A POLICY PROPOSAL FOR EXPANSION OF U.S. FEDERAL CLIMATE SERVICES TO ACCELERATE SUBNATIONAL REDUCTION OF GREENHOUSE GAS EMISSIONS

By
Denice Warren Ross

A capstone submitted to Johns Hopkins University in conformity with the requirements for the degree of Master of Science

Baltimore, Maryland
December 2021

EXECUTIVE SUMMARY

Cities contribute more than 70% of global greenhouse gas (GHG) emissions[1] and are essential players in decarbonization. Monitoring sub-national emissions is broadly considered a key first step in identifying where to focus local climate mitigation efforts[2]. Despite twenty years of incrementally refining standards and tools to build local self-reported GHG inventories, the process remains prohibitively resource-intensive for many jurisdictions. The methods for this policy paper include a review of the academic and gray literature and interviews with experts in the field, with the **goal of creating policy recommendations for the development of a Federal GHG Information Service to support local governments in understanding their GHG emissions so they can take strategic actions to reduce them**.

Recent years have seen a shift in the field of estimating local emissions. One line of thinking is toward a new scientific architecture, with nationwide integrated GHG estimates based on carbon sensors, additional data sources, and atmospheric inversion modeling. The other is about a new social architecture, oriented toward taking immediate action on reducing emissions and centering community input on the path toward carbon neutrality. The current incremental approach, as well as these emerging scientific and social infrastructures all share a common goal: reducing the level of effort for local governments to understand their GHG emissions. With the Biden-Harris Administration engaged on climate with

executive actions, legislation, and plans for climate services to infuse science into climate action, the timing is ideal to build out a Federal GHG Information Service so every local jurisdiction has a regularly updated, geographically-detailed estimate of emissions to inform climate planning and emissions reduction. Policy recommendations are: 1) expand climate services to include mitigation, 2) identify high-value data to continuously improve emissions estimates, 3) develop a research agenda to expand the scope of covered emissions for the GHG Information Service, 4) increase the density of carbon sensors nationwide to enable the scaling of detailed estimates, 5) enlist design expertise to bring a human-centered approach to climate services so they meet the decision-making needs of domestic local governments, and 6) identify an inter-agency home for climate services.

Advisors: Daniel Barrie and Daniel Zachary

ACKNOWLEDGEMENTS

I extend my deepest gratitude to my capstone advisor Daniel Barrie, who helped me navigate the divide between the current practices in the field and the emerging science—which it turns out, are not as far off from each other as they initially seemed. Dr. Barrie taught the first class I took in the Energy Policy & Climate program, *The Science of Climate Change and its Impact*; his ability to connect this highly technical science to real-world challenges is a huge factor in my success transitioning back into the classroom after twenty-five years. Many thanks also to Daniel Zachary, who provided a valuable sounding board as this research took some unexpected turns.

I am grateful to the many people who shared their expertise and insights for this paper. The field of measuring greenhouse gas emissions is full of professionals who are creative, mission-driven, incredibly sharp, and generous with their wisdom. Special gratitude to Angie Fyfe/ICLEI USA, Calyn Hart/ICLEI USA, consultant Joshua Radoff, Michael McCormick/Farallon Strategies, Michael Armstrong/City Scale, Kevin Gurney/Northern Arizona University, and Rich Freeh/Urban Sustainability Directors.

Speaking with career Federal staff was especially inspirational as I was in the process of returning to Federal service while writing this policy paper. Conversations with Vincent Camobreco and Andrea Denny at EPA, Arlyn Andrews at NOAA, and Dana Chisnell at the U.S. Digital Service sharpened my sense of what was possible and raised my awareness of the robust Federal assets we can bring to bear on this challenge.

I also want to thank Allen Square, my former boss at the City of New Orleans who, knowing about my desire to work on climate change, handed the phone to me in 2014 when the White House called about the launch of their new Climate Data Initiative. His act of sponsorship changed the trajectory of my career.

I am also thankful for my spouse, David Ross, who nudged me to pursue this degree as I near my 50th revolution around the sun, and delivered with many weekends of getting the kids out of the house so “mom could do her homework.”

Lastly, I dedicate this paper to my late father, Joe Coleman Warren, who left school at the age of 13 to start a 50-year career as a natural gas pipeline welder. He is my personal inspiration for setting the stage for a just transition to a carbon-neutral future.

DISCLAIMER

This research and resulting capstone was conducted solely in my personal capacity and as a student of Johns Hopkins University. The views expressed herein are my own and are not intended to reflect the views of the White House, the Office of Science and Technology Policy, or any of the agencies whose staff were kind enough to talk with me during the process leading up to this final document.

TABLE OF CONTENTS

INTRODUCTION

With the U.S. pullout from the Paris Agreement under the previous Administration, some 440+ cities [3] stepped forward to honor the U.S. commitment to reduce greenhouse gas (GHG) emissions 26-28% below 2005 levels by 2025[4]. Although the politics of the moment may have inspired this uptick in subnational commitments in the United States, cities have always been essential players in decarbonization, as they contribute more than 70% of global emissions[1]. Despite this early enthusiasm, in December of 2020, the Environmental Defense Fund published an analysis using projections based on current policies that revealed significant gaps remaining between state-level ambition and action[5]. They note that state leaders need to "build on the momentum they created by setting climate targets, publicly acknowledge their current emissions gaps, and take policy action to achieve the cumulative reductions consistent with achieving their targets." Boston Mayor Marty Walsh, then-chair of Climate Mayors, summed up the challenge for state and local governments' ability to deliver on climate commitments during the Trump Administration with the acknowledgment that "there's no partner like the federal government"[6]. With the Biden-Harris Administration strongly engaged on climate, shared responsibility for climate action across all levels of government can once again be a pathway toward reducing GHG emissions.

