Fuelling Effective Climate Governance: How High-Quality GHG Inventories Can Empower City Governments

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Abstract. Cities are major contributors to climate change and crucial actors in the mitigation and application of climate governance. They must establish complete and accurate greenhouse gas emissions inventories in order to formulate successful climate strategies, yet, few papers explore the benefits of data-driven climate governance. Through analyzing qualitative and quantitative papers, this literature review highlights the vital role of cities in mitigating climate change and how precise and complete inventories can empower local governments. Such inventories empower cities by ensuring data accuracy for informed decision-making, enabling targeted mitigation strategies, facilitating progress on monitoring, and providing access to collaboration and funding.

1 Introduction

Cities play an essential role in the mitigation of climate change, and their involvement is necessary for achieving the goals set by the Paris Agreement. They are responsible for over three-quarters of worldwide carbon emissions, and therefore, are also significant contributors to climate change and its effects (Feiock and Bae, 2011). To achieve the goals set by the Paris Agreement and national plans for 2030, cities must establish applicable climate strategies, which requires as a first step, a complete and updated greenhouse gas emissions inventory (Arioli et al., 2020).

The first step for cities to address climate mitigation is having a sustainable and reliable emissions inventory (Wright et al., 2011). An accurate GHG emissions inventory allows municipalities to create mitigation strategies and monitor the effectiveness of their current climate plan when regularly updated (Mueller et al., 2021). While there are different methods to achieve such inventories, high quality, accuracy, comparability and completion are among the main characteristics cities should aim for (Ibrahim et al., 2012; Ramaswami et al., 2012; Mueller et al., 2021). Although GHG inventories are not the only indicator of climate mitigation, investing in quality inventories is an essential starting point for cities to create targeted climate strategies (Feiock and Bae, 2011).

Cities are continually investing in new forms of accountability. Through data-driven governance to civil collaborations, advancements in data and technology are pushing governments to use new tools in decision-making toward more transparent processes (Hughes et al., 2020). With that, the science of cities is evolving (Bai et al., 2018). Policy-makers are transitioning into evidence-based decision processes to mitigate risks and develop new climate strategies (Bai et al., 2018).

Research on how cities quantify their climate plans and to which state inventories contribute to it is still vague (Hughes et al., 2020; Krause et al., 2019). This report aims to explore the gray area of how such inventories may benefit urban climate governance, answering the following question: How can high-quality Greenhouse Gas inventories empower city governments?

2 Methods

This report is based on qualitative research methods, through a literature review, to investigate the potential benefits of high-quality greenhouse gas emissions inventories for cities. A systematic literature analysis of 19 qualitative and quantitative-based research papers and an exploration of national and transnational climate agreements was conducted. The selected papers were sourced from Google Scholars, ScienceDirect and other resources, such as inventory databases and relevant research articles, provided by Ph.D. candidate Patrick Aigner. The research approach includes a comparative analysis of these studies to identify potential similarities

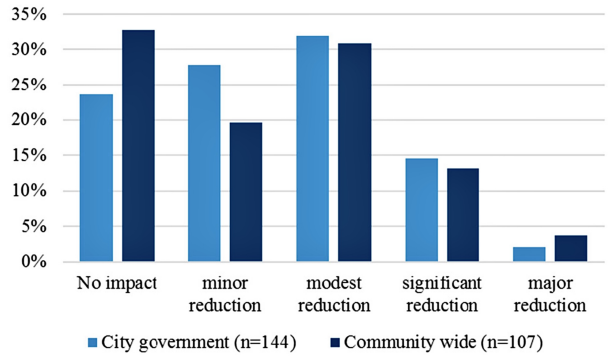

Figure 1. Percent of cities indicating the degree to which GHG inventories served as the basis for emissions reduction. The Y-axis represents the percentage of city government and community-wide that have described inventories, as seen in the X-axis, as being the basis for minor, modest, significant, or major emissions reductions. The colors differentiate between city government (light blue), and community-wide (dark blue). (Krause et al., 2019)

and challenges cities may face within their search and use of climate data.

3 Results

City governments often don't quantify their climate plans, and when they do, they face challenges with such processes. With that, GHG emissions inventories have shown to have a moderate to low impact on the emissions reductions of cities (See Figure 1), with only a minority of cities inventories, 15%, being described as 'significant' or 'major' for mitigation reductions in urban climate plans (Krause et al., 2019).

The findings of the analysis include advantages cities may have when having access to high-quality GHG inventories and challenges they currently face. The literature analysis identified four primary areas in which cities can benefit from the use of such inventories: Accuracy for informed climate governance decision-making, Targeted and effective mitigation strategies, Reporting and monitoring progress of climate action, Access to collaborations, funding and higher-level support. Each area will be explored in the results sections.

3.1 Accuracy for informed climate governance decision-making

Many cities have generated self-reported emissions inventories, but their value on climate mitigation highly depends on the accuracy of these inventories (Gurney et al., 2021). Inventory accuracy can contribute to two significant assessments for the city: to identify key sectors and activities contributing to emissions in order to create policies and identify opportunities, and to stay informed on the potential impact of different measures.

Only by accurately tracing GHG emissions can cities enter a process of data-driven governance based on GHG emissions reduction. The absence of such precision highly challenges prioritization for climate mitigation and can lead to misallocation of resources and low-impact policies (Gurney et al., 2021). In the paper by Gurney et al. (2021), the research presents a comparison between its own inventory, Vulcan Version 3.0, and self-reported inventories in multiple cities across the United States, along with the Mean Across-Sector Absolute Difference for each city. When examining the paper's results, there were significant differences seen within individual sectors, even despite a relatively close agreement in total emissions (Gurney et al., 2021). Overall, the study shows that inaccuracy is still prevalent within sectoral inventories today, and cities in the U.S. underreport their Scope 1 emissions by 18.3% on average (Gurney et al., 2021; Mueller et al., 2021).

Accurate city-scale inventories can allow city governments to develop, implement and track climate measurements (Arioli et al., 2020). Additionally, precise inventories are also useful in the management of risks and identification of opportunities for city governments (D' Avignon et al., 2010). In a study case of the city of São Paulo, by D' Avignon et al. (2010), the use of GHG emissions inventories identified the major focal points for climate action in the municipality. When analyzing the contribution of socio-economic sectors to fossil fuel emissions, the research shows an overwhelming contribution of the transport sector to municipal emissions. With that, the recognition of opportunities led to governmental incentives for the use of public transportation, through multiple interventions in the transportation sector, in order to improve traffic flow in the city and reduce emissions (D' Avignon et al., 2010).

While tackling resource restraints and data visualization, cities are starting to adopt visual inventory tools as a user-friendly approach to staying informed on the potential impact of climate measures through scenario-building. Tools like ClimateView, ClearPath and City Climate Intelligence provide municipalities with the anticipation of measures by creating possible scenarios with the current GHG emissions inventories the cities provide. Such tools have shown to be extremely efficient for cities to visualize a digital twin on their pathway towards net-zero (Wray, 2021), but in order to deliver accurate and applicable results that will benefit decision-makers, tools should be fed with up-to-date quality inventories.

3.2 Targeted and effective mitigation strategies

The climate crisis requires precise GHG inventories in order for cities to develop, implement and track climate solutions (Erickson and Morgenstern, 2016). To accelerate the low-carbon transition, city policymakers need data about how much, where, and when greenhouse gasses are emitted in their communities (Arslanalp et al., 2023). Therefore, high-

quality inventories are crucial for targeted and effective mitigation strategies on sectors and activities contributing to emissions, and to assess the link between their inventories and climate mitigation (Ibrahim et al., 2012; Arioli et al., 2020; D' Avignon et al., 2010).

A case study in the city of Shenyang, China, shows how precise inventory analysis on emissions at a city level can contribute to identifying industries and societal sectors and its reduction efforts to ultimately assist in climate policymaking (Xi et al., 2011). The study highlights a predominance of GHG emissions within the energy sector, and uses this information to explore how detailed emissions from different sectors can contribute to targeted policies for low-carbon mitigation (Xi et al., 2011). By providing a detailed understanding of emissions sources within a city, city policymakers can use such insights to identify sectors and activities in need of targeted strategies.

On the assessment between inventories and mitigation strategies, climate plans generally do a poor job of linking mitigation actions to reduction targets (Boswell et al., 2010). In a study analysis by Boswell et al. (2010) of 30 city climate plans selected as a stratified random sample, most climate plans either failed to quantify mitigation reductions, or failed to make assumptions clear. Data-driven decision-making requires officials to be well-trained and the public to be educated on the matter in order to work (Hughes et al., 2020). Potential challenges cities face when quantifying climate plans can include a lack of resources, such as inaccessible data and infrastructure (Hughes et al., 2020). With that, partnerships between city governments and research institutions possess the ability to contribute to data accessibility as well as data interpretation.

3.3 Reporting and monitoring progress of climate action

Cities can highly benefit from up-to-date and explicit reporting and monitoring progress of climate action. Higher-quality GHG inventories can provide cities with improved monitoring systems to better evaluate the success rate of their climate action strategies, and be an essential player in tracking the progress of emissions reduction close to real-time. Regularly updated inventories have been shown to contribute positively to cities' climate governance, such as described in Boswell et al. (2010) and Krause et al. (2019). Cities that have inventories that are closer to real-time are more likely to provide a basis for successful emissions reductions and have approximately 2.4 times the odds of being evaluated as being the basis for major reductions than cities with older inventories (Krause et al., 2019). Research has also shown that city leaders committed to investing in up-to-date inventories may be more inclined to use such inventories as a basis for policy action (Krause et al., 2019).

Up-to-date data is essential for city-scale GHG emissions inventories (Arioli et al., 2020), but urban governments often face challenges in this regard. For instance, the Covenant of Mayors' 2020 report indicated an average of the last emissions monitoring year as early as 2014 (Rivas et al., 2022). This temporal gap in reporting emissions poses a challenge for policymakers to analyze annual trends in emissions and monitor their current strategies. Cities face similar challenges regarding monitoring and reporting of their current climate mitigation. While monitoring is considered an essential component to the success of climate action (Rivas et al., 2022; Reckien et al., 2018), only 47% of climate plans included monitoring within their climate strategies, according to the climate plan analysis of Boswell et al. (2010)(See Table 1). The lack of monitoring and up-to-date data can be explained by technical and financial barriers in the public spectrum, and shows the necessity for outside stakeholder collaborations (Rivas et al., 2022; Boswell et al., 2010).

Table 1. Percentage of sample of climate action plans containing specific content. Analysis matrix summarizing whether certain elements were present in the climate plans' sample. On the right, the specific contents are mentioned, and on the left, the percentage to which they were found within the climate plan sample. (Boswell et al., 2010)

	% of plans
Climate science basics/primer	73
Local/regional climate change impacts	77
Planning process description	60
Public participation description	47
GHG emissions inventory (summary or entire report)	97
GHG emissions reduction target	100
GHG emissions forecast	70
Mitigation policies/programs/actions	100
Adaptation policies/programs/actions	27
Financing	27
Monitoring and evaluation	47

3.4 Access to collaborations, funding and higher-level support

Having precise and updated GHG inventories allows cities to become model systems for climate governance while enhancing their credibility, opening the door to collaborations, funding and higher-level support. By investing in data-driven governance, city governments can grow their accountability and transparency processes. Both data-driven governance and accountability are crucial in the climate transformation, however, data-driven decision-making is still not well understood in the context of climate governance (Hughes et al., 2020).

Memberships and collaborations with transnational city networks have been shown to influence cities towards using higher-quality GHG emissions inventories. For instance, cities' completion of inventories was largely shaped by

whether the city was a member of the ICLEI sustainability network, increasing the odds of inventory completion by around five times (Krause et al., 2019). Cities that substantially use GHG emissions inventories as the basis for their climate mitigation strategies are also positively associated with its government stability, inventory updates, and the city's electric utility (Krause et al., 2019). Cities that engage with higher quality GHG emissions inventories often join global reporting platforms, such as the Carbon Cities Climate Registry (Hughes et al., 2020). The Covenant of Mayors has also shown to play a role in pushing smaller cities to formulate improved climate plans (Reckien et al., 2018). By accessing collaborations with such networks, municipalities often become incentivized to further develop their inventories and climate action strategies. Accordingly, some transnational city networks also advise cities to develop inventories and climate plans in order to become members.

Another benefit that quality inventories can bring to cities is to strengthen collaborations with science and civil society. Research shows that only around 47% of randomized climate plans include public participation descriptions (See Table 1) (Boswell et al., 2010). Online platforms and innovative data collection techniques have been shown to increase opportunities for civil participatory systems within governments (Hughes et al., 2020). With that, city governments can push for science and civil stakeholders to become more involved in decision-making processes by increasing the visibility of policy measures through open data (Hughes et al., 2020) and building partnerships for better GHG emissions inventories.

Ultimately, investing in quality inventories will further benefit the city governments by complying with their national commitments to the United National Framework Convention on Climate Change (D' Avignon et al., 2010).

4 Challenges to consider

Although city governments have an essential role in climate mitigation, they can't do it alone. Most cities rely on partnerships and collaborations, from funding to labor and expertise, in order to meet climate mitigation goals (Bai et al., 2018; Lombardi et al., 2017). There are obstacles to overcome in order to make it possible for cities to invest in complete and up-to-date GHG emission inventories, therefore, such should be carefully considered.

One crucial challenge cities face today is access to data. Data collection needs to be improved in order for cities to have completed GHG inventories (Arioli et al., 2020; Bai et al., 2018). From availability to coverage, quality, resolution and reliability, and especially in the global south, where the biggest data gap is found (Arioli et al., 2020; Bai et al., 2018).

Today, many city governments have to rely on spending public money to purchase data in order to develop their city inventories, or outsource to other institutions to do so. With that, local governments often build inventories with available data and therefore, have incomplete or out-of-date inventories.

There are different ways local governments attempt to address this issue, with collaborations with outside stakeholders and the adoption of data policies being some of them. In a study of 150 climate governance initiatives in China, research suggests that city stakeholders use collaborations with outside stakeholders as a strategic endeavor to receive information, technology, and funding (Westman and Broto, 2018). Through these cross-sectoral partnerships, city governments are able to overcome barriers and gain access to resources beyond their individual capabilities (Westman and Broto, 2018).

5 Conclusions

The main goal of this review was to identify the potential benefits that high-quality Greenhouse Gas emissions inventories can provide to city governments. Improved Greenhouse Gas inventories hold great power to empower city governments, and the first step to address city climate strategies requires a completed inventory. Complete and accurate inventories can assist cities in adopting data-driven policies, prioritizing climate mitigation, and closely monitoring climate strategy progress. With that, cities can benefit from precise inventories by having accuracy for informed climate governance decision-making, targeted and effective mitigation strategies, better reporting and monitoring progress of climate action, and further access to collaborations, funding and higher-level support.

The accuracy of inventories is essential to assist cities in identifying major sectors of emissions to effectively implement strategies and understand the impact that different measurements may have through scenario-building. This is presented through multiple study cases of Gurney et al. (2021), where sectoral differences and underreporting were found as common practices in multiple U.S. city-reported inventories, and D' Avignon et al. (2010), where detailed sectoral inventories in the city of São Paulo led to the recognition of opportunities from the city governments. The use of online tools, such as ClearPath and ClimateView, appear to also assist cities but require better data.

Precise inventories are also needed for targeted mitigation strategies and in order to assist cities in quantifying their climate plans. Research shows that cities struggle with using their current inventories to justify and quantify climate strategies, and many climate plans don't include monitoring and evaluation processes. High-quality inventories can benefit municipalities with quantification through data accessibility, but lack of trained personnel and resources are still obstacles cities have to overcome.

Up-to-date inventories have high potential in supporting cities with climate reporting and monitoring of their cur-

rent mitigations. Research shows that cities with closer-to-real-time inventories are more likely to use inventories on their climate plan mitigation of emissions reductions (Krause et al., 2019), and many cities today don't have the capacity to acquire it. In 2020, city members at the Covenant of Mayors reported an average of 2014 as its latest inventory year (Rivas et al., 2022). Thus, the accessibility of data, user-friendly inventory tools and long-term maintenance of inventories can contribute to the urban climate governance transition towards data-driven processes.

The literature review concludes that climate mitigation is a complex field and requires the collaboration of multiple actors (Feiock and Bae, 2011; Arioli et al., 2020; Bai et al., 2018; Krause et al., 2019; Lombardi et al., 2017). Many cities still lack access to updated, accurate and transparent inventories, and investing in collaborations of city governments with the scientific community is essential in order to co-create knowledge and assist municipalities in meeting their climate goals.

6 Outlook

Cities are continuously pushing to become data-driven governance, and require key contributors in order to succeed.

From a local government's perspective, it is challenging to allocate resources efficiently. Frequently, local policymakers will base their decisions in order to meet higher-level requirements and lack resources to invest in voluntary approaches, such as in higher-quality GHG emissions inventories. Local governmental decisions and budgeting are also influenced by politically driven factors, instead of purely scientific approaches, and still lack full transparency from policymakers. From the research papers' insights, cities seem more likely to invest in inventories of areas that bring them the most benefit, such as the energy, transportation and residential factors, and focusing collaborations in these areas may assist research stakeholders to initiate partnerships.

Collaborations have been shown to have a crucial role in the success of local climate mitigation. Investing in ongoing partnerships between research institutions and the city governments is highly beneficial to both parties, and is a key contributor in the transition of cities towards data-driven governments and the development of high-quality GHG emissions inventories. Research stakeholders may also benefit from private businesses and non-profit stakeholder collaborations. For instance, organizations such as ClimateView offer close partnerships with cities and a visual platform for researchers to apply complete and accurate inventories.

Overall, the analysis of the use of GHG emissions inventories in policymaking has several limitations. Firstly, a few papers were aimed at investigating how cities quantify their mitigation strategies and use data-driven approaches in their decision processes. Most city study cases did not include results directly applied to the city governments and their mitigations, but potential scenarios of how governments could benefit from it. Working on long-term close collaborations between researchers and the city government has the potential to become a compelling area for a science-based policymaking process. Therefore, future research should investigate the use of inventories and big data within decision-making processes and how it is being applied to local climate governance.

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