city, mainly in the government of Maurício de Nassau (1637 - 1644) (Recife, 2018), and the city was considered the most cosmopolitan city in Latin America (Levy, 2008).

The city elaborated its first urban plan, as shown at figure 5, and, in 1638, the first dam was built, with more than 2 km on the Capibaribe riverbed, to protect Recife from floods. At the end of Dutch colonization in 1654, Recife had about 8,000 inhabitants, spread over an area of 24.7 hectares (ARIES, 2016). Part of the Dutch Jews deported from Recife by the Portuguese migrated to the USA, helping in the formation of New York City (Levy, 2008)

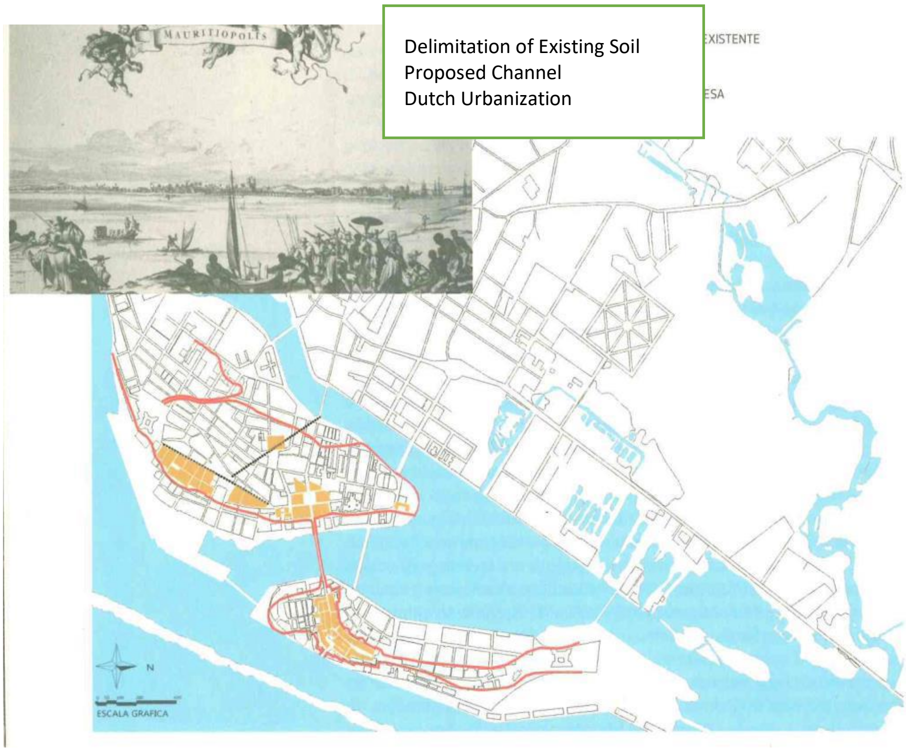

Figure 5: Dutch Urbanization Plan (Recife, 2018).

4.3 From 1654 to the end of the 19th century

With the Portuguese reconquest, the city starts to expand occupying the mangroves. According to Recife (2018), in the 1840s, there was a process of modernization and expansion of the old colonial city, to adapt to the needs of the great economic and demographic growth. Urban structuring interventions such as the implementation of public transport (with railways and steam and electric trams) and the first basic sanitation networks guided the urban expansion that would take place in the following century. Emblematic buildings in the city were also built at that time, such as the Government Palace (figure 6), the Public Library, and the Santa Isabel Theater.

Figure 6: Current photo of the Pernambuco State Government Palace, which was built in 1890.

4.4 From 1900 – 1950: The first demographic explosion

According to Recife (2018), during this period there is a considerable urban expansion, with the occupation of wetlands close to the central regions and the coastal region on the shores of the Atlantic Ocean. The urbanized area was approximately 1,000 hectares in the early 20th century. About four decades later, it was possible to calculate an extension of about 4,000 hectares. In the first half of the 20th century, the city's population had its first major demographic explosion, going from around 200,000 to 500,000 inhabitants, between the 1940s and 1950s (ARIES, 2016).

At the beginning of the 20th century, Recife's growth model was planned to seek: (I) the port remodeling; (II) the creation of a road system capable of uniting it to areas of urban growth and (III) the sanitation of a significant area. The project increased the urban connection, with a strong impact on peripheral growth and, consequently, it required interventions in other areas of the city.

In the 40s, the city started to register the occupation of the hills in its northern zone, because of policies for “mocambos” (precarious housing where the poor population lived) removal in the central area. The period was marked by the expulsion of a significant portion of the poor population to the peripheries. It is estimated that for every three mocambos destroyed, only one house was built, which led to the densification of the hills in the north and south areas and an increasing housing deficit in the municipality (Recife, 2018).

4.5 From 1951 to 1999 - The Urban Expansion

In the second half of the 20th century, the city experienced significant changes. The urbanized area of Recife at the beginning of the 21st century (ARIES, 2016) is about 12 thousand hectares. Twice the urban area of 1960. Between 1950 and 2000, the population jumped from 524 thousand inhabitants to 1.4 million, as evidenced by figure 7.

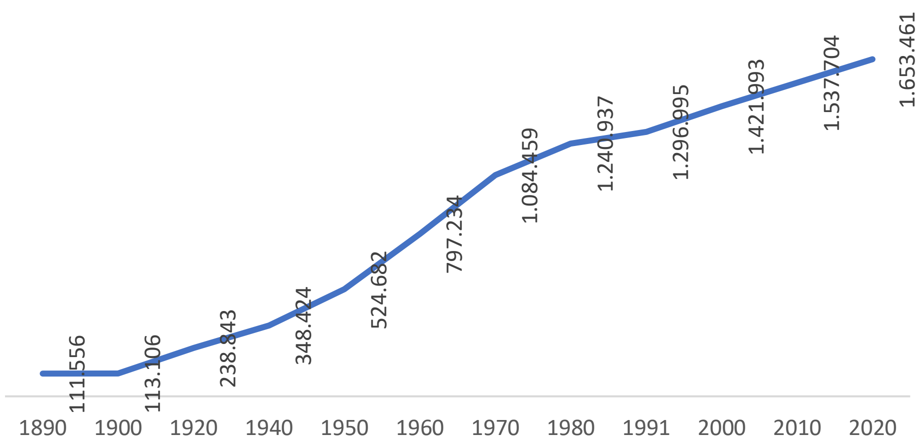

Figure 7: Population Growth from 1890 to 2020

Source: Elaborated by Authors based IBGE data (2020a; 2020b).

The following figure 8 shows the urban occupation evolution in Recife from 1909 to 2018:

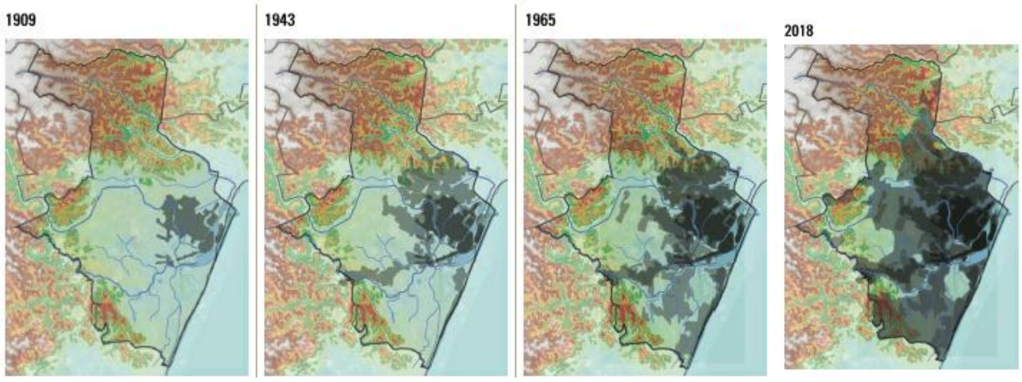

Figure 8: Urban Occupation from 1909 to 2018 (Recife, 2018)

From the 1960s onwards, according to studies published by Recife's City Hall (Recife, 2018), Recife assumed the condition of metropolitan center. The central region consolidates as a commercial region and the suburbs expand.

There is an intensification of rural exodus and pressure for access to urban land. Several families are moved from precarious housing in the central region to territories in need of public services. They are installed in areas such as the hillsides, the mangrove landfills, the banks of rivers and canals (where stilts are built), with no basic sanitation. This process portrays the critical situation of poverty that endures today (SANEAR, 2014). At the same time, the trajectory of densification and verticalization gains scale in the 1970s.

According to Recife (2018), from the 1950s, Brazil opted for a model for expanding the road network, making public transport systems secondary. Recife bases its urban model on the expansion of the road network, with the introduction of expressways and viaducts, to meet the growing demand for individual vehicles.

The urban mobility model based on the road modal was consolidated between 1960 and 1970. This movement was followed by the decline of the tram system, replaced by fossil fuel buses in the 1980s, which remain as the main platform of public transport in the city to the present day.

4.6 From 2000 to 2020

The city expansion occurred much more based on densification than spreading over the territory and it was not followed by infrastructure and services provision (ARIES, 2016).

In 2017, only 43% of the population had wastewater treatment (IBGE, 2020c). Although 99% of the population is connected to the water supply network, almost 26% of the city's population lives with supply on alternate days or do not receive water (SANEAR, 2014).

The social inequality is alarming. According to IBGE (2020c), in 2019, while the average per capita household income of people in the lowest 20% income was R$ 210, the top 20% received an average of R$ 6,268. 25.3% of Recife residents were below the poverty line. They have household income per capita less than U$ 5.5/per day.

The City's GDP in 2017 (IBGE, 2020c) of R$ 51.86 billion is concentrated in service activities (more than 87%). The most important economic activities in the municipality are the activities of civil construction, private health, and food services. It is also a state center for wholesale trade. The industry represents only 12% of the municipal GDP.

The urban mobility based on individual transport increasingly impacts the quality of life of Recife residents. According Detran - PE (2020), in the last 30 years, the number of cars and motorcycles registered in city registered increased by 155% and 1,058%, respectively. According to a TomTom survey (2020), Recife has the 16th worst level of congestion in the world, being the first Brazilian city in the ranking. Its population spends 49% more time to reach its destination due to congestion.

Between 1990 and 2010, the Master Plan and the City's Land Use Law were reviewed on two occasions each, seeking changes in the city's zoning and urban standards. The creation of specific areas for the construction of popular housing (Special Zones of Social Interest - ZEIS) and the Natural Soil Rate, expected to favor soil permeability, are mentioned as advances.

The weakness and often the omission of the public management has led to a more aggressive actions in the real estate market. The city verticalization increased, promoting a high visual impact, as shown at figure 9. Vegetation coverage was reduced. Areas for collective use and public spaces and the population's mobility and quality of life were negatively impacted (ARIES, 2016).

Figure 9: Contemporary urban landscape between Aflitos and Jaqueira Neighboorhoods (ARIES, 2016)

5 Contemporary Challenges and Climate Vulnerabilities

Recife combines low average topography with areas of high declivity, intense urbanization, and high population density. Historically, Recife suffers from extremes of precipitation over areas of inadequate occupation, insufficient drainage infrastructure that, consequently, lead to occurrences of floods and landslides. “The high temperatures, associated with the strong urbanization with poorly distributed green areas, translate into the phenomenon of heat islands. This influences the well-being and thermal comfort of the population. All of these problems can be aggravated by changes in the climate system, caused by greenhouse gases (GHG) concentration in the atmosphere” (Recife, 2019a).

Due to these characteristics, Recife was recognized by IPCC as one of the most vulnerable cities to climate change in the world (IPCC, 2007), occupying the 16th position. It is possible to identify six major vulnerabilities within the city: Floods, landslides, communicable diseases, heat waves, droughts, and sea level rise (Recife, 2019a).

The expectation of higher levels of rain in a short period of time may further worsen the risks of floods and landslides. Throughout its history, Recife has lived with several flood events. The first record of flooding dates from 1632. In the 19th century, Recife reported nine major floods, causing deaths and loss of homes, as well as destruction of bridges, houses, and establishments. (ARIES, 2016). In the 20th century, Recife lived with more than fifteen occurrences. In 1975, about 80% of the city was flooded, displacing 60,000 people (figure 10). In the 1980s, the city invested in dam systems to prevent new major floods (Recife, 2018).

Figure 10: Record of the 1975 flooding (Recife, 2018)

Some characteristics contribute to the constant presence of this threat and increase the risk of landslides to the vulnerable population: (I) The presence of poorest populations in the hills and slopes in precarious housing, without adequate access to urban infrastructure and services; (II) Inefficient or absent drainage systems, (III) suppression of vegetation cover, as well as (IV) irregular dumping of waste on the slopes.

PMBC (2016) predicts for the northeast of Brazil an increase in the frequency of extreme temperatures as well as an increase in the duration of heat waves. Also, the population density and the urbanization patterns of the city (verticalization, paving, waterproofing, poor distribution of green areas, among others) aggravated these heat waves. According to Recife (2019a), children and the elderly are those who will suffer the most from the increase in temperature, especially those with low income. The increase in temperature can worsen air quality and lead to higher occurrences of respiratory diseases.

The socioeconomic vulnerability of part of the population is a factor which increases the risks linked to drought events (Recife, 2019a). It is even a greater risk when the continuous water supply is not yet a reality for a large part of the population (SANEAR, 2014).

The entire population of the city is subject to some degree to the threat of contracting diseases such as Dengue, Zika and Chikungunya, compounding a serious public health problem (Recife, 2019a). The social vulnerability of a significant portion of the population residing in precarious housing and with low access to the health system increases the possibility of contracting these diseases.

Finally, studies show that the annual average sea level in Recife has increased by an average of 0.54 cm / year since 1940. The scenarios of rising sea can cause the flooding of the city’s significant areas (Recife, 2016a). Costa et al. (2010) indicated that the 0.5m elevation scenario by 2100 would produce an estimated flooded area of 25.38 km^2. On the other hand, the elevation of 1 m would flood an area corresponding to 33.71 km^2. Besides that, 81.8% of urban constructions, which are less than 30 m from the coastline are expected to be rapidly affected by the change in the level of current sea. The city's coastline has 45.7% of its extension under a highly vulnerable zone. (Recife, 2019a).

6 Climate Agenda Advance in the City

Recife has, over the past few years, placed itself as an important leader among Brazilian cities in the climate agenda. In 2013, the city joined ICLEI- Local Governments for Sustainability. In 2015, it was chosen as a model city for the Urban-LEDS Project “Accelerating Climate Action through the Promotion of Low Emission Urban Development Strategies”, promoted by ICLEI and UN-Habitat. The project has an engagement of more than sixty cities in eight countries. (ICLEI, 2020). ICLEI is a global network of more than 1,750 local and regional governments committed to sustainable urban development (ICLEI, 2020).

In 2013, the city became member of the CDP Cities – Carbon Disclosure Project, a network for climate change strategies disclosure, with more than 8,400 companies and 900 cities, states, and regions worldwide. The city is also a signatory of the Global Compact of Mayors for Climate and Energy.

Being part of these multinational networks of cities helped the development and strengthening of a technical, institutional, and political framework that made possible climate agenda advance in the city (ICLEI, 2020). The importance of being part of multinational networks is widely recognized in the literature (Van der Heijden, 2019; Reckien et al., 2018; Castán Broto, 2017; Bulkeley & Kern, 2006).

In 2013, the Sustainability and Climate Change Committee - COMCLIMA and the Executive Group on Sustainability and Climate Change – GECLIMA were created (Recife, 2013) to plan, coordinate and execute climate plans and policies in the city. These forums established the municipality's commitment to debate the climate issue in a participatory and collaborative environment, engaging public, private, NGOs and academic institutions.

In 2014, the Sustainability and Climate Change Policy was approved (Recife, 2014), establishing the city's principles and objectives in combating climate change. In the same year, the city prepared its first greenhouse gas (GHG) emissions inventory with 2012 as the base year, and projections of the emissions scenarios until 2040 (Recife, 2014).

In 2015, Recife prepared its first climate action plan, called the Sustainable and Low Carbon Recife Plan (SLCRP) (Recife, 2016a). The city identified the sectors of (I) Transport and Urban Mobility; (II) Waste and Sanitation; (III) Energy and (IV) Sustainable Urban Development as priorities for GHG emissions reductions. Recife established mitigation and adaptation objectives and actions and projected scenarios for the city by 2040, based on 2012 GHG emissions inventory. The city set targets for GHG emissions reductions (Recife, 2015a) seeking to reduce 14.9% in 2017 and 20.8% in 2020 in relation to the Business as usual (BAU) trend scenario of the SLCRP.

In 2017, the city developed its GHG inventory and water footprint for 2013-2015 period with support of the Andean Development Cooperation (CAF) (Recife, 2017). In 2019 (Recife, 2019a), with CAF and ICLEI Support, city's Climate Risk and Vulnerability Analysis was developed. This study mapped main climate risks and threats.

In 2019, Recife hosted the 1st Brazilian Climate Change Conference. In the same year, the municipality recognized the climate emergency and defined the goal of achieving carbon emissions neutralization by 2050 (Recife, 2019b), in line with the commitments established in the Paris Agreement. It was the first Brazilian city to recognize the climate emergency status.

In 2020, the city published 2016 and 2017 GHG inventories and low carbon plan, now called the Local Climate Action Plan (LCAP) (ICLEI, 2020). This plan points the path for the city to become carbon neutral and projects new emission scenarios for the years 2030, 2037 and 2050.

6.1 GHG Emissions Profile

So far, the city has already measured GHG emissions from 2012 to 2017 (Recife, 2012; Recife, 2017; ICLEI, 2020). In all GHG inventories, the city followed the Global Protocol for Community-Scale GHG Emissions - GPC methodology (WRI, 2014) and measured Stationary Energy, Transportation and Waste emissions (Recife, 2014, Recife, 2017; ICLEI, 2020). According to ICLEI (2020), Agriculture, Forestry and Land Use (AFOLU) emissions have not been measured because Recife is a 100% urban city.

However, Climate Action Plan of the City (ICLEI, 2020) considers several actions to strengthen and expand green areas (Recife, 2016a; ICLEI, 2020) and particularly counts on emissions compensation as an important instrument for climate neutralization by 2050. Carbon stock variation of AFOLU shall be accounted in the city's emissions inventory. Without this, climate benefits of planting trees in the city are not measured.

Industrial Processes and Product Use (IPPU) was not accounted either because IPPU activity was not a considered a significant emission (Recife, 2014, Recife, 2017).

Recife GHG inventories follow a production-based approach (PBA) instead a consumption-based approach (CBA) (Recife, 2014, Recife, 2017; Baltar de Souza Leão et al., 2020; Andrade et al., 2018). Emissions related to the final consumption of goods and services have not been accounted. This fact is particularly important when Recife GDP is 87% based on Services. Following PBA, Recife emissions may have been underestimated in these GHG inventories (Baltar de Souza Leão et al., 2020; Andrade et al., 2018; Lombardi et al., 2017).

The consumption-based approach can offer a broader diagnosis of the city's emissions, also considering the consumption patterns of its population (Baltar de Souza Leão et al., 2020; Andrade et al., 2018) and direct efforts towards more sustainable consumption in the city. In addition, as the center of a metropolitan region, Recife has its urban dynamics intertwined with 13 more cities. Climate impacts and risks can be better understood, if also seen in a metropolitan way.

GHG Inventories result shows that On-Road Transport is the main emission source of the city during the period (from 32% to 45% of the total). This fact evidences the impact of urban mobility to GHG emissions. Recife is also an important touristic and business hub of the Brazilian northeast, which explains the relevance of Aviation (between 17% and 21% of the total emissions). The disposal and treatment of solid waste is the third more important emission source requiring education campaigns to sustainable consumption and technologies to avoid GHG emissions during solid waste treatment. At the Stationary Energy sector, electricity consumed by residential and commercial buildings and petroleum liquified gas used by residential building are the main emission sources during these years. The figure 11 presents emission by subsectors[21]:

[21] At this Graph, Stationary Energy Sources are initiated by the acronym "EN"; Transport by "TRANS" and Waste by "WAS".

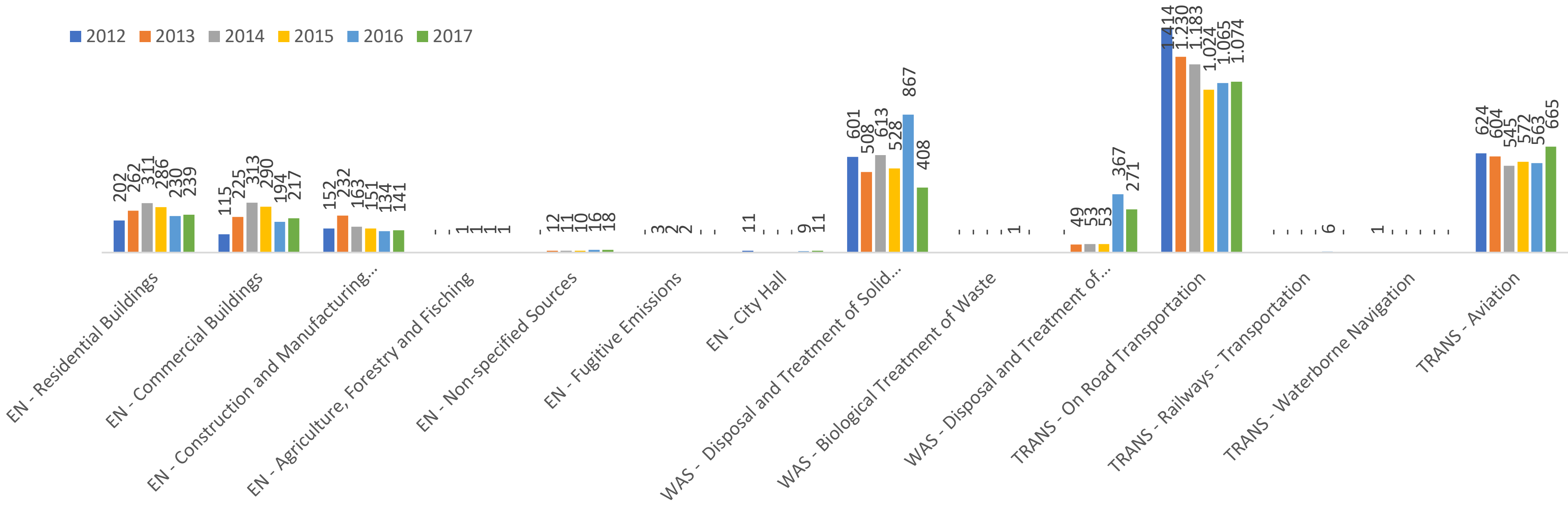

Figure 11: Recife GHG Emissions by sub-sector (1,000 TCO_2e)

Source: Elaborated by Authors based on Recife GHG Inventories (Recife, 2014; Recife; 2017; Recife; 2018)

In 2017, GHG emissions were 2.4% lower than 2012 results. The main reduction was related to on road transportation and disposal and treatment of solid waste. In urban mobility, the decrease (-24%) may be associated with the policies for prioritizing collective and active transport, in conjunction with the highest percentage of ethanol in gasoline (from 20% in 2012 to 27% in 2017) and biodiesel in diesel (from 5% to 8%). Emissions from disposal and treatment of solid waste decrease 32% due to methane burning at the landfill that receives the city's waste.

6.2 Climate Action Plans

Two plans to combat climate change were already released by the city. The first one, called the Sustainable and Low Carbon Recife Plan (SLCRP) (Recife, 2016a), was based on the 2012 GHG inventory and released in 2016. It designed scenarios until 2040 and established action plan by sectors that resulted in the GHG emissions reduction goal established by the municipal management.

The second is the Local Climate Action Plan (LCAP), drawn up in 2020. It is based on 2017 GHG emissions inventory and on the Climate Risk and Vulnerability Analysis (Recife, 2019a) to design emissions scenarios until 2050 and to indicate the strategies to achieve carbon neutrality (Recife, 2019b).

In the SLCRP (Recife, 2016a), two scenarios are projected: (I) The BaU scenario, which shows GHG emissions trajectory, considering the absence of actions by the municipal management to combat climate change; and (II) the Mitigation Scenario, which considers the impacts of GHG emissions reductions projected from actions that the municipal government planned.

In addition to the BAU and Mitigation scenarios, LCAP considers an ambitious scenario that leads the city to achieve carbon neutralization in 2050, in line with the commitments of the Paris Agreement (UNFCCC, 2015).

LCAP's mitigation scenario contemplates not only the actions that municipal government planned and executed but also the technological developments in the energy and mobility sector. The ambitious scenario considers, besides mitigation actions, bolder measures, and compensation actions (ICLEI, 2020).

In both plans, four sectors are identified as priorities: Energy, Sanitation, Mobility and Resilience. The SLCRP calls the Resilience sector as "Sustainable Urban Development" (Recife, 2016a; ICLEI, 2020). But both refer to measures related to adaptation to climate change and urban planning that, in some cases, interrelate with mitigation measures. The plans projects goals, objectives and details of actions are presented.

The energy sector was chosen as a priority, because the BaU scenario points to a 139% emissions growth by 2050 (ICLEI, 2020) and, according to Gouldson et al. (2015), the total expenditure of the city on energy would grow 162% by 2030. Ensuring that the energy supply necessary for the city growth happens based on energy efficiency and clean energy sources is the great objective of the city in this sector.

Energy efficiency projects in public lighting advanced through the (I) Ilumina Recife Program, which predicts 100% of public lighting with LED lamps by 2021, and the (II) Environmental Sustainability Certification Program for Real Estate Developments (Recife, 2016b), which certifies buildings that adopt sustainable measures to reduce the GHG emissions and environmental impact and (III) measures of energy efficiency and rational use of water in new public buildings (Recife, 2019c). In addition, pilot projects have been developed, such as the energy efficiency and photovoltaic generation project at the Recife Woman Hospital.

The LCAP (ICLEI, 2020) foresees bold measures that seek the city's energy supply through 100% Renewable energies, the definition of an energy efficiency target and efforts to reduce and offset emissions from fossil fuels. However, all these measures are still in the initial planning stage, dependent on the commitment of future management and multilevel coordination.

Energy actions implemented so far are mainly considered low cost within the scope of what the municipal management has control over. This reality is in line with the findings found in European cities (Pablo-Romero et al., 2018; Castán Broto & Bulkeley, 2013; Bulkeley & Kern; 2006).

The LCAP choose the sanitation sector, which includes the management of solid waste and the wastewater treatment, as a priority to serve the city’s demands due to the poor rates of recycling and reuse of solid waste in the municipality (0.8%) (ICLEI, 2020) besides the low percentage of the population with access to wastewater treatment (43%) (IBGE, 2020c).

According to LCAP (ICLEI, 2020), the advancement of reuse and recycling and sanitation rates should occur with technologies that burn or generate electricity from methane released at both treatments. The energetic use of biogas generated by the waste at the landfill has already been installed. It is already providing GHG reductions. The responsibility for advancing the city's sewage treatment lies on a public-private partnership to reach 90% of households with sewage collection and treatment by 2037. LCAP (ICLEI, 2020) makes it clear, however, that the use of methane in wastewater treatment still must be articulated.

Also, the relevance of transport emissions (Recife, 2012; Recife, 2016a; ICLEI, 2020) justifies the sector as a priority. In addition, as previously mentioned, urban mobility is a problem in the daily lives of the city's population. GHG emission reduction in urban mobility necessarily requires a migration from individual transport to collective and active transport (walking and bicycles) and the use of less emitting fuels in the individual cars. LCAP (ICLEI, 2020) foresees this migration, aligned with the initiatives of European cities (Pablo-Romero et al., 2018; Croci et al., 2017).

Recife has made considerable progress in offering bicycle infrastructure (figure 13), recovery of sidewalks and exclusive bus lanes (figure 12). The following actions can be mentioned: (i) the revision of the mobility plan; (ii) the implementation of over 60 km exclusive bus lanes; (iii) the *Calçada Legal* program, with the requalification of 134 km of sidewalks and (iv) the increase of the bicycle infrastructure from 24 km in 2013 to 140 km in 2020 (ICLEI, 2020).

However, more than just infrastructure offerings are needed. The lack of thermal comfort and the high rates of urban violence are challenges to be faced to increase the use of public and active transport (ICLEI, 2020). The advancement of green areas, for example, must be executed in a coordinated manner alongside the institutions responsible for mobility projects, since the shading of green areas on cycle paths and sidewalks can attenuate high temperatures, benefiting active transport. The need for horizontal coordination of actions must be highlighted.

Figure 12: Bus exclusive lane in Recife (Mobilize Brasil, 2020).

Figure 13: Bike lane in Recife (Jornal do Comércio, 2020).

LCAP (ICLEI, 2020) also foresees technological developments in the automotive and aviation sector, with the adoption of more efficient fuels and technologies. Otherwise, regulations that encourage these technologies are necessary.

Another challenge in the transport sector is the increase in emissions from air transport, which represent more than 20% of the city's total emissions. LCAP BAU scenario points to a growth of 165% of these emissions until 2020 (ICLEI, 2020).

To achieve carbon neutrality by 2050, measures to compensate unavoidable emissions were set. According to LCAP (ICLEI, 2020), the legal framework necessary to demand compensation must still be created by 2024 and strategies will still be defined.

Emissions compensation is responsible for 48% of the city's emission reductions in 2050 (ICLEI, 2020), showing that over time, the city needs to review and incorporate new mitigation measures with even bolder results.

In the Resilience sector, there are goals and actions to combat threats identified in the Risk and Vulnerability Analysis (Recife, 2019a). The city's objective is to expand the ability to anticipate, prevent, absorb, and recover from extreme shocks and events, improving its response capacity (ICLEI, 2020).

The expected heavy rainfall in short periods of time are relevant threats to the city due to its geographic characteristics. And these risks are even higher by the relevant amount of low-income population residing on hills and hillsides in houses without basic infrastructure (ICLEI, 2020).

LCAP has among its objectives (I) to reduce by 100% the areas of remarkably high risk of landslides and floods in accordance with the Risk Reduction Municipal Plan and (II) to urbanize these risky areas with the aim of bringing security, quality of life and making it possible to face climate threats by 2037.

The high rainfall volume concentrated in time also increases the risk of flooding, which is aggravated by the city's low drainage capacity (ICLEI, 2020). The city intends to use existing water courses as structural elements of the territory and to strengthen nature-based solutions.

It is essential to strengthen the green infrastructure formed by rivers, canals, riparian forests, and mangroves, restoring, and reconnecting the natural spaces of the watercourses, recovering, and preserving them for water drainage (Recife, 2018). LCAP plans to (I) review, by 2025, the Municipal System of Protected Units (SMUP) and (II) to make progress in promoting the afforestation and using sustainable infrastructures (such as green roofs) that can mitigate the islands and heat waves.

Coordinating efforts and defining the best strategies to deal with sea level rise and to assure water access for all population are also challenges addressed in the LCAP. The plan shows that there is not yet a specific working group and a strategic definition for adapting to the sea level rise, which has already occurred in the city.

To increase the city's resilience, the city implemented actions that: (I) conserve green areas, providing access, such as the implementation of part of the *Parque Capibaribe* Project, the Arborization Plan, and the approval of Protected Areas System; (II) improve city's drainage capacity, such as the Master Plan for Drainage and Rainwater Management and the Law on Green Rooftops and Retention Reserves (Recife, 2015b) and (III) promote mitigation actions related to landslides risk. In this sense, the Master Plan and the Land Use Law are under review, considering the threats climate change imposes on the city (ICLEI, 2020).

It is worth highlighting the *Parque Capibaribe* project (figure 14), which includes a system of integrated parks along 15 km on each side of the Capibaribe River, reaching 30 km of transformations at the edges of the city's main watercourse. It includes wide sidewalks, cycle routes and bridges that allow crossing via active transport between the banks. The objective of the project is to transform Recife into a park-city, reconnecting the river to the citizens lives.

Figure 14: Illustration of Parque Capibaribe Project.

Recife (2020b)

LCAP's climate change adaptation measures are considered in the Resilience sector (ICLEI, 2020). Thus, the LCAP integrates mitigation and adaptation measures in a single instrument. This is already a notable fact. According to Reckien et al. (2018), assessing local climate mitigation and adaptation plans across 885 urban areas from EU-28, 66% of European cities had only mitigation actions in their plans and only 17% had mitigation and adaptation actions in their local climate plans.

Through CITinova project, funded by the Global Environmental Facility (GEF), the city will develop sectorial adaptation plans by 2022. In addition, it will be implemented innovative pilot projects, such as the filter gardens and solar powered boat for crossing Capibaribe river.

All measures adopted between the SLCRP and the LCAP have already resulted in GHG reductions, in addition to changes in the projected curves in the emission scenarios. According to ICLEI (2020), 2017 emissions were 2.46% lower than 2012 and 17.7% lower than the level projected at BAU scenario of SLCRP, exceeding the target established by city government of 14.9%. The results were also 7.69% lower than the mitigation scenario outlined at that time.

6.3 Drivers to Climate Action

Recife presents significant advances in the climate agenda. Some factors were important for this evolution. This experience can also contribute for the insertion and advancement of climate actions in other cities around the world, especially in developing and less developed countries.

6.3.1 Presence of a Committed Leadership

The climate agenda advance in the city coincides with the city management by a Mayor sensitive to the theme, whose mandate took place from 2013 - 2020. In addition to having sealed the city's entry to international networks, such as ICLEI, CDP and Global Compact of Mayors for Climate and Energy, this Mayor directly sponsored mitigation and adaptation actions. Since 2019, he became the first Brazilian mayor to occupy the position of President of ICLEI South America. He actively participates in the UNFCCC Conference of the Parties and in city events related to climate change.

Committed Leadership is highlighted by several authors as essential for strengthening the climate agenda in cities (Van der Heijden, 2019; Reckien et al., 2018; Castán Broto, 2017; Bulkeley & Kern, 2006).

However, the end of management occurs in 2020. It is necessary to strengthen the climate agenda institutionally. Also, it is fundamental to engage leaders from public, private, and non-governmental institutions. In the two last years of the mandate, it was observed weakening of the Secretariat for the Environment and Sustainability (SMAS), home of the climate agenda in the municipality. There was also a demobilization of a relevant part of the technical team involved with climate agenda. This can generate a technical weakening and the loss of knowledge accumulated by the city.

6.3.2 Being part of International Networks

The participation in cities' international networks was fundamental for climate change advance in Recife. It allowed the city to have technical and financial support to create and strengthen municipal legislation on the climate issue; build technical capacities; raise funds; give visibility to the city's actions, allowing cooperation with other cities and international institutions. To be part of international networks is an important driver for climate agenda advance, recognized by several authors (Van der Heijden, 2019; Reckien et al., 2018; Castán Broto, 2017; Bulkeley & Kern, 2006).

6.3.3 Access to funding for climate action

In recent years, Recife participation in multinational networks of cities has favored access to financial resources for technical support in studies, plans and projects to combat climate change, such as GHG inventories, Climate Risk and Vulnerabilities Analysis, the Climate Action Plans and the Sectoral Adaptation Plans.

Accessing these resources and expanding the sources for executing the climate actions is fundamental (Van der Heijden, 2019; Castán Broto, 2017; Reckien et al., 2015). Moreover, it seems essential continuing to participate both in the multinational networks of cities, as well as in international events related to the theme, with strong commitment from municipal leaders.

The existence of committed leadership, a multilevel governance mechanism, being part of an international network and having access to funding for climate action are drivers for climate action known and debated in the literature.

However, the actions of the Recife Climate Action Plan, which will be presented in the next section, are related to its development priorities, also that the socio-economic and infrastructure gaps in Recife, as in other cities in least developed or developing countries, are also drivers of climate action.

6.3.4 Multilevel Governance

Several studies consider that local governments are not the only urban actors who can lead and deliver climate action. Instead, a myriad of state and non-state actors plays key roles in climate change governance. (Van der Heijden, 2019; Romero-Lankao et al., 2018; Castán Broto, 2017). A range of other non-state actors, including business, networks, and communities, are a vital part in the governance of climate change in urban areas, opening new areas of intervention and supporting action where there is little capacity. Supra-national levels and international organizations also play a crucial role in informing regulation and enabling innovation.

Collaboration between a wide range of stakeholders will improve the outcomes of urban climate governance. Actors at state and national level provide crucial support to local governments and may lead actions at the local level.

In a similar vein, horizontal coordination is also considered a relevant condition in urban climate governance trajectories that spur on climate action. Coordination across different departments and organizations within a city is fundamental. A dedicated climate action body or working group at city level may help traditionally organized departments to break out of these siloes and achieve synergies (Van der Heijden, 2019; Aylett, 2015).

COMCLIMA and GECLIMA are the environments where this multilevel governance takes place in the city of Recife. Promoting effective multilevel governance and participation is fundamental for climate agenda institutionalization and strengthening in cities (Van der Heijden, 2019; Romero-Lankao et al., 2018; Castán Broto, 2017).

6.3.5 Autonomy

The effect to which cities and those within them can govern climate action also depends on their autonomy for taking urban climate action and governing local affairs (Van der Heijden, 2019; Romero-Lankao et al., 2018)

In Recife case, sanitation, and water supply, for example, are the responsibility of the state government and the management of the Airport and airspace are federal responsibility (ICLEI, 2020). Electricity supply is responsibility of private institutions. The autonomy of local government is limited in these sectors. Thus, actions to combat climate change in these sectors do not take place, without vertical multilevel articulation. Local government has the power to coordinate efforts, to promote discussions and to influence actions, through appropriate public policies. However, the results will only be effective with the direct involvement of these actors, highlighting the importance of multilevel governance.

6.3.6 A supportive political and legal context

Reckien et al. (2018) evidence that the existence of national regulation that makes local climate plan development mandatory has a significant impact on local climate action. Countries with national climate legislation (A2), such as Denmark, France, Slovakia and the United Kingdom, are found to have nearly twice as many urban mitigation plans, and five times more likely to produce urban adaptation plans, than countries without such legislation.

There are no federal or state legal requirements that require the city of Recife to develop inventories of greenhouse gas emissions and climate action plans. In the Brazilian context, these initiatives are voluntary, as is the Recife case.

Brazil has had a national policy on climate change approved since 2009. It ratified the Paris Agreement, assuming commitments to mitigate and neutralize GHG emissions by 2060. Actions to achieve the commitments assumed are carried out at the federal level, without direct involvement of the municipalities. Since 2018, the Brazilian Federal Government has been adopting contradictory attitudes in relation to its historical constructive position to multilateral agreements to fight climate change. Federal support for cities for climate action plans does not exist. There is no participation of federal government institutions in the climate discussion environments of the city of Recife (ICLEI, 2020; Recife, 2013).

At the state level, the state of Pernambuco, where the city of Recife is located, also does not require climate action plans from its municipalities. There is a defined climate change legal framework in the state (ICLEI, 2020). However, there are no specific requirements for municipalities in favor of climate action. The State developed its first GHG emissions inventory in 2020 and is updating its climate action plan, prepared in 2010. The participation of state institutions in COMCLIMA and GECLIMA is limited (ICLEI, 2020; Recife, 2013).

6.3.7 Climate Risks

Recife has experimented extreme rain events and flooding during all centuries of its existence. Landslides in hillside areas occupied by vulnerable populations have also been part of the city's history. The identification of the six main vulnerabilities and risks that climate change will impose to the city (Recife, 2019a) exposed urgent need to action, which led to the climate neutrality goal.

Reckien et al. (2015) analyzed 200 large and medium sized cities across 11 European countries. Their result suggest that climate risk is not an effective driver of climate action. They highlight that “is noteworthy that risk is not an effective driver of climate change action even in high-risk areas”. Another noteworthy result of this study is that being at risk of flooding from sea level rise was not as a driver for climate change plans. Climate Risk was either not found as important driver, when analyzing 885 European cities in Reckien et al. (2018).

Despite these previous studies, in Recife case the climate risk and potential impacts due to city development needs are an important driver. (I) The existence of irregular housing on the seacoast; (II) the inefficient drainage systems; (III) the low sanitation coverage and (IV) the irregular waste disposal at the hills and slopes are characteristics of the city caused by its historical occupation and development process. The predictions of higher rain levels in a short period of time and sea level rise make the city even more vulnerable to landslides, floods, offering risks to the local community, mainly to the low-income population demanding an urgent response from the local government for climate action. Severe droughts and heat waves in a city where more than 25% of the population does not have daily access to water is another factor that worsen the risk situation of the most vulnerable people.

The need to promote climate mitigation and adaptation actions that address development problems, and the climate vulnerabilities underpinned the climate action plans developed by the city so far and constituted an important driver for climate action in the city.

The table 2 presents a brief analysis of how each driver contributed to climate action in Recife.

Table 2: Analysis of drivers impact for climate action in Recife

Driver	**Analysis**
A supportive political and legal context	Although there is a legal framework that favors climate action, there is no technical and financial support for these actions. There is no participation of federal institutions in the city's climate governance and state participation is limited (ICLEI, 2020; Recife, 2013). This was not a positive driver.
Autonomy	The municipal government does not have management over some sectors that are important for mitigating climate change, such as sanitation, energy, air transportation and airspace. The measures contained in the LCAP predicts articulation with the responsible institutions, but are still at an early stage (ICLEI, 2020). This was not a positive driver.
Access to funding for climate action	Recife could access international funds from ICLEI, European Union, UN-Habitat, CAF and Global Environmental Facility (GEF) for climate action (ICLEI, 2020). This was an important driver to make your actions feasible.
Multilevel Governance	COMCLIMA and GECLIMA, forums engaging public, private, NGOs and academic institutions, are the environments where this multilevel governance takes place in the city of Recife (ICLEI, 2020; Recife, 2013). Climate plans, policies and actions are debated and decided at these forums. The existence of this forum was an important driver to legitimize climate decisions. Horizontal coordination happens satisfactorily with engagement of several local administration department. However, vertical coordination is weak. There is no engagement from Federal Government and low participation from state-government agencies.
Being part of international networks	Being part of international networks of cities committed to fight climate change as ICLEI and CDP was one of the most important drivers for strengthening climate actions in the city. With ICLEI support, Recife could access financial and technical resources to develop the local climate action plans and Climate Risk and Vulnerability Analysis. The city could exchange experiences with other national and international cities and promote capacity building.
Presence of a committed leadership	The presence of a committed leadership was fundamental for climate agenda advance in the city, sponsoring: (I) the access to international networks international; (II) studies, plans and mitigation and adaptation measures; (III) policies to combat climate change and (IV) structuring specific department and team to deal with climate change issues
Climate risk	The identification of the six main vulnerabilities and risks that climate change will impose to the city (Recife, 2019a) guided several measures

Driver	Analysis
	and projects of the LCAP. The climate risk and potential impacts due to city development needs was an important driver for local climate action in the city.

7 Final Remarks

The existing literature about climate governance and drivers to local climate action is focused developed countries' realities, evidencing a literature gap.

This case study examined how climate agenda advanced in the Brazilian city of Recife, discussing the main drivers and barriers. Legal framework and institutional mechanisms for population participation in climate decisions were implemented. GHG emission reductions was already achieved, and mitigation and adaptation actions have been implemented.

It was clear that in addition to the traditional drivers found in the literature, such as the presence of a committed leadership, being part of international networks, multilevel governance, and access to funding for climate actions, the climate risks offered in a city with a lower socio-economic development level is one of the most relevant drivers. These risks guide the main actions present in the city's climate action plans. A supportive political and legal context was not found as positive driver and for sectors that the city has no autonomy to act, climate measures are in the initial stage.

Recife's geographic characteristics, urbanization process and socio and economic development needs increase the threats imposed by climate change. The projected climate change impacts for Recife are challenging. They already have consequences for the urban environment and affect the city's population, especially the most vulnerable groups.

Previous studies did not identify climate risk as relevant for European cities (Reckien et al., 2015; Reckien et al., 2018). However, in the context of cities in less developed countries, climate impacts and risks are even more severe. Thus, considering climate risk as one of the most important drivers for strengthening climate governance in the city is the principal theoretical implication of this paper.

As contributions for policy makers, mainly in cities that are severely impacted by climate change and are in the early stages of developing low-carbon strategies, especially in developing and less developed countries, can exploit these drivers to strengthen their climate agenda and structure actions to combat climate change. As contributions for policy makers of this kind of cities, the path adopted by Recife can serve as an example for these cities in their climate planning.

Some challenges remain and can be found in other cities. The institutionalization of the climate agenda is fundamental to avoid interferences due to changes in the city's political management. The formation of climate leaders must be perennial in all spheres of society, especially of public management team. The training of these professionals is essential to reduce the need of external support.

The multilevel governance and the mechanisms for participation must be strengthened and institutionalized. They must enable an increasing participation of federal and state institutions, civil society, NGOs, and private sector.

The continued presence of the city in the multinational networks seems fundamental for moving forward for capacity building, finance, and cooperation with other cities.

Finally, a more accurate and complete GHG inventory, also considering the consumption-based approach and, a metropolitan climate risks and vulnerabilities assessment, can provide a more complete diagnosis of the city's climate impacts and threats and more inputs to climate action plans.

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3.4 Article 4: Drivers and barriers of climate actions in cities of the Global South: Evidence from the city of Recife, Brazil.

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Abstract

To explain the insufficient uptake of climate policies and actions, scientific studies identify drivers and barriers of policy development and implementation. However, the most part these studies focus their attention on the actions of the Global North and their related drivers and barriers. Few studies have been carried out examining cities in the Global South. This paper presents the climate actions adopted in the city of Recife, Brazil and examines the main drivers and barriers to their effective implementation. The theoretical basis for this case study is grounded in the literature surrounding climate actions, and the drivers and barriers to climate governance. Results of the analysis indicate that Recife has implemented important energy, transport, and waste mitigation actions. Moreover, the city has also established climate adaptation policies and actions, particularly in the fields of engineering and the built environment, ecosystem-based solutions, education, and information. However, it remains at the early stages of developing technological and economic measures to promote climate adaptation actions. The drivers identified include having committed leadership and being part of a multinational network of cities, which supports existing theory, as well as identified climate risks, much in contrast to other European cases. Additionally, in contrary to other cases, funding for climate action is not considered a barrier. It is fundamental to institutionalize the climate agenda in the local government to avoid political interferences, which was considered a primary barrier. This article provides insights to academics and policymakers on low carbon strategies for cities. Moreover, it suggests steps that can

assist cities to adopt climate actions, particularly in developing or less developed countries.

Key Words: Climate Action; Climate Governance; Low Carbon Development; Mitigation; Adaptation.

1 Introduction

The need for cities to adopt climate change mitigation and low-carbon development actions has been widely recognized by the international community (Hsu et al., 2020). However, most actions and emission reduction targets are voluntary and, a large percentage of cities are not on track to meet the targets they've established. For example, roughly 40% of the more than 1,000 cities affiliated with the EU Covenant of Mayors are not in line with their targets, and the remaining 60% of those who are tend to have less-ambitious targets and higher baseline emissions (Hsu et al., 2020). Thus, there appear to be barriers that are unaccounted for when it comes to effectively implementing climate action and planning for mitigation.

To date, most of the previous studies examining empirical climate governance and the drivers and barriers to climate action have been carried out in the Global North (Van der Heijden, 2019; Mi et al., 2019; Castán Broto & Bulkeley, 2013; Van der Heijden, 2019; Reckien et al., 2018; Romero-Lankao et al., 2018; Castán Broto, 2017). Moreover, these studies tend to connect with an extensive body of authors examining the mitigation and adaptation actions being developed by cities and the reasons for their doing so (Pablo-Romero et al., 2018; Croci et al., 2017; Bulkeley & Castán Broto, 2012; Castán Broto & Bulkeley, 2013; Bulkeley & Kern, 2006). However, it is reasonable to consider that there is no unique path to achieve a low-carbon city.

There are diverse pathways that can be followed to achieve climate governance, and they may differ between cities located in countries in the Global North and those located in the Global South (Van der Heijden, 2019). Yet, there is a profound gap in the environmental governance literature when it comes to examining the climate actions adopted by cities in the Global South, particularly with respect to understanding the drivers of, and barriers to, such actions in these cities. More studies on climate action, and the associated barriers and drivers to policy development and implementation in cities of the Global South are needed.

To fill this gap in literature on climate change responses among cities in the Global South, this paper will present a case study of the city of Recife, in northeastern Brazil. The IPCC has identified Recife to be among the most vulnerable cities in the world to the effects of climate change. Recife was the first Brazilian city to recognize the extent of the climate emergency and, subsequently, to establish the goal of becoming carbon neutral by 2050. Since 2012, the climate agenda in the city has advanced considerably and, according to the Carbon Disclosure Project (CDP, 2021), in 2020 Recife was among a group of 88 cities around the world leading the fight against the climate crisis. What specific actions have been implemented in the city? What are the drivers of climate action in the city? What are the barriers or obstacles that stand in the way of advancing the climate agenda? Finally, are these barriers and obstacles similar to those experienced by cities in the Global North?

This paper seeks to identify the climate actions adopted by the city of Recife and the main drivers and barriers to their effective implementation, thereby addressing the lack of climate governance studies from cities in the developing world (Van der Heijden, 2019; Mi et al., 2019; Castán Broto & Bulkeley, 2013). Moreover, considering existing academic debates surrounding the drivers and barriers to climate action this paper seeks to both fill existing gaps in the scientific literature on the barriers and drivers to climate action in cities in the Global South, and to provide useful guidance for policymakers. Finally, this paper suggests a pathway to guide policymakers toward strengthening the climate agendas in other cities, particularly in developing and less developed countries.

2 Literature Review

2.1 Climate Actions

Climate actions adopted by cities can follow one of two main strategies: mitigation or adaptation. Mitigation actions are directed toward attacking the root causes of climate change and have been defined as "[…] anthropogenic interventions to reduce the sources or enhance the sinks of greenhouse gases (GHG)" (IPCC, 2014a). Adaptation actions, in turn, aim to reduce local vulnerability to climate change and have been defined as "[…] adjustments in natural or human systems in response to actual or expected climate change and its effects" (IPCC, 2014a).

Within these broad categories, cities can adopt multiple types of climate actions. Table 1 and 2 identify examples of mitigation and adaptation actions identified in the literature.

Mitigation[22]		
Energy[23]	**Transport[24]**	**Waste[25]**
• Energy efficiency • Energy certification labelling • Smart grid infrastructure • District heating/cooling plant • Use of renewable energy • Renewable energy pilot projects • Energy efficiency schemes for municipal buildings • High energy efficiency standards in new buildings • Purchasing green energy by public buildings • Energy/carbon taxes • Eco-house pilot projects • Strategic planning to enhance energy conservation • Planning guidance on energy efficiency and renewable energy projects • Contracts to guarantee renewable energy installations • Campaigns for energy efficiency • Provision of advice on energy efficiency to businesses and citizens • Grants for energy efficiency and/or renewable energy measures • Guidance for architects and developers on energy efficiency and/or renewables	• Implementation of new low-carbon transport infrastructure • Public fleet replacement • Bike Lanes • Electric vehicles • Transport mobility planning/regulation • Traffic light optimization • Integrating ticketing and charging • Road network optimization • Improvement of logistic and freight transport • Fuel switching and enhancing energy efficiency at existing fleet • Car sharing/pooling • Reducing the need to travel through planning policies • Mobility management for public employees • Pedestrianization • Workplace levies and road-user charging • Road pricing congestion charge • Park zoning and pricing • Policies to reduce car use • Education campaigns on mobility enhancement Quality partnerships with public transport providers	• Enable methane capture and/or combustion from landfill sites • Waste prevention, recycling, and reuse within the local authority • Provision of sites for recycling, composting and ‘waste to energy’ facilities • Procurement of recycled goods • Recycling, composting, reuse schemes • Campaigns to reduce, reuse, and recycle waste • Promote use of recycled products • Sustainable consumption campaigns • Wastewater treatment for the entire population • Enable methane combustion from wastewater treatment • Green technologies for wastewater treatment

Table 1: Main mitigation actions identified in the literature[26]

[22] Pietrapertosa et al. (2019); Pablo-Romero et al., 2018; WRI, 2014; Castán Broto & Bulkeley, 2013.
[23] Pietrapertosa et al., 2019; Pablo-Romero et al., 2018; Croci et al., 2017; WRI, 2014; Castán Broto & Bulkeley, 2013; Bulkeley & Kern, 2006.
[24] Pietrapertosa et al., 2019; Pablo-Romero et al., 2018; Croci et al., 2017; WRI, 2014; Castán Broto & Bulkeley, 2013; Bulkeley & Kern, 2006.
[25] Pietrapertosa et al., 2019; Pablo-Romero et al., 2018; Croci et al., 2017; WRI, 2014; Castán Broto & Bulkeley, 2013; Bulkeley & Kern, 2006.
[26] The 2006 IPCC Guidelines for National GHG Emission Inventories considers four sectors: Energy, Waste, Industrial Processes and Product Use (IPPU), and Agriculture, Forestry and Land Use (AFOLU). Actions related to IPPU were considered in the Energy Sector given that these measures are generally related to Energy efficiency. The AFOLU sector was considered in the Adaptation category due to its overlapping benefits with climate change adaptation measures. In the IPCC methodology, Transport is included in the Energy Sector. However, in the Global Protocol for Community-Scale GHG emissions (GPC), which is the methodology predominantly used by cities to calculate GHG inventories, Transport is

Source: Table based on Pietrapertosa et al., 2019; Pablo-Romero et al., 2018; Croci et al., 2017; WRI, 2014; Castán Broto & Bulkeley, 2013; Bulkeley & Kern, 2006.

The IPCC (2014b) has defined three categories of adaptation actions: (I) Structural/Physical (STR), (II) Social (SOC), and (III) Institutional (INST), and provided examples of adaptation strategies. Table 2 summarizes the main adaptation actions identified in the literature. The broader adaptation categories are identified in brackets by their acronym.

Category	**Examples of specific adaptation strategies**
Engineered and built environment (STR)	• Sea walls and coastal protection structures • Flood levees and culverts • Water storage and pumps • Sewage works • Improved drainage • Beach nourishment • Flood and cyclone shelters • Building codes • Storm and wastewater management • Transport and road infrastructure adaptation
Technological (STR)	• New crop and animal varieties • Genetic techniques • Efficient irrigation • Water saving technologies, including rainwater harvesting • Conservation agriculture • Food storage and preservation facilities • Hazard mapping and monitoring technology • Early warning systems • Building insulation • Mechanical and passive cooling • Renewable energy technologies • Second-generation biofuels
Ecosystem-based (STR)	• Ecological restoration • Increasing biological diversity • Afforestation and reforestation • Conservation and replanting of mangrove forests • Bushfire reduction and prescribed fire • Green infrastructure (e.g., shade trees, green roofs) • Controlling overfishing • Fisheries co-management

a specific sector. Most city GHG inventories only measure GHG emissions from Stationary Energy, Transport, and Waste (Baltar de Souza Leão et al., 2020). Therefore, table 1 presents mitigation actions in these three sectors.

Category	Examples of specific adaptation strategies
	• Ecological corridors • Ex situ conservation and seed banks
Services (STR)	• Social safety nets and social protection • Food banks and distribution of food surpluses • Municipal services, including water and sanitation • Vaccination programs • Essential public health services, including reproductive health services and enhanced emergency medical services
Educational (SOC)	• Awareness raising and integrating into education • Gender equity in education • Sharing local and traditional knowledge including integrating into adaptation planning • Participatory action research and social learning • Community surveys • Knowledge-sharing and learning platforms • Research networks and communication through media
Informational (SOC)	• Hazard and vulnerability mapping • Early warning and response systems, including health early warning systems • Systematic monitoring and remote sensing • Climate services, including improved forecasts • Downscaling climate scenarios • Longitudinal data sets • Integrating indigenous climate observations • Community-based adaptation plans
Behavioral (SOC)	• Household preparation and evacuation planning • Retreat and migration • Soil and water conservation • Changing livestock and aquaculture practices • Crop rotation • Changing cropping practices, patterns, and planting dates • Silvicultural options • Reliance on social networks
Economic (INST)	• Financial incentives, including taxes and subsidies • Insurance, including index-based weather insurance schemes • Catastrophe bonds • Revolving funds • Payments for ecosystem services • Water tariffs • Savings groups • Microfinance • Disaster contingency funds
Laws and regulations (INST)	• Zoning laws • Building standards • Water regulations and agreements • Laws to support disaster risk reduction • Protected areas • Marine protected areas

Category	Examples of specific adaptation strategies
	• Fishing quotas • Patent pools and technology transfer
Government policies and programs (INST)	• National and regional adaptation plans, including mainstreaming climate change • Sub-national and local adaptation plans • Municipal water management programs • Disaster planning and preparedness • City-level plans, district-level plans, and sector plans, which may include integrated water resource management, landscape, and watershed management • Integrated coastal zone management, adaptive management, ecosystem-based management, sustainable forest management, fisheries management, and community-based adaptation

Table 2: Main adaptation categories identified in the literature[27]

2.2 Drivers of Climate Action

The factors that contribute toward climate change mitigation and adaptation actions are known as drivers of climate action, sometimes also called enabling factors. In this paper, the authors consider “drivers of climate action” to be activities, processes or patterns that produce positive incentives for climate action (Reckien et al., 2015).

Several authors have previously discussed and analyzed the drivers of climate action in the cities (Van der Heijden, 2019; Reckien et al., 2018; Romero-Lankao et al., 2018; Reckien et al., 2015; Castán Broto, 2017; Aylett, 2015). Among them, some authors have highlighted the need to examine and discuss these drivers in more depth and under different circumstances. For example, Van der Heijden (2019) pointed to a lack of knowledge on the enabling factors that lead to effective urban climate governance. Reckien et al. (2018) called attention to the drivers of Local Climate Plans (LCPs) and

[27] The IPCC Guidelines for National GHG Emissions Inventories (2006) consider four sectors: Energy, Waste, Industrial Processes and Product Use (IPPU), and Agriculture, Forestry and Land Use (AFOLU). Actions related to Industrial Processes and Buildings were considered in the Energy Sector given that these measures are generally related to Energy efficiency. The AFOLU sector was considered in the Adaptation category due to its overlapping benefits with climate change adaptation measures.

concluded that they need to be further explored, especially in countries lacking national climate action legislation, such as Brazil. Romero-Lankao et al. (2018) highlighted a need for research that supports urban climate action under different local conditions.

A summary of the literature surrounding the main drivers of climate action, which mainly includes studies of cities located in developed countries, is presented in Table 3.

Driver	**Description**	**References**
Access to funding for climate action	• Some cities suffer from a lack of creditworthiness in international financial markets and limited national financial support. • Cities do not have the autonomy to borrow funds and face restrictions when it comes to bidding and procurement. • According to the literature, access to funding for climate action is relevant to urban climate governance.	Van der Heijden (2019); Castán Broto (2017); Aylett, (2015), Bulkeley & Kern (2006).
Committed leadership	• Political will and commitment among city mayors and other urban political leaders are both considered to be essential elements of effective urban climate governance. • Climate engaged leaders are more likely to seek connections with other cities and establish networks beyond national borders.	Van der Heijden (2019); Reckien et al. (2015); Castán Broto (2017); Bulkeley & Kern (2006).
Member of one or more international networks	• Being part of one or more city networks positively influences urban climate governance at the city level. • Climate networks foster capacity building, information exchange and access to financial and political resources.	Van der Heijden (2019); Reckien et al. (2018); Castán Broto (2017); Bulkeley & Kern (2006).
Multilevel Governance	• Local governments of cities that successfully implement climate actions do not do so in isolation, but rather count on other urban actors to also lead and deliver climate actions.	Van der Heijden (2019); Reckien et al. (2015); Romero-Lankao et al. (2018); Castán Broto (2017); Bulkeley & Kern (2006).

Driver	Description	References
	• Multilevel climate governance is key to creating a supportive context for climate action. • Both vertical coordination, between cities and their regional and national governments, and horizontal coordination, across different local government departments and, when possible, a dedicated city-level climate action agency or working group, are considered fundamental to effective climate governance at the local level	
A supportive political and legal context	• The extent to which cities and their residents can govern climate action depends on, and is affected by, the regional and national political and legal contexts in which they are embedded.	Van der Heijden (2019); Reckien et al. (2015; 2018); Castán Broto (2017).
Autonomy	• The city must have the power to act and the autonomy to take urban climate action.	Van der Heijden (2019); Romero-Lankao et al. (2018).
Climate risk	• Climate risk or climate vulnerability is the propensity or pre-disposition to be adversely affected by climate change. It is related to the degree of past, current, or future susceptibility of people or systems to climate change.	Reckien et al. (2015; 2018); Castán Broto (2017).

Table 3: The most important drivers of climate action, as identified in previous literature

2.3 Barriers to Climate Action

Different barriers can affect the ability of local governments to design and implement local climate strategies. Reckien et al. (2015) defines barriers as obstacles that can be overcome with concerted effort, creative management, change of thinking, prioritization, and related shifts in resources, land uses, and institutions. Overcoming obstacles requires sufficient political will, social support, resources, and effort.

Several studies have previously discussed the barriers to local climate action. Aylett (2015) analyzed 236 ICLEI member cities worldwide. Reckien et al. (2015) took a statistical approach to analyze 200 large and medium-sized cities across 11 European countries. Romero-Lankao (2007) showed that climate policymaking in Mexico City has been constrained by diverse factors. The main barriers to climate action identified in the literature are presented in Table 4.

Barrier	Definition	References
Lack of funding	• A lack of funding is considered one of the most important barriers to climate action. • In a context of scarce resources, competing priorities, such as healthcare, housing, sanitation, public security, and economic growth, can challenge climate action.	Van der Heijden (2019); Castán Broto (2017); Aylett (2015); Reckien et al. (2015); Bulkeley & Kern (2006).
Lack of local political leadership	• Weak leadership can undermine the capacity and willingness to implement effective climate actions. • The focus of political leaders on short term goals is also considered to be important barrier to climate action.	Aylett (2015); Reckien et al. (2015).
Lack of horizontal coordination among municipal agencies/departments and vertical coordination between local and sub-national and national level governments.	• Among the literature, the difficulty to mainstream climate change into existing departmental functions and implement policies that require collaboration between siloed local government agencies has been recognized as a barrier to climate action. • When it comes to certain key policy areas in which local governments lack jurisdiction over, they are required to cooperate with sub-national and national level governments. The intergovernmental	Van der Heijden (2019); Reckien et al. (2018); Romero-Lankao et al. (2018); Castán Broto (2017); Aylett (2015); Romero-Lankao (2007); Bulkeley & Kern (2006).

Barrier	Definition	References
	inability and incapacity to cooperate at the vertical level has been identified in previous studies to be an important barrier to climate action.	
Lack of information on the likely local impacts of climate change	• Some cities have no knowledge of the likely local impacts of climate change, thus they do not plan or take actions to mitigate and adapt to it. • This lack of information has also been identified in the literature as a barrier to climate action.	Castán Broto (2017); Reckien et al. (2015); Aylett (2015).

Table 4: Most common barriers to local climate action, as identified in previous literature.

3 Materials & Methods

This exploratory study takes a case study approach to generate insights on the climate change response of a city in the global south and the associated drivers and barriers to climate action. According to Yin (2001), a single case study is eminently justified when it either represents (a) a crucial test of existing theory, (b) a rare or exclusive circumstance, or (c) a typical or representative case, or serves a (d) revealing or (e) longitudinal purpose. In this study, the single case study approach was adopted to generate detailed findings that are invited to be further tested in future studies.

The city of Recife was chosen given that: (I) in 2020 the city was considered by a relevant international institution (CDP, 2021) to be among the world's leading cities when it comes to climate actions; (II) the city is located in a developing country, thereby addressing a gap in the literature, (III) the city has been considered by the IPCC (2014a) to be among the most vulnerable cities in the world to climate change, (IV) the city was the first in Brazil to recognize the climate emergency and set targets to neutralize GHG emissions by 2050, (V) the city has advanced considerably in the climate agenda in recent years with the development of several studies and effective actions to mitigate and adapt to climate change.

As recommended by Eisenhardt & Graebner (2007) and Yin (2001), multiple sources of information were sought to carry out the case study. Data collection involved: (I) a document and content analysis, (II) interviews, and (III) observations to obtain results from a variety of data sources through triangulation.

Regarding the document analysis, special attention was given to the targets, measures, and requirements established by climate policies and plans. These documents provided elements to design the interview script (see Supplementary Material) and to confirm information obtained from interviews.

Topics	**Documents**
Recife GHG inventories	Recife (2015c); Recife (2017); ICLEI (2020).
Recife Climate Action Plans	Recife (2016); ICLEI (2020).
Analysis of Risks and Climate Vulnerabilities and Adaptation Strategy of Recife Municipality.	Recife (2019a).

Laws and Decrees related to Climate Change	Recife (2013); Recife (2014); Recife (2015a); Recife (2015b); Recife (2019b); Recife (2019c); Recife (2020).
Data and studies on urban planning and climate change	Sanear (2014); Recife (2018); TomTom (2020); IBGE, (2020a); IBGE (2020b); IBGE (2020c); CDP (2021).

Table 5: Documents submitted for Content Analysis.

Regarding the interviews, fifteen interviews with key informants were conducted between August,2020 and September,2020. The institutions and people were selected based on their direct involvement with city's climate governance. All interviews were carried out online and recorded. Interviewee profiles are presented in Table 6.

Interviewee	Role/Institution
I#1	Chief of Urban Afforestation /Secretary of the Environment and Sustainability (*Secretaria de Meio Ambiente e Sustentabilidade - SMAS*)
I#2	Manager of Environmental Studies and Programs/ Secretary of Urban Development and Housing of Pernambuco State (*Secretaria de Desenvolvimento Urbano e Habitação de Pernambuco*)
I#3	Innovation Analyst and Coordinator of the Recife 500 *anos* Project/ Recife Agency for Innovation and Strategy (*Agencia de Inovação e* Estratégia - *ARIES*)
I#4	CEO assessor/ EMLURB –Recife Maintenance and Urban Cleaning Company (*Empresa de Manutenção e Limpeza Urbana de Recife)*
I#5	Project Manager/ ICLEI – Local Governments for Sustainability (South America)
I#6	Analyst and Coordinator of Project CITinova/ *ARIES*
I#7	General Manager of Social Attention/ Secretary of Civil Defense
I#8	General Manager of Sustainability and Urban Resilience/Pelópidas Silveira Institute of the City (*Instituto da Cidade Pelópidas Silveira - ICPS*)
I#9	Manager of Environmental Policies/ *SMAS*
I#10	Former Chief of Low Carbon Policies and Climate/ *SMAS*
I#11	Former Environmental Executive Secretary/ *SMAS*
I#12	Executive Coordinator of Parque Capibaribe Project
I#13	CEO/ Traffic and Urban Transportation Company (*Autarquia de Trânsito e Transporte Urbano do Recife – CTTU*)
I#14	Geoprocessing and analysis manager/*ICPS*
I#15	Urban Development Analyst/ *ICPS*

Table 6: Interviewee Profiles

To verify the information obtained in interviews, participant observation was also carried out, whereby one or more authors of this study was present in diverse institutional meetings. Specifically, one of the authors participated in six online meetings between the city and an international climate network that occurred between March,2020 and December,2020. Local stakeholders and representatives of one multinational city climate network participated in these meetings to discuss and contribute to the elaboration of local climate action (*LCAP*) (ICLEI, 2020). During these meetings, the authors of this study observed climate actions, drivers, and barriers to their implementation.

Meetings	Date	Subject	Participants
O#1	03/06/2020	Presentation of GHG Emissions Scenarios and Preliminary Action Plan.	Representatives from Local Government, *ICLEI*, Universities, the private sector, and local NGOs.
O#2	05/06/2020	Discussion of the concept of green areas and targets to be defined.	Representatives from Local Government, *ICLEI*, and Universities.
O#3	26/06/2020	Discussion on targets related to green areas.	Representatives from Local Government, *ICLEI*, and Universities.
O#4	20/08/2020	Workshop to collect opinions from youth of the city on climate actions.	Representatives from Local Government, *ICLEI*, and the youth community.
O#5	14/10/2020	Workshop to validate the Climate Action Plan	Representatives from Local Government and *ICLEI.*
O#6	15/12/2020	Presentation of the Local Climate Action Plan	Representatives from Local Government, *ICLEI*, Universities, the private sector, and local NGOs.

Table 7: Overview of Participant Observation in Institutional Meetings

More information on the participant observation process and the interviews, including a brief description of each interviewee and the date and duration of each interview, is supplied in the supplementary material.

In the results and discussion section, the acronyms “I#” and “O#” stand for interviews and observations, respectively. The documents analyzed are presented in the reference section and mentioned throughout the paper.

4 Recife Case Study

4.1 Characterization of the City

Recife is the capital of the state of Pernambuco and located in Brazil's Northeast region. In 2020 it has an estimated population of 1,653,461 inhabitants, spread over a territory of 218.84 km^2 and concentrated in a 100% urban environment. The metropolitan region of Recife (*Região Metropolitana de Recife - RMR*), which includes 13 other municipalities, is home to the fifth largest metropolitan population in Brazil. Figure 1 below shows the location of Recife in the state of Pernambuco and in Brazil.

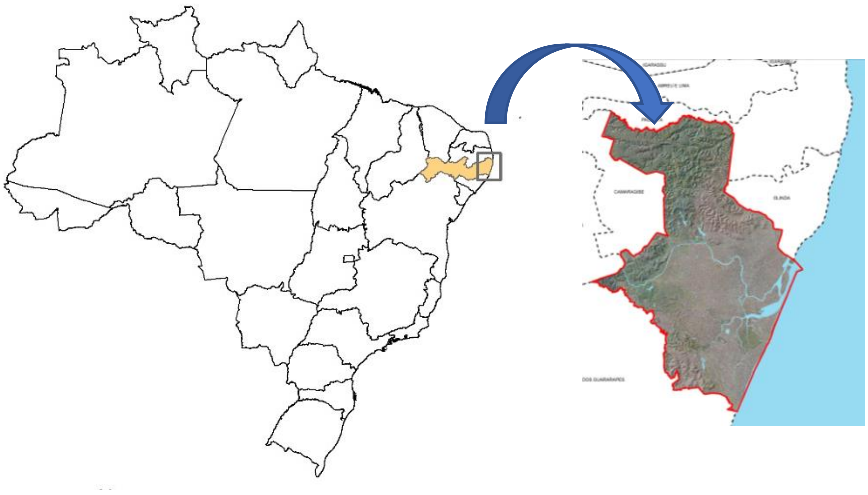

Figure 1: Location of Recife in Brazil

Recife is located on the Atlantic Ocean coast and, on average, at an altitude of 4 meters above sea level. The city is known as the "Brazilian Venice". Four rivers cross through the city and the city has more than 70 artificial drainage canals that are two or more meters wide (ICLEI, 2020). The city's topography is a combination of low average and high declivity areas. Moreover, it is characterized by intense urbanization and a high population density of 7,555 inhabitants/km^2 (IBGE, 2020a).

The city’s climate is humid tropical with a monthly average temperature of above 18°C. The average temperature in the summer is above 30°C. The rain index is greater than 2,000 millimeters (mm) per year (Iclei, 2020).

The city's GDP in 2017 was R$ 51.86 billion and the city’s economy is based on the services industry (more than 70% of GDP). Recife has the thirteenth largest GDP among all cities in Brazil (IBGE, 2020b). The most important economic activities are the construction industry, private healthcare, and food services. Moreover, the city is also a state center for wholesale trade. The social inequality in the city is alarming. According to the Brazilian Institute of Geography and Statistics -IBGE (2020c), in 2019 the average monthly per capita household income of people in the lowest 20% income bracket was R$ 210 whereas for those in the top 20% income bracket it was R$ 6,268. A total of 25.3% of Recife residents are below the poverty line, with a income of less than U$ 5.5 per day.

Historically, Recife has had to cope with flooding events. Several natural characteristics hinder the drainage process in the city and make it particularly vulnerable to flooding, including: the city’s low average altitudes, the presence of flat areas, the city’s water table is close to the surface, outcropping in the rainy season, and sea-level rise. Moreover, inadequate urban settlements and insufficient drainage infrastructure have been known to cause flooding and landslides (Recife, 2018).

With respect to the city’s climate, the combination of high temperatures, a high degree of urbanization, and poorly distributed green areas results in heat islands, which influence the well-being and thermal comfort of the population. The Brazilian Climate Change Panel (*Painel Brasileiro de Mudanças Climáticas* - PBMC, 2016) has predicted increases in the frequency of extreme temperatures and the duration of heat waves in the future in Brazil’s northeast region. Moreover, the heat waves are expected to be aggravated by the city's population density and urbanization patterns (verticalization, paving, waterproofing, poor distribution of green areas, among others).

According to the Analysis of Risks and Climate Vulnerabilities and Adaptation Strategy of Recife *(*Recife, 2019a), both children and the elderly, especially those from low-income residences, are expected to suffer the most from temperature increases. Temperature increases can worsen air quality and lead to higher occurrences of respiratory diseases. Moreover, the same report shows that the entire population of the city is at risk of contracting diseases such as Dengue, Zika and Chikungunya to a certain degree, thus leading to serious public health problems (Recife, 2019a). The social vulnerability of a significant portion of the population who reside in precarious housing and have little access to healthcare makes these populations most at risk of contracting these diseases.

With respect to future climate events in the city, this same analysis predicts decreases in precipitation to below average levels (Recife, 2019a). Given the socioeconomic vulnerability of part of the population, they are more at risk of suffering the negative impacts of future drought events. Compounding this is the fact that a large contingent of the population do not have access to a continuous water supply (SANEAR, 2014). Studies have shown that since 1940 the average annual sea level in Recife has increased by 0.54 cm/year. Studies have shown that significant areas of the city are at risk of becoming permanently flooded (Recife, 2016). Currently, 45.7% of the city's coastline is in a highly vulnerable zone. (Recife, 2019a)

As a result of these characteristics, Recife was recognized by IPCC as one of the most vulnerable cities in the world to climate change (IPCC, 2014a), occupying the 16th position. Six major vulnerabilities have been identified in the city: Floods, landslides, communicable diseases, heat waves, droughts, and sea level rise (Recife, 2019a).

4.2 The advancement of Recife's Climate agenda

The Recife climate agenda has advanced over the past few years. In 2013, the city joined both ICLEI, a global network of more than 1,750 local and regional governments committed to sustainable urban development (ICLEI, 2020), and CDP Cities – Carbon Disclosure Project, a network for climate change strategies disclosure with more than 8,400 member companies and 900 member cities, states, and regions worldwide. In 2015, it was chosen as a model city for the ICLEI and UN-Habitat financed Urban-LEDS Project. This project seeks to promote Low Emissions Urban Development Strategies and is directly engaged with more than sixty cities throughout eight countries. (ICLEI, 2020). Fnally, Recife is also a signatory to the Global Compact of Mayors for Climate and Energy.

In 2013, Recife created the Sustainability and Climate Change Committee - COMCLIMA and the Executive Group on Sustainability and Climate Change – GECLIMA (Recife, 2013) to plan, coordinate and execute climate action plans and policies in the city by engaging with public, private, and non-governmental sectors, as well as academic institutions.

In 2014, the city approved the Sustainability and Climate Change Policy (Recife, 2014) that established the city's principles, guidelines, and objectives when it comes to combating climate change. During that same year, the city prepared its first GHG emissions inventory with the base year being 2012. This inventory took into account emissions scenarios projected until 2040 (Recife, 2014).

In 2015, the city designed its first climate action plan, called the Sustainable and Low Carbon Recife Plan (SLCRP) (Recife, 2016). In it, the city set GHG emission reduction targets (Recife, 2015a), at 14.9% by 2017 and 20.8% by 2020, considering the SLCRP Business as Usual (BaU) scenario.

In 2017, with the support of the Andean Development Cooperation (CAF), Recife developed its GHG inventory and water footprint for the years 2013 to 2015 (Recife, 2017). In 2019, with support from the CAF and ICLEI, the city developed its Climate Risks and Vulnerability Analysis, which identified the main climate risks and threats (Recife, 2019a).

In 2019, the mayor of Recife recognized the climate emergency in the city and the city set a goal to achieve zero net carbon emissions by 2050 (Recife, 2019b), in line with the commitments established in the Paris Agreement. Moreover, the city was the first in Brazil to recognize the climate emergency and set such targets. In 2019, the city hosted the first Brazilian climate change conference and was the first Brazilian city to include climate change in the early childhood education curriculum.

In 2020, Recife updated its 2016 and 2017 GHG inventories and its low carbon plan to become known as the Local Climate Action Plan (ICLEI, 2020). This plan outlines the pathway to reach carbon neutrality by 2050.

In 2021, the Carbon Disclosure Project (CDP) positioned Recife among a group of 88 cities in the world that had been leading the fight against the climate crisis in 2020. According to the CDP (2021), these cities have made major progress since the signing of the Paris Agreement. Figure 2 below shows these 88 cities, of which only six are in Latin America and two are in Brazil.

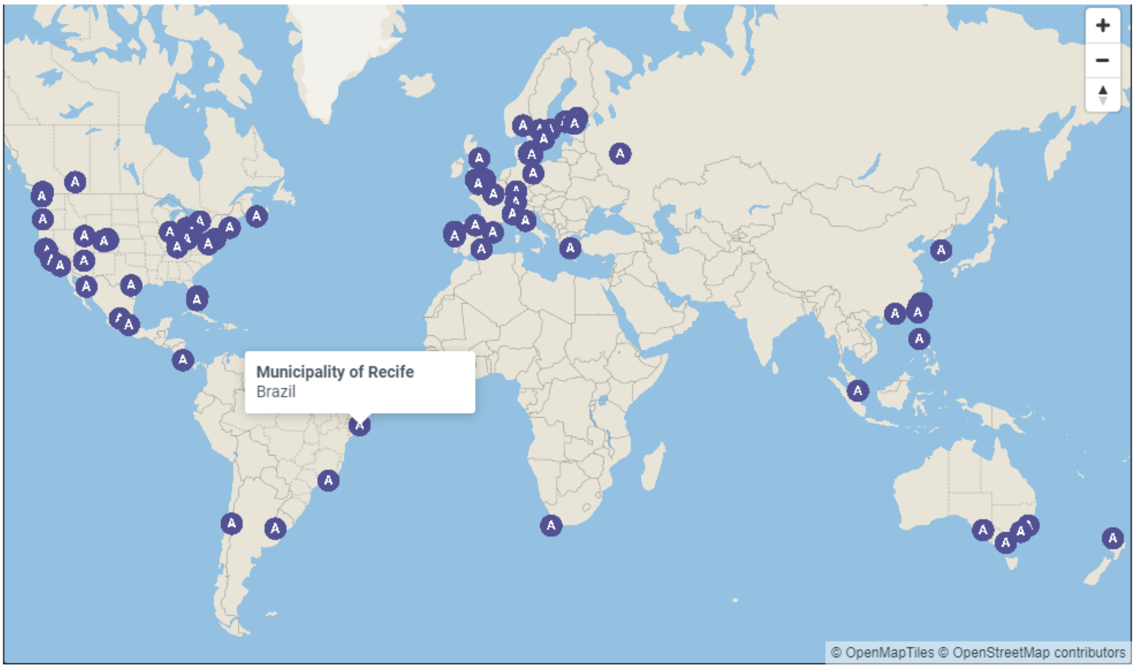

Figure 2: CDP 2020 list of cities leading climate action

Source: CDP (2021)

5 Results

This section presents the main climate actions implemented by the city of Recife, and the main drivers and barriers to the advancement of its climate agenda. These results were obtained by triangulating (Yin, 2001; Eisenhardt & Graebner, 2007) information obtained from interviews, documentary sources, and content analysis throughout the observation process.

5.1 Climate Actions

To date, two climate action plans have been released by the local Recife government. The first was the Sustainable and Low Carbon Recife Plan -SLCRP, which was released in 2016 (Recife, 2016) based on the 2012 GHG inventory and projected emissions scenarios to 2040. To reach the total GHG emissions reduction goal established by the local government, the plan divided actions into The second climate action plan, known as the Local Climate Action Plan (LCAP), was drawn up in 2020 (ICLEI, 2020) and considered the 2017 GHG emissions inventory and Climate Risk and Vulnerability Analysis (Recife, 2019a) to design emission scenarios until 2050, and to identify strategies to achieve carbon neutrality by 2050 (Recife, 2019b).

Together, the measures adopted in the SLCRP and those adopted in the LCAP have already resulted in reduced GHG emissions. According to ICLEI (2020), in 2017 GHG emissions in Recife were 2.46% lower than those in 2012 and 17.7% lower than those projected in the SLCRP BAU scenario, thus exceeding the 14.9% target established by city government. Furthermore, these results were also 7.69% lower than the reductions outlined in the mitigation scenario at that time.

Four sectors were identified to be priorities in both plans: Energy, Sanitation, Mobility, and Climate Resilience. Climate resilience covered adaptation actions whereas the other three sectors covered mitigation measures (Recife, 2016; ICLEI, 2020). For each sector, a plan identified goals, objectives, and detailed actions. The climate actions identified, which were subsequently implemented, are presented in the next section

Energy Sector Mitigation Actions

The BaU scenario points to a 139% emissions growth in the Energy Sector in Recife by 2050 (ICLEI, 2020). Under this scenario, the city of Recife's total energy expenditure would increase by 162% by 2030. The city seeks to ensure that its growth is based on energy efficiency and clean energy sources (ICLEI, 2020).The main energy efficiency projects designed to achieve that goal are: (I) the Ilumina Recife Program, which seeks to outfit 100% of public lighting with LED lamps by 2021; (II) the Environmental Sustainability Certification Program for Buildings (Recife, 2020), which determines that buildings adopt sustainable measures to reduce both GHG emissions and environmental impacts; and (III) the *Municipal Decree No. 32,939* that promotes measures of energy efficiency and rational use of water in new public buildings (Recife, 2019c).

The Ilumina Recife Program has advanced since 2019 and it is in line with what was planned (O#5; O#6; I#9; I#11). By contrast, the Environmental Sustainability Certification Program for Buildings has had a smaller reach than intended, with a smaller number of buildings applying this certification than what was planned, which some interviewees (I#9; I#10; I#11) attributed this to poor promotion by the local government. Finally, the program on measures of energy efficiency and rational use of water in new public buildings has had a limited impact and limited results (I#9; I#10; O#1; O#5; O#6).

According to several interviewees (I#9; I#10; I#11), the local government does not promote energy efficiency campaigns. They are promoted by a private local electricity company. However, energy efficiency is addressed in environmental education programs promoted by the local government. The city tried to purchase green energy for public buildings, but the project did not advance (I#10; I#11; O#1; O#6).

The LCAP (ICLEI, 2020) foresees bold measures, including converting the city's energy supply to100% renewable energy sources, defining energy efficiency targets, and articulating efforts to reduce and offset fossil fuel emissions. All these measures are still in the initial planning stages, and depend on the commitment of future city governments and multilevel coordination (O#1; O#5; O#6; ICLEI, 2020).

Actions to Mitigate Waste

The waste sector accounts GHG emissions from solid waste management and wastewater treatment. The city has identified these areas as priorities given (I) the city's extremely low rates of recycling and reuse of solid waste (0.8%) (ICLEI, 2020), and (II) the small percentage of the city’s population who have access to wastewater treatment (43%) (IBGE, 2020c).

LCAP (ICLEI, 2020) establishes that waste disposal and increasing rates of sanitation should be accompanied by technologies that burn or generate electricity from methane. The use of methane energy sources has already been providing GHG reductions in Recife (I#2; I#9; I#10; I#11; O#1; O#6; ICLEI, 2020).

Responsibility for city's wastewater treatment program, and the goal of to service 90% of households with sewage collection and treatment by 2037 falls on both the public and private sectors through a public-private partnership (I#4; I#8; I#11: O#1; O#6; ICLEI, 2020). The use of methane in wastewater treatment has yet to be articulated (O#1; O#6; ICLEI, 2020).

Respondents highlighted the role of the City's Environmental Education programs in raising public awareness on the correct way to dispose of waste (I#9; I#10; I#11). The “*Ecoestations*” project, places where the population can dispose of recyclable waste, was highlighted by interviewees as an important step in this direction by the city (I#9; I#10; I#11).

Several actors are involved in the city’s waste management program. According to E#2, for the city’s solid waste management program to achieve more effective results, there needs to be better articulation and coordination among these actors: “The structure is very fragmented, which makes it difficult. In the Solid Waste Plan, the necessary structure was identified. Resources are available. There is a lack of coordination that, for example, generates low results for the city”.

Transportation Mitigation Actions

Transportation emissions are the city's highest emission source (Recife, 2012; Recife, 2016; ICLEI, 2020). Urban mobility in Recife has been considered among the worst in Latin America and the city has been considered to have the 16^{th} worst level of traffic in the world (TomTom, 2020).

To reduce GHG emissions from urban mobility, it will require that the city's population migrate from individual transport to collective and active transport (walking and bicycles) and to individual fleet that use and emit less fuels (Recife, 2016; ICLEI, 2020).The main transport actions implemented by the city are: (I) The city revised its mobility plan; (II) two lanes of Rapid Bus Transit were implemented between 2013 and 2015 (O#1; O#5); (III) over 60 km of exclusive bus lanes were implemented; (IV) the *Calçada Legal* (great sidewalks) program updated 134 km of sidewalks and (V) bicycle infrastructure has advanced from 24 kms of bike lanes in 2013 to 140 kms in 2020 (ICLEI, 2020; I#13).

Furthermore, the city implemented "road network optimization" actions, such as the project "*Via Mangue*" ("Mango Drive"), which reduced travel time by 30% to 35% in the main neighborhood of the city's south area, according to interviewees (I#11; I#13). The use of electric buses in the central region of the city is also being discussed (I#13; O#5; O#6).

Despite these advances, improvements beyond the supply of infrastructure are needed. Additional challenges to overcome to increase the use of public and active transport include increasing thermal comfort and addressing the high rates of urban violence (ICLEI, 2020). To reduce the circulation of private vehicles, respondents stated that a culture change is needed. For example, I#8 highlighted that " a debate among the citizens on the city they want is needed (...) If there the upper class and most of the population cannot comply, the needed changes will not occur, given that the upper class only gets around Recife by car. They do not ride bicycles or use public transportation”.

The LCAP (ICLEI, 2020) predicts technological developments in the automotive and aviation sectors, including the adoption of more efficient fuels and technologies. Regulations that encourage these technologies are needed (O#1; O#5; O#6; ICLEI, 2020).

Another challenge in the transport sector is how to reduce increasing emissions from air transport, which currently represent more than 20% of the city's total emissions (ICLEI, 2020). The LCAP BAU scenario points to a 165% growth in these emissions by 2050 (ICLEI, 2020). The LCAP only predicts compensation actions to deal with this challenge and local stakeholders have not started any actions to deal with this issue (O#1; O#5; O#6; ICLEI, 2020).

Climate Resilience/Adaptation Actions

Goals and actions were considered in the Recife Climate Resilience Sector (Recife, 2016 and LCAP, 2020) to address the threats identified in the Risk and Vulnerability Analysis (Recife, 2019a). The objective is to expand the city’s response capacity by improving its ability to anticipate, prevent, absorb, and recover from extreme shocks and events (ICLEI, 2020).

Heavy rainfall falling over short periods of time, for example, presents a threats to the city due to its geographic characteristics. And this threat is aggravated by the large of low-income population residing on hills and hillsides in houses without basic infrastructure (ICLEI, 2020). The city’s risk reduction plan identified 677 risk areas in the city (I#7; O#5; O#6). The civil defense secretariat is responsible for implementing disaster prevention and protection measures in the local community. Moreover, the city has implemented early climate warning and response systems (I#7; I#9; I#10).

The LCAP has defined the following objectives to prevent disasters (I) to reduce the areas at a remarkably high risk of landslides and floods by 100%, in accordance with the city's risk reduction plan, and (II) to urbanize these risky areas to bring security and quality of life to the populations and make it possible to face climate threats by 2037. High volumes of rainfall over short periods of time also increases the risk of flooding, which is aggravated by the city's low drainage capacity (ICLEI, 2020).

To increase the city's resilience, the city implemented actions to: (I) improve urban green infrastructure with developments and projects such as the Parque Capibaribe Project, the Tree Planting Plan, and the approval of Law 18,014/2014 to create the System of Protected Areas (*Sistema Municipal de Unidades de* Proteção - SMUP) (I#1; I#11; I#12; I#14; #15; O#2; O#3); (II) improve the city's drainage capacity with projects such as the Master Plan for Drainage and Rainwater Management (I#4) and the Green Rooftops and Retention Reserves Law (Recife, 2015b; I#10), and (III) mitigate landslide related risks (I#7). Currently, both the Master Plan and the Land Use Law are under review to include information that considers the risks and threats that climate change imposes on the city (ICLEI, 2020).

LCAP (ICLEI, 2020) plans (I) to review the SMUP by 2025 and (II) to advance afforestation in the city and increase the use of sustainable infrastructure (such as green roofs) that can mitigate heat islands and heat waves (O#2; O#3). To achieve these goals, green infrastructure formed by rivers, canals, riparian forests, and mangroves needs to be strengthened to restore, and reconnect natural watercourses, and recover and preserve them for water drainage (Recife, 2018).

Furthermore, the city of Recife planted 60,000 trees over six years between 2014 and 2020 (I#1; I#11). A tree planting handbook was designed to guide tree planting in the city. The program “Bora Plantar” (Let’s Plant) opened a channel for the population to voice their demands to the local government to plant trees in the city (I#1; I#11; I#15).

In addition to the initiatives listed above, the city has also developed the Parque Capibaribe project, which is a system of integrated parks that runs for 15 km on both sides of the Capibaribe River for a total length of 30 km of transformations along the city's main watercourse. This system of integrated parks plans to include wide sidewalks, bike lanes and bridges (I#12). The objective of the project is to transform Recife into a park-city by connecting the river to the daily lives of its residents. However, to date, only a small portion of the project has been implemented, as its continuation depends on the renewal of a cooperation agreement between the local government and local university (I#11; I#12; I# 14; I#15).

Additional challenges addressed in the LCAP include how best to coordinate efforts and define the strategies to best deal with sea level rise and ensure that the entire population has access to water (ICLEI, 2020). To date, there is no specific working group to address these issues. Emergency measures related to sea level rise have been taken (e.g., coastal protection structures in Boa Viagem beach), but no specific strategy has been defined to guide the city on how best to adapt to sea level rise (I#4; O#1; O#5; O#6).

Under the CITinova project, which is funded by the Global Environmental Facility (GEF), consulting companies have already been hired to develop sectorial adaptation plans by 2022 (I#3; I#6). Moreover, innovative pilot projects are expected to be implemented, such as the filter gardens and Capibaribe river solar powered boat for crossing.

Tables 6 and 7 present the main mitigation and adaptation actions implemented by the city of Recife so far.

Sector	Mitigation Actions	
	✅ Implemented	❎ Not implemented
Energy[28]	• Energy efficiency; • Renewable energy pilot projects; • High energy efficiency standards in new buildings; • Target for renewable energy supply established	• Energy certification labelling; • Smart grid infrastructure; • District heating/cooling plant • Use of renewable energy; • Energy efficiency schemes for city buildings; • Purchasing green energy by public buildings; • Energy/carbon taxes; • Eco-house pilot projects; • Planning guidance on energy efficiency, conservation and renewables energy projects; • Contracts to guarantee renewable energy installations • Campaigns for energy efficiency • Provision of advice on energy efficiency to businesses and citizens • Guidance and grants for energy efficiency and/or renewables.
Transport[29]	• Implementation of new low-carbon transport infrastructure; • Bike Lanes; • Electric vehicles; • Transport mobility planning/regulation; • Traffic light optimization; • Road network optimization; • Car sharing/pooling; • Pedestrianization; • Park zoning and pricing; • Education campaigns on mobility enhancement;	• Public fleet replacement; • Integrating ticketing and charging; • Improvement of logistic and freight transport; • Fuel switching and energy efficiency at existing fleet; • Reducing the need to travel through planning policies; • Mobility management for public employees; • Workplace levies and road-user charging; • Road pricing congestion charge; • Policies to reduce car use; • Quality partnerships with public transport provider.
Waste[30]	• Enable methane capture and/or combustion from landfill sites; • Waste prevention, recycling, and reuse within the local authority; • Provision of sites for recycling, composting and 'waste to energy' facilities; • Campaigns for reducing, reusing, recycling waste and sustainable consumption;	• Procurement of recycled goods; • Recycling, composting, reuse schemes; • Promote use of recycled products; • Green technologies for wastewater treatment;

[28] Pietrapertosa et al., 2019; Pablo-Romero et al., 2018; Croci et al., 2017; WRI, 2014; Castán Broto & Bulkeley, 2013; Bulkeley & Kern, 2006.
[29] Pietrapertosa et al., 2019; Pablo-Romero et al., 2018; Croci et al., 2017; WRI, 2014; Castán Broto & Bulkeley, 2013; Bulkeley & Kern, 2006.
[30] Pietrapertosa et al., 2019; Pablo-Romero et al., 2018; Croci et al., 2017; WRI, 2014; Castán Broto & Bulkeley, 2013; Bulkeley & Kern, 2006.

	• Wastewater treatment for all population (Target established); • Enable methane combustion from wastewater treatment (Target established).	

Table 6: The main mitigation actions implemented in Recife

Category	Adaptation Actions	
	Implemented	Not implemented
Engineered and built environment (STR)	• Sea walls and coastal protection structures; • Flood levees and culverts; • Improved drainage; • Building codes.	• Water storage and pump; • Sewage works; • Beach nourishment; • Flood and cyclone shelters; • Storm and wastewater management; • Transport and road infrastructure adaptation.
Technological (STR)	• Early warning systems; • The only technological action identified was the pilot project of filter gardens and solar powered boat for crossing Capibaribe river.	• New crop and animal varieties; • Genetic techniques; • Efficient irrigation; • Water saving technologies including rainwater harvesting; • Conservation agriculture; • Food storage and preservation facilities; • Hazard mapping and monitoring technology; • Building insulation; • Mechanical and passive cooling; • Renewable energy technologies; • Second-generation biofuels.
Ecosystem-based (STR)	• Ecological restoration; • Afforestation and reforestation; • Green infrastructure (e.g., shade trees, green roofs).	• Increasing biological diversity; • Conservation and replanting mangrove forest; • Bushfire reduction and prescribed fire; • Controlling overfishing; • Fisheries co-management; • Ecological corridors; • Ex situ conservation and seed banks.
Services (STR)	• Municipal services including water and sanitation; • Vaccination programs; • Essential public health services including reproductive health services and enhanced emergency medical services.	• Social safety nets and social protection; • Food banks and distribution of food surplus.
Educational (S0C)	• Awareness raising and integrating into education; • Research networks; communication through social media;	• Gender equity in education; • Sharing local and traditional knowledge including integrating into adaptation planning; • Participatory action research and social learning; • Community surveys;

Category	Adaptation Actions	
	✅ Implemented	❎ Not implemented
		• Knowledge-sharing and learning platforms.
Informational (SOC)	• Sea walls and coastal protection structures; • Flood levees and culverts; • Improved drainage; • Climate risk and vulnerability analysis	• water storage and pump; • sewage works; • beach nourishment; • flood and cyclone shelters; • storm and wastewater management; • transport and road infrastructure adaptation.
Behavioral (SOC)		• Household preparation and evacuation planning; • Retreat and migration; • Soil and water conservation; • Changing livestock and aquaculture practices; • Crop-switching; • Changing cropping practices, patterns, and planting dates; • Silvicultural options; • Reliance on social networks.
Economic (INST		• Financial incentives including taxes and subsidies; • Insurance including index-based weather insurance schemes; • Catastrophe bonds; • Revolving funds; • Payments for ecosystem services; • Water tariffs; • Savings groups; • Microfinance; • Disaster contingency funds.
Laws and regulations (INST)	• Land zoning laws; • Building standards; • Laws to support disaster risk reduction; • Protected areas.	• Water regulations and agreements; • Marine protected areas; • Fishing quotas; • Patent pools and technology transfer.
Government policies and programs (INST)	• National and regional adaptation plans including mainstreaming climate change; • Sub-national and local adaptation plans; • Municipal water management programs; • City-level plans, district-level plans, sector plans, which may include integrated water resource management, landscape and watershed management.	• Disaster planning and preparedness; • Integrated coastal zone management, adaptive management, ecosystem-based management, sustainable forest management, fisheries management and community-based adaptation.

Table 7: Main adaptation actions implemented in Recife

The city's climate action plan highlights strategies and targets. But it also makes it clear that several mitigation and adaptation actions still need to be articulated. For example, to achieve carbon neutrality by 2050, the city set measures to compensate unavoidable emissions. The legal framework needed to demand compensation has yet to be created and must be done so by 2024. Moreover, compensation strategies also have yet to be defined (ICLEI, 2020; O#1; O#5; O#6). According to LCAP data (ICLEI, 2020), compensation for emissions reductions will be responsible for 48% of the city's emission reductions by 2050, thereby demonstrating that the city will need to review and incorporate new mitigation measures with bolder results to achieve its goal.

Although the city has already developed several studies, plans and regulations surrounding the climate issue, several actions still need to be implemented to change the city's vulnerable situation.

5.2 Drivers and Barriers to Climate Actions in Recife

The following findings were obtained from the process of triangulating information from interviews, documentary sources, and participant observation.

Table 8: Main findings and results concerning the drivers and barriers to climate action in Recife

Driver/Barrier	Main Findings and Results
Access to funding for climate action	• Overall, both interviews (I#3; I#5; I#6; I#8; I#10; I#11) and documentary sources (Recife, 2016; ICLEI, ICLEI, 2019a) confirmed that funding is not a barrier. • Funding has been an important driver to advancing the climate agenda in Recife. Information gathered through participant observations (O#1; O#5; O#6) revealed that the city had access to international funds from the ICLEI, the European Union, UN-Habitat, CAF, and the Global Environmental Facility (GEF) for climate action (ICLEI, 2020).

Driver/Barrier	Main Findings and Results
Committed leadership	• The mayor's engagement and support of the climate agenda, along with his effective participation (from 2013 to 2020) contributed fundamentally to strengthening policies that address and combat climate change in the city. • Participant observation during events surrounding elaboration of the LCAP (O#1; O#5; O#6) revealed that the mayor actively participated in the process. Moreover, the mayor also occupies the role of President of ICLEI South America. • The mayor's consistent participation in international events to debate climate issues, such as COPs, also demonstrated his commitment to these issues. • These observations were further confirmed in the interviews.
Being part of an international network	• Being part of one or more international networks of cities committed to fighting climate change, such as the ICLEI and CDP, was found to be one of the most important drivers to strengthening climate actions in the city. • This was highlighted by all interviewees and evidenced by the fact that ICLEI has supported and been directly involved in several of the city's climate initiatives, including both climate plans, GHG inventories, climate risks and the city's vulnerabilities assessment. • Being part of these networks has allowed the city to exchange experiences with other Brazilian and international cities and promote capacity building (I# 6; I#8; I#9; I# 10; I#11)
Multilevel Governance	• Climate plans, policies and actions are debated at COMCLIMA and GECLIMA. These forums engage both the public and private sectors, NGOs, and academic institutions, and are where this multilevel governance takes place in the city of Recife (ICLEI, 2020; Recife, 2013; O#5; O#6). • Despite these forums, vertical coordination is weak. There was a consensus among interviewees that engagement from National Government is lacking and that participation from state-government agencies is limited (I#8; I#9; I#10; I#11). This was also evidenced in observations (O#1; O#5; O#6). • Interviewees also relayed difficulties in horizontal coordination also (I#6; I#7; I#8; I#9), for example, that the communication between departments is weak. • Knowledge of climate issues is concentrated in a small number of people in the local government. It is necessary to widespread climate

Driver/Barrier	Main Findings and Results
	knowledge in the public administration. According to I#6, "the topic needs to become transversal in all local government departments”.
A supportive political and legal context	• At the local level, the city has an established legal framework that favors local climate action (Recife, 2014; Recife, 2016; ICLEI, 2020), which is considered an important driver for the city. • According to all interviewees, between 2012 and 2020, the city had an active mayor who contributed to a positive political context. • Interviewees did not consider it important to consolidate a specific department to address climate issue in the local government (I#8; I#9; I#10; I#11). SMAS was created in 2012 and its organizational chart establishes specific roles to address both climate change issues and low carbon policies. • Despite the facts that climate policies and plans have been defined at the National and Sub-national levels, no national institutions are involved in the city's climate governance (O#1; O#5; O#6) and state participation is limited (ICLEI, 2020; Recife, 2013). This was observed during events surrounding the elaboration of the LCAP (O#1; O#5; O#6) and confirmed in interviews (I#8; I#9; I#10; I#11).
Autonomy	• For certain actions, autonomy is a barrier to local climate actions in the city. There are some important climate issues that the local government does not have autonomy to deal with (ICLEI, 2020; O#1; O#5; O#6; I#2; I#8; I#11; I#13). • Partnerships with the state and national governments are essential given that the local government does not have control over issues such as sanitation, water supply, and air space. • Important climate agenda topics, such as waste management (I#2) and public transport, are managed at the metropolitan level and demand the involvement of 13 other cities (I#13).
Climate risk	• The evidence showed that Recife has a history experiencing the impacts of climate change, such as rising sea levels and heavy rainfalls with landslides (Recife, 2019a). • Several LCAP measures, objectives, and actions (ICLEI, 2020) were designed to deal with the six main vulnerabilities and risks that climate change will impose on the city, as identified in the Climate vulnerabilities and risks Assessment (Recife, 2019a). • Interviewees also confirmed that the climate risks and potential impacts from city development needs were important drivers of local climate action in the city (I#5; I#7; I#8; I#9; I#10; I#11).

Driver/Barrier	Main Findings and Results
Interference of political accords in the climate agenda	• It was a consensus among interviewees that political accords are a significant barrier to the climate agenda. • Several interviewees (I#3; I#5; I#6; I#7; I#8; I#9; I#10; I#11; I#15) stated that, even with a consistent city mayor, the game of accommodating political party interests led to changes to the SMAS that weakened it, and difficulted the advancement of climate action.
Integration of climate change issues in medium and long-term planning	• Several respondents (I#3; I#6; I#9; I#10; I#11) highlighted the fact that the climate issues are being integrated into medium and long-term planning strategies. • This was evidenced by documents such as the urban mobility plan, the municipal sanitation plan, and the city's master plan, which is currently under revision. • Including climate issues into long term planning is considered to be a step toward fostering climate action in the future.

6 Discussion

Climate Actions

Reckien et al. (2018) assessed local climate mitigation and adaptation plans in 885 urban areas throughout the EU-28 and found that 66% of them only had mitigation actions in their plans and only 17% had both mitigation and adaptation actions in their local climate plans. The Recife LCAP (ICLEI, 2020) combines mitigation and adaptation measures into a single instrument.

With respect to mitigation, to date the energy actions that have been implemented are mainly low-cost actions within the scope of what the municipal administration has control over. This reality is in line with findings from European cities (Pablo-Romero et al., 2018; Broto & Bulkeley, 2013; Bulkeley & Kern; 2006). LCAP (ICLEI, 2020) establishes that reductions of GHG emissions from urban transportation necessarily requires that the population migrate from individual transport to collective and active transport (walking and bicycles), and to individual vehicles that emit less fuels. This finding is also in line with findings for European cities (Pablo-Romero et al., 2018; Croci et al., 2017). In the waste sector, biogas from waste disposal is already used to generate electricity in line with examples from many developed countries (Pablo-Romero et al., 2018; Croci et al., 2017). Despite this, the percentage of recycling and wastewater treatment in the city is low.

With respect to the IPCC (2014b) adaptation categories, in the structural category Recife has implemented engineered and built environment actions and ecosystem-based actions, but has yet to present any relevant technological measures and services related to climate adaptation needs. In the social category, the city has implemented educational and informational actions, but has not yet implemented any behavioral measures. In the institutional category, over the last 15 years Recife has implemented several laws, policies, plans and projects related to climate change adaptation, but has yet to implement any economic incentives or instruments.

Drivers and Barriers

The literature describes access to funding for climate action to be a main barrier to effectively implementing climate change adaptation and mitigation actions, given that financial support at the national level for local initiatives is often limited. In some countries, particularly in developing countries, cities generally either (I) do not have access to funds from national governments, (II) lack creditworthiness in international financial markets, or (III) do not have the authority to borrow funds independently. In other words, many cities face restrictive requirements for bidding and procurement (Van der Heijden, 2019; Castán Broto, 2017; Aylett, 2015, Bulkeley & Kern, 2006).

Several initiatives in Recife have received financial support from GEF, CAF, IDB, ICLEI, and UN-HABITAT. This demonstrates that the city has had access to resources to implement actions. All interviewees agreed that access to financial resources is a driver, rather than a barrier to the city's implementation of climate actions. According to I#5, "there are more than US$ 1 trillion in resources in the world available for climate action . Cities need to structure appropriate proposals for each type of financier to be able to accesss resources for climate action (...) to show GHG reductions, the cost of carbon, and the benefits of mitigating and adaptating to climate change".

City mayors and other urban political leaders engagement in climate issue is seen as an important driver for effective urban climate governance in the literature (Van der Heijden, 2019; Reckien et al., 2015; Castán Broto, 2017; Bulkeley & Kern 2006). Vocal, charismatic, and experienced leaders are more likely to connect with other cities and build networks that reach beyond national borders. A lack of local political leadership can create barriers to climate actions in a city (Aylett, 2015; Reckien et al., 2015). Almost all interviewees considered the presence of a city leader who is committed to the climate agenda to be essential to strengthening policies to address and combat climate change in the city. The mayor of Recife between 2013 and 2020 was directly involved with climate issues, and participated in several LCAP elaboration meetings (O#1; O#6). In 2019, he became the first Brazilian mayor to occupy the role of President of ICLEI South America. Moreover, during his time as mayor, he also participated in several UNFCCC Conferences of the Parties.

Despite the mayor's great involvement, however, some interviewees highlighted a need understanding of the climate agenda to be better distributed across all local government departments. For example, I#9 stated that "Only one city councilor is directly involved with the climate change agenda and there is little involvement of other local government departments with the climate issue. The [previous city] mayor was a great leader, but the climate issue needs to be disseminated to all departments".

Previous authors have highlighted that being part of international networks (Van der Heijden, 2019; Reckien et al.; 2018; Castán Broto 2017; Bulkeley & Kern, 2006) is a fundamental driver to climate action. The participation of Recife in international city networks, such as ICLEI and CDP Cities, and national networks, such as CB-27, was considered by all respondents to be fundamental to advancing the municipality's climate agenda. This fact was also evidenced by the presence of these networks in all climate planning documents prepared by the city, such as the GHG inventories (Recife, 2015c; Recife, 2017), climate plans (Recife, 2016; ICLEI, 2020), and the city's climate risks and vulnerability assessment (Recife, 2019a).

According to previous authors (Van der Heijden, 2019; Reckien et al., 2015; Romero-Lankao et al., 2018; Castán Broto, 2017; Bulkeley & Kern, 2006), successful cities do not act in isolation, but rather are embedded in multi-level networks that ensure vertical coordination between municipal, regional, and national governments. Moreover, this is considered key to creating supportive urban governance contexts to develop climate actions. Similarly, these authors consider horizontal coordination to be an important condition of urban climate governance and climate actions. Furthermore, they point to the importance of coordination across different departments, agencies, and organizations within a city, and describe a lack of horizontal and vertical coordination to be an important barrier to climate action.

Despite the existence of the COMCLIMA and GECLIMA forums, the city continues to face a lack of horizontal and vertical coordination. Interaction and support from the National Government toward local climate actions has been lacking and creates challenges, particularly since 2019. Nevertheless, Brazil has a national climate change policy, and, at the sub-national level, the state of Pernambuco has a state climate change policy and plan. No national entities participate in these forums and sub-national government participation is limited (O#1; O#4; O#5; O#6).

The lack of horizontal coordination is also a barrier to consolidating the city's climate agenda, as stated by I#6: "Horizontal coordination is a problem for sure. (…). There is a "coordination crisis". There are several ongoing initiatives, but each department deals with its projects secretly. They [the projects] are not treated as city projects. A permanent structure to coordinate all actions is needed. There is no coordination".

The extent to which cities and their governments can govern climate actions depends on, and is affected by, both regional and national political agendas and the legal contexts in which they are embedded. Several authors have highlighted a supportive political and legal context to be a driver of climate actions (Van der Heijden, 2019; Reckien et al., 2015; Reckien et al., 2018; Castán Broto, 2017). The city of Recife has an established legal framework that favors local climate actions (Recife, 2014; Recife, 2016; ICLEI, 2020). All interviewees confirmed this to be an important driver of climate actions in the city. Furthermore, the creation of a specific department in the local government to deal with climate-related issues was also considered to be important. The Secretariat for the Environment and Sustainability (*Secretaria de Meio Ambiente e Sustentabilidade* - SMAS) was created and specific functions have been established in the department's organizational chart to address the issue of climate change and low carbon policies. According to interviewee I#11, "From that moment [when the SMAS was created] on, the climate issue has been treated as one of the pillars of the local government".

Previous authors have attributed the autonomy to act to be a driver of climate actions (Van der Heijden, 2019; Romero-Lankao et al., 2018). In the case of Recife, autonomy continues to be a barrier to local climate action when it comes to certain actions. There are some important climate issues that the local government does not have the autonomy to deal with. For example, to deal with sanitation, water supply, and air space issues, among others, the city is required to form partnerships with both state and national governments. Similarly, certain issues such as waste management and public transport, which are important to the climate agenda, are managed on a metropolitan basis and, thus, any climate actions in these areas necessarily require the involvement of 13 other municipalities. These difficulties were expressed by I#8 who stated: “There is a black box on the issue of wastewater treatment in the state of Pernambuco. It is a Public Private Partnership but the city has never been able to access the [related] information”.

Literature (Reckien et al., 2015; Reckien et al. 2018) showed that climate related risks are not effective drivers of climate action in European cities. Historically, the city of Recife has experienced the impacts of climate change, such as rising sea levels and heavy rainfalls with landslides (E. Baltar de Souza Leão et al., 2021). Interviewees I#7, I#8, and I#11 considered the Climate Risks and Vulnerability Analysis (Recife, 2019a) to be a fundamental element in the planning and implementation of adaptation actions. Observations O#1, O#5, and O#6 revealed that both the city’s history with climate events and projections of heavy climate impacts in the future guided all LCAP resilience sector discussions. Several measures contained in the LCAP (ICLEI, 2020) resilience sector were designed based on climate risks. Therefore, it can be deduced that climate risks were an important driver of climate actions in the city.

In addition to the climate action drivers and barriers most cited in the literature, other drivers and barriers were highlighted by interviewees. Interviewees I#3, I#6, I#8, I#10, and I#11, for example, cited the integration of climate change issues in the city's medium and long-term planning as a driver to climate action. The plan "Recife 500 years" (from portuguese *Recife 500 anos*,) which describes city planning to 2037, as well as the urban mobility plan, the municipal sanitation plan, and revision of the city's master plan all considered several aspects of the city's local climate action plan. According to interviewee I#11, "The climate action plan started to have a strong influence on the city's policies and projects. However, it is important that [the city] ensure that the premises and principles of the plan become a reality in its execution".

An important barrier to climate action that was highlighted by several interviewees (I#3, I#5, I#6, I#8, I#9, I#10, I#11, I#14, and I#15) was the impact of political arrangements on the climate agenda. For example, even without a change of mayor, the political game of accommodating different party interests led to changes in the SMAS that weakened it. As stated by I#11, "The political game has severely damaged the [climate action implementation] process and has left a long-term negative impact on [climate-action] initiatives". Moreover, according to I#10, "With the political changes, the secretariat has lost its leadership". Changes made to the SMAS leadership and technical teams during the last two years of the mayor's mandate contributed to weakening the department (O#1, O#5, O#6, E#3, E#6, E#8, E#10, E#11). Some of the climate issues were picked up by other departments involved in the long term planning of the city (O#1, O#5, O#6, E#8, E#10, E#11).

Among the concerns expressed by the interviewees, is the possibility that advancements made to the climate agenda will be lost with future political changes. According to I#8, "There is an institutional weakness, since most of the people dealing with the municipality's climate agenda are temporary professionals (commissioned positions). They are not local government career employees".

7 Conclusions

The existing literature on the drivers and barriers to local climate actions tends to focus on cities in the Global North, thereby demonstrating a gap in the literature when it comes to other regions, such as the Global South. This case study examined the advancement of the climate agenda in the city of Recife, Brazil, and discussed the drivers and barriers to effective implementation of climate actions.

Mitigation planning actions implemented by Recife in the energy, transport and waste sectors were found to be aligned with actions found in the literature. Although the city has already implemented relevant actions, many additionally planned actions still require intense articulation among the city's stakeholders to be implemented. A relevant part of the current strategy to decarbonize by 2050 is linked to compensation actions. This denotes that the city needs to review and incorporate new mitigation measures with bolder results to be aligned with Paris Agreement targets.

Moreover, the city has already implemented relevant engineered and built environment actions, ecosystem-based actions, and education and information based actions, and has developed several laws, policies, plans, and projects related to climate change adaptation. However, it is only at the early stages of implementing technological and economic measures to promote climate actions.

Several traditional drivers of climate action identified in the literature were shown to be fundamental to strengthening the climate agenda in Recife, including: the presence of a leader who is committed to the climate agenda, and the fact that the city is part of an international network.

Multilevel governance has also been previously identified to be an important driver of climate action, however, often encounters barriers that may be common in less developed countries. In the case of Recife, the local government does not have the autonomy to make important decisions or take important action when it comes to certain climate-related issues and necessarily needs to articulate with both national and sub-national governments. Although multilevel governance mechanisms have been created in the city, the participation of other spheres of government is minimal and horizontal and vertical coordination is deficient. Thus, there is an essential need to turn the climate issue into a cross-cutting issue within the local government administration.

The case of Recife shows that institutionalization of the climate agenda is fundamental if the city is to avoid interruptions from changes to its local administration. The changes that occur within government to accommodate various political interests were identified to be the main barrier to climate actions. Similarly, several respondents stated the integration of climate change issues into medium and long-term planning to be important to the continuity of these actions in the future.

Two important findings emerge from this study. This first is that, unlike what is described in the literature, securing funding is not considered to be a barrier to effectively implementing climate actions in Recife. Second, is that climate risk is considered to be one of the most important drivers of climate actions in the city. Within the context of cities in less developed countries, who often suffer from infrastructure deficiencies and fewer resources, climate impacts and risks can be more severe and are perceived more by their populations.

This paper offers some contributions for policy makers, particularly those in cities that are severely impacted by climate change and are in the early stages of developing low-carbon strategies, especially in developing and less developed countries.

Specifically, it suggests the following steps to structure actions to address climate change and strengthen the climate agenda:

1. Join international cities networks.
2. Develop studies to understand the city's specific climate profile (GHG inventory and a climate risks and vulnerabilities analysis).
3. Promote capacity building among city leaders and encourage their involvement in the regional and global climate debate.
4. Institutionalize multilevel governance mechanisms that strengthen horizontal and vertical coordination and enable the effective participation of national and sub-national institutions, civil society, NGOs and the private sector.
5. Train local administrative staff and make climate change a cross-cutting topic.
6. Develop a climate action plan that considers mitigation and adaptation actions.
7. Create financial instruments to support climate actions.
8. Integrate climate change issues into medium and long-term planning.

Among the limitations of this study are the fact that it reflects the reality of a city that has already advanced in its climate change agenda. Cities that are just beginning to adopt climate change agendas may face other relevant drivers and barriers than those discussed here. Furthermore, this study is limited by the act that it included a small sample of actors. Although interviews covered a wide range of stakeholders in the city's climate agenda, it was not possible to interview all relevant actors, nor was it possible to interview the city's main leader on the topic, i.e., the former city mayor between 2013 and 2020. Participant observations were also hampered by the COVID-19 pandemic.

For future studies, it is suggested that new case studies be carried out in developing or less developed countries to corroborate the findings of study and identify new drivers or barriers to climate action in the context of developing or less developed countries. Given that the number of cities implementing climate actions in these countries is increasing, there is a need to develop further studies with medium and large sample sizes focused on the reality of these countries, as well as studies that compare these results with the literature based on the reality of developed countries.

Finally, future studies should examine the differences between the rhetoric of action plans and documents produced by cities to address climate change, and the effectiveness of practical implemented actions.

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4. FINAL CONSIDERATIONS

It is in urban centers that climate change has its greatest effects and where new technologies, and innovations can emerge to mitigate and adapt to climate impacts. The results of a city's GHG emissions inventory show where the main impacts are to climate change provided by its population and economic activities. Understanding the methodologies used, analyzing the quality of inventories, and understanding their impacts for local planning for climate actions is relevant. The literature review (Mi et al., 2019; Mia et al., 2019) showed a literature gap in this issue.

Several authors converge on the fact that there are diverse pathways that can be followed to achieve climate governance, and they may differ between cities located in countries in the Global North and those located in the Global South (Van der Heijden, 2019). However, the literature review showed that most of the previous studies examining empirical climate governance and the drivers and barriers to climate action have been carried out in the Global North (Van der Heijden, 2019; Mi et al., 2019; Reckien et al., 2018; Romero-Lankao et al., 2018; Castán Broto, 2017; Castán Broto & Bulkeley, 2013). It was identified gap related to climate actions adopted by cities in the Global South, particularly with respect to understanding the drivers of, and barriers to, such actions in these cities.

The four studies that compose this thesis aimed at solving the general objective of to analyze the quality and gaps of GHG inventories and the main drivers and barriers to climate agenda strengthening in Brazilian cities.

In the articles presented, the thesis defends that: (I) there are two main types of GHG reporting gaps: incompleteness and lack of transparency which hinder the results accuracy and comparability between cities GHG reporting and can limit local climate action plans; (II) to analyze GHG reports and to compare results, it is essential to identify methodology, base year, emission sources included, global warming potential, and calculation methods, information which are not transparent in several reports; (III) having committed leadership, being part of a multinational network of cities, the existence of multilevel governance; and climate risks are fundamental drivers to cities climate action and, (IV) political interference in one of the main barriers in the context of Brazilian cities.

To reach these conclusions, this thesis was based on: (I) the content analysis of all GHG emission inventories developed by Brazilian cities until July/2021, considering the most recent reports from Brazilian cities and the GHG results from these same cities and years, published by SEEG; (II) innovatively comparison of two methodologies application in GHG inventories of the same cities; (III) interviews with fifteen key-informants directly involved with climate agenda in Recife; (IV) content analysis of regulatory, planning and studies on urban planning and climate change in Recife; and (V) observation of the Recife's stakeholders debates during climate action plan development.

The general objective of this thesis was reached through the achievement of the five specific objectives proposed, as follows:

1) **Specific Objective 1:** To contribute to the literature in comparing the different GHG methodologies for cities in terms of coverage, efforts, and usage.

The first specific objective was met from articles 1 and 2 that compare carbon accounting approaches and the application of different GHG inventory methodologies for cities.

PBA and CBA are complementary. They provide important perspectives to analyze city's impact to climate change (Sudmant et al., 2018; Andrade et al., 2018) and both approaches have positive and negative sides (Peters, 2008; Dodman, 2009; Harris et al., 2012; Afionis et al., 2017; Lombardi et al., 2017; Sudmant et al., 2018; Andrade et al., 2018; Franzen & Mader, 2018).

Although several authors support the adoption of the CBA approach, the disadvantages of this approach are also highlighted by several studies, such as the lack of data available at the local level impacting the accuracy of the results (Peters, 2008; Afionis et al., 2017; Franzen & Mader, 2018).

The methodologies IPCC (IPCC, 2006), which uses PBA, and GPC (WRI, 2014), which uses a combination of PBA and CBA, are the most used by cities to develop GHG inventories. Article 1 found that GPC is also the methodology most used by Brazilian cities. Despite these methodologies have similarities of sectors and subsectors measured and principles, their differences can produce significantly different results as showed by Brazilian cities case in article 2.

This is an alert to GHG emissions inventory users. When analyzing and comparing the results of inventories from different cities, it is essential to identify the methodology being used, understanding their differences. For public policy developers, it is also important to understand the methodological differences when starting their planning for climate actions. An inventory carried out according to the IPCC methodology, for example, does not provide subsidies to fully understand the impacts of population's consumption and imported inputs (from construction and food supply, for example) on GHG emissions.

2) **Specific Objective 2**: To identify the main shortcomings of the GHG inventories in terms of quality and gaps by assessing the inventories of Brazilian cities**.**

The literature review showed that there is lack of empirical research that investigates the quality of GHG disclosures at city level (Mia et al., 2019). By assessing GHG inventories of Brazilian cities, papers 1 and 2 evidenced that cities' GHG inventory reports present two main gaps: lack of transparency and incompleteness. Several reports do not present information on assumptions, input data, emission factors, and calculation methods, which hinders the assessment of data accuracy. Some cities do not account important sectors and sub-sectors in their GHG reports. Relevant emission sources in some cities may be neglected. Therefore, GHG results can be underestimated. Without these types of information, it is difficult to verify the accuracy of the report and make it difficult to replicate the study in future inventories, as well as to make comparisons among cities and changes in carbon emissions over time, which is important for benchmarking and analysis of the actions effectiveness to mitigate climate change.

These uncertainties and deficiencies in cities' emissions inventories, identified in articles 1 and 2, impact the quality of GHG inventories. Consequently, they can guide climate action plans that ignore important emissions sources, such as those related to consumption patterns of the population and local businesses.

3) **Specific Objective 3:** To propose actions policy makers can take to overcome these gaps and improve the quality of the cities GHG inventories.

Efforts are necessary to reduce uncertainties of GHG inventories result (Mi et al., 2019) and articles 1 and 2 contribute to these efforts proposing actions to improve the quality of the GHG inventories. To overcome gaps identified, it is proposed that GHG inventories must (I) disclose clearly methodology used, assumptions, input data, emission sources included, exclusions, and equations for each emission source and (II) use information technology to estimate GHG emission in an integrated production-consumption approach. This would improve consistency and comparability of GHG emissions data at the city level which is one of the four remaining gaps in the urban climate actions research area, according to Mi et al. (2019). Third party verification of cities GHG inventories is also recommended.

As few cities from Brazil and other developing and less developed countries have developed emission inventories, for policy makers there is an opportunity to develop broader, completer, and more transparent GHG inventories. This would contribute for more effective local climate action plans.

4) **Specific Objective 4:** To identify drivers and barriers for climate actions adopted by Brazilian cities.

The existing literature on the drivers and barriers to local climate actions tends to focus on cities in the Global North, demonstrating a gap in the literature regarding to other regions, such as the Global South. Articles 3 and 4 examined the advancement of the climate agenda in the city of Recife and discussed the drivers and barriers to effective implementation of climate actions.

Several traditional drivers of climate action identified in the literature were shown to be fundamental to strength the climate agenda in Recife, including: the presence of a leader who is committed to the climate agenda, and the fact that the city is part of an international network of cities committed to combat climate change.

Multilevel governance has also been previously identified to be an important driver of climate action, however, often encounters barriers that may be common in less developed countries. In the case of Recife, the local government does not have the autonomy to make important decisions or take important action when it comes to certain climate-related issues and necessarily needs to articulate with both national and sub-national governments. Although multilevel governance mechanisms have been created in the city, the participation of other spheres of government is minimal and horizontal and vertical coordination is deficient. Thus, there is an essential need to turn the climate issue into a cross-cutting issue within the local government administration.

The case of Recife shows that institutionalization of the climate agenda is fundamental to avoid interruptions from changes to its local administration. The changes that occur within government to accommodate various political interests were identified to be the main barrier to climate actions. Similarly, the integration of climate change issues into medium and long-term planning is fundamental to the continuity of these actions in the future.

Two important findings emerge from articles 3 and 4. The first is that climate risk is considered to be one of the most important drivers of climate actions in the city. The second is that, unlike what is described in the literature, securing funding is not considered to be a barrier to effectively implementing climate actions in Recife. It was found in Recife case that geographic characteristics, urbanization process and socio and economic development needs increase the threats imposed by climate change. The projected climate change impacts for Recife already have consequences for the urban environment and affect the city's population, especially the most vulnerable groups. Within the context of cities in less developed countries, who often suffer from infrastructure deficiencies and fewer resources, climate impacts and risks can be more severe and are perceived more by their populations.

5) **Specific Objective 5**: To suggest a pathway to guide policymakers toward climate agenda strengthening in cities, particularly in developing and less developed countries.

Articles 3 and 4 offers some contributions for policy makers, particularly those in cities that are severely impacted by climate change and are in the early stages of developing low-carbon strategies, especially in developing and less developed countries. The following steps are suggested to structure actions to address climate change and strengthen the climate agenda:

1. Join international cities networks.
2. Develop studies to understand the city's specific climate profile (GHG inventory and a climate risks and vulnerabilities analysis).
3. Promote capacity building among city leaders and encourage their involvement in the regional and global climate debate.
4. Institutionalize multilevel governance mechanisms that strengthen horizontal and vertical coordination and enable the effective participation of national and sub-national institutions, civil society, NGOs and the private sector.
5. Train local administrative staff and make climate change a cross-cutting topic.
6. Develop a climate action plan that considers mitigation and adaptation actions.
7. Create financial instruments to support climate actions.
8. Integrate climate change issues into medium and long-term planning.

The thesis and the articles that comprise it have limitations. One of them is that articles 1 and 2 focused their analysis on Brazilian cities emission inventories. The lack of transparency of the GHG inventories released by cities and a lack of detailed description of how the emissions estimated by SEEG are allocated in each municipality makes it difficult to analyze in-depth variations. Despite these limitations, these articles were among the most complete studies in Latin America and paper 1 is already published by prestigious Journal of Cleaner Production.

Papers 3 and 4 reflects the reality of a city which has already advanced in its climate change agenda. Cities that are just beginning to adopt climate change agendas may face other relevant drivers and barriers than those discussed. Furthermore, these studies are limited by the fact that it included a small sample of actors. Although interviews covered a wide range of stakeholders in the city's climate agenda, it was not possible to interview all relevant actors, nor was it possible to interview the city's main leader on the topic, i.e., the former city mayor between 2013 and 2020. Participant observations were also hampered by the COVID-19 pandemic.

Due to the COVID-19 pandemic, it was either not possible to develop the visiting scientist period during 2020, approved by Twente University in the Netherlands. Even though this was not possible, cooperation with researcher Diana Reckien occurred remotely, which resulted in article 4 of this thesis.

Finally, table 12 proposes an agenda to future studies on urban emissions, carbon accounting and drivers and barrier to climate action. Also, new research could investigate how GHG reports impacts climate action planning in these cities.

Urban Emissions and Carbon Accounting	Drivers and Barriers to Climate Action
Studies using a larger sample of cities from different countries and regions. Studies developing GHG inventories using CBA. More research comparing GHG results using top-down and bottom-up data collection approaches. Research that suggests methods to facilitate GHG inventory development using CBA. Research which investigates how GHG reports impact climate action planning. Longitudinal studies that examine whether climate change performance in cities has improved, or whether GHG emissions have reduced following their actions. Studies providing methods to improve the comprehensiveness and accuracy of carbon accounting for cities.	New case studies be carried out in developing or less developed countries to corroborate or deny the findings of this study and identify new drivers or barriers to climate action in the context of developing or less developed countries. Studies with medium and large sample sizes focused on the reality of cities from developing and less developed countries. Studies that compare drivers and barriers in cites from developed countries and developing or less developed countries. Studies that examine the differences between the rhetoric of action plans and documents produced by cities to address climate change, and the effectiveness of practical implemented actions. Research to understand whether and how promising examples of urban climate governance can be scaled up. Research to investigate the various pathways that may lead to effective urban climate governance. Studies discussing how we can ensure that the progress made so far is not reversed by future swings in political leadership.

Table 12: Future Studies Agenda

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ANNEX I – INTERVIEW SCRIPT

INTERVIEW SCRIPT

Date:

Time:

Name:

Position:

Institution:

Decription about involment with climate agenda in Recife:

Questions:

1. What are the main difficulties to develop GHG inventory? Considering emission sources not included in the inventory, please explain why they were not included.
2. How was emission reduction target defined? How is the climate vulnerability analysis guiding mitigation and adaptation plan? How the city plan to become carbon neutral?
3. How is the forum organized? How horizontal coordination happen in this forum?
4. Why your city is member of an international network? How this membership helps the city to climate actions?

5. How are mitigation and adaptation actions defined in the low carbon plan? How are mitigation and adaptation integrated to other long-range or sectoral plans?
6. About mitigation actions in the Energy Sector, which actions were implemented? What factors could assist its implementation?

Energy

- Energy efficiency in buildings .
- Energy efficiency in industrial processes .
- Energy efficiency in lighting systems .
- Energy efficiency measures in council housing .
- Energy certification labelling .
- Smart grid infrastructure .
- District heating/cooling plant .
- The use of renewable energy .
- Energy efficiency schemes for municipal buildings .
- Purchasing green energy by public buildings.
- Energy/carbon taxes.
- Eco-house demonstration projects.
- Strategic planning to enhance energy conservation.
- Planning guidance on energy efficiency design.
- Planning guidance on renewables energy projects.
- Contracts to guarantee renewable energy installations.
- Campaigns for energy efficiency.
- Provision of advice on energy efficiency to businesses and citizens.

- Provision of grants for energy efficiency and/or renewable energy measures.
- Guidance for architects and developers on energy efficiency and/or renewables.
- Please, specify, any additional action on Energy Sector developed by your city:____

Please explain about the difficulties to implement actions not implemented?

7. About mitigation actions in the Transport Sector, which actions were implemented? What factors could assist its implementation?

Transport

- Implementation of new low-carbon transport infrastructure.
- Public fleet replacement.
- Bike Lanes.
- Electric vehicles (including infrastrucuture).
- Transport mobility planning/regulation. .
- Traffic light optimization.
- Integrating ticketing and charging .
- Road network optimization .
- Improvement of logistic and freight transport .
- Fuel switching .
- Car sharing/pooling .
- Enhancing energy efficiency at existing fleet .

- Reducing the need to travel through planning policies .
- Mobility management for municipal employees .
- Pedestrianisation.
- Workplace levies and road-user charging.
- Road pricing congestion charge.
- Park zoning and pricing.
- Policies to reduce car use.
- Education campaigns on mobility enhancement.
- Quality partnerships with public transport provider.
- Please, specify, any additional action on Transport Sector developed by your city:____

Please explain about the difficulties to implement actions not implemented?

8. About mitigation actions in the Waste Sector, which actions were implemented? What factors could assist its implementation?

Waste

- Enable methane combustion from landfill sites and landfill gas capture.
- Waste prevention, recycling and reuse within the local authority.
- Provision of sites for recycling, composting and 'waste to energy' facilities .
- Procurement of recycled goods.
- Recycling, composting, reuse schemes.
- Campaigns for reducing, reusing, recycling waste .
- Promote use of recycled products.
- Campaigns for sustainable consumption.

- Universalization of basic sanitation (PPP/Plano Recife 500 anos);
- Enable methane combustion from Wastewater treatmen :
- Green Technologies for wastewater treatment.
- Please, specify, any additional action on Waste Sector developed by your city:____

Please explain about the difficulties to implement actions not implemented? What factors could assist its implementation?

9. About mitigation actions in the Urban Planning and Infrastructure sector, which actions were implemented?

Urban Planning and Infrastructure

- Building standard Law.
- Building insulation.
- Land use planning regulation.
- Urban Greening.
- Tree Planting.
- Green Roofs Initiatives
- Reuse of Brownfield land .
- Nature-Based Solutions.
- Recovery of urban rivers
- Ocean Management.
- Please, specify, any additional action on Urban Planning and Infrastructure developed by youR city:

Please explain about the difficulties to implement actions not implemented? What factors could assist its implementation?

10. **About adaptation, which actions were implemented of developed policies to motivate it?**

Adaptation

- Resilience Plan.
- Measures to prevent landslide risks.
- Measures for Flood protection.
- Actions to combat sea level rise.
- Policies to prevent the spread of contagious diseases.
- Policies to prevent heat waves.
- Measures securing energy and water supply.
- Modernization of existing drainage networks.
- Revitalization / Renaturalization of rivers and canals.
- Urban requalification (in floodable areas, coastal and hillside areas) (ARV).
- Bushfire protection.
- Relocation and zoning policies.
- Blue and green infrastructure.
- Building codes for extreme weather.
- Early warning systems.

BARRIERS

how each barrier impact planning and implementation of climate actions?

- Lack of funding for implementation.
- Lack of staff or staff time.
- Lack of leadership from Mayors and other elected officials.
- Lack of strong national leadership.
- Lack of information about local greenhouse gas emissions.
- Political focus on short term goals.
- Lack of information on the likely local impacts of climate change.
- Lack of awareness among staff about the local impacts and relevance of the issue.
- Lack of understanding of how local governments can address the issue of climate change.
- Lack of coordination across municipal agencies/departments.
- Lack of coordination across municipal agencies and National/Sub-national (State) agencies/departaments.
- Difficulty factoring climate change responses into infrastructure budgeting.
- Local Government lacks jurisdiction over key policies area.
- Difficulty mainstreaming climate change into existing departmental functions.
- Competing Priorities.

DRIVERS - how each driver impact planning and implementation of climate actions?

- Local Political Leadership.
- Sub-National (State) Political Leadership.
- National Political Leadership.
- Be a member of climate international networks (Iclei, C-40, etc).
- Acesse to funding for climate action.
- Multilevel Governance.
- A supportive political and legal context.
- Presence of specific budget for climate change and/or environmental issues.
- External technical assistance about climate change.
- Experienced Climate Impacts.
- Climate Risks.
- Autonomy.
- Engagement of partners from civil Society.
- Public opinion about the importance of climate change.