President Biden's day one Executive Order 14008 on *Tackling the Climate Crisis at Home and Abroad*[7] directed the Director of the Office of Science and Technology Policy (OSTP; which houses the interagency U.S. Global Change Research Program; USGCRP) and other relevant agency heads, to provide "a report on ways to expand and improve climate forecast capabilities and information products for the public" and further required the Federal Geographic Data Committee (FGDC), an organization of federal and public geospatial professionals charged with overseeing the National Spatial Data Infrastructure, to "assess and provide to the [National Climate] Task Force a report on the potential development of a consolidated Federal geographic mapping service that can facilitate public access to climate-related information that will assist Federal, State, local, and Tribal governments in climate planning and resilience activities"[7]. The mission of the National Climate Task Force, chaired by the National Climate Advisor, is to "facilitate the organization and deployment of a Government-wide approach to combat the climate crisis" and, specifically, members are to "prioritize action on climate change in their policy-making and budget processes...in their engagement with State, local, Tribal, and territorial governments"[7].

In an October 2021 report in response to E.O. 14008, OSTP, NOAA, and FEMA[8] outlined the provision of "climate services," which they define as "scientifically-based information and products that enhance users' knowledge and understanding about the impacts of climate change on potential decisions and actions." Though

the primary focus of the report is on adaptation, the authors call out research on "advancing greenhouse gas monitoring" as essential for effective climate services. They expand with the following:

> "Improved monitoring is needed of greenhouse gases, including through integration across different datasets (e.g., in situ, airborne, and satellite), filling observational gaps, integrating socioeconomic information, and monitoring the benefits of carbon sequestration from nature-based solutions, such as carbon sequestration and storage on agricultural lands, as well as from conservation and restoration in forests and the ocean. More robust information systems would help decision makers demonstrate the benefits and impacts of climate mitigation measures, from local to global scales."

These are strong first steps that set the stage for additional Federal programming to influence state and local data-driven action on climate. Still, the focus to date has been primarily on increasing access, relevance, and usability of data to inform *adaptation* rather than *mitigation*.

Monitoring sub-national GHG emissions is broadly considered a key first step in identifying where to focus local climate mitigation efforts[2]. Like data for climate adaptation — but even more so — data tailored for local decision-making on reducing emissions remains 1) siloed across Federal agencies, 2) focused at the national or large regional level, and 3) with often significant reporting lags. Additionally, some key types of emissions (e.g., embedded carbon in products and services, propane heating, residential energy consumption) are difficult to measure, meaning important data for decision-making are absent or must be roughly approximated. Taken together, these barriers mean that subnational jurisdictions

cannot merely tap into Federal data to inform their plans for reducing emissions. Instead, each local government builds their own local GHG inventory, using primarily bottom-up accounting and little economy of scale. Self-reported GHG inventories require an onerous, time-consuming process that is often beyond state and local governments' technical and staffing capacity[9] *and* the process must be repeated regularly if a locality wants to measure progress. Both the academic literature and emerging conversations in the field reinforce the need to "prioritize dramatically reducing the time required to complete annual [GHG inventory] reporting"[10] while also broadening the scope of the typical GHG inventory to include consumption-based emissions, and multi-jurisdictional and multi-scale perspectives.[11,12]

Gurney and Shepson[13] argue that we would never expect local governments "to gather and analyze data or create and run weather models to predict weather" and that, similarly, estimating local GHG emissions should reside "at an apolitical institution with a centralized and common approach that adheres to scientific best practices and technical standards" — like the Federal government.

Given this, what role might the Federal government play in curating the most relevant data to lighten the local load of creating or updating a GHG inventory? Could the Federal government provide a "good enough" solution to local estimates of GHG emissions so local jurisdictions could skip the inventory and move straight to planning and action? And more importantly, what are the special requirements

of local estimates of GHG emissions if the data are to inspire actions that reduce emissions and, can current technologies and techniques meet these requirements? ***The purpose of this research is to create a policy document to inform the development of a Federal GHG Information Service to support state, local, and tribal governments in understanding their GHG emissions so they can take strategic actions to reduce them***.

METHODS

The field of local GHG inventories and emissions reduction planning is at an inflection point. The peer-reviewed literature describes the current standard of practice for self-reported GHG inventories, with city-specific forays into novel methods of estimating emissions. Meanwhile, opinion pieces, the gray literature, organizational reports, and conversations among practitioners reveal a growing sense of urgency to move beyond the current standard of practice in order to enable cities to engage in the substantive decarbonization needed to avoid the worst of global warming, capitalizing on the momentum when the U.S. pulled out of the Paris agreement. Given this flux in the field plus the stunting impact of the Covid-19 pandemic on the professional exchange of ideas in in-person settings, this paper aims to bring the disparate lines of thinking together in a way that can inform Federal policy and programs.

Primary methods to answer the research question are a literature review (covering both academic and gray) and interviews with subject matter experts.

Subject matter experts include data stewards in Federal government (including EPA, OSTP, and NOAA), people who advise local governments as they create GHG inventories (from organizations such as ICLEI USA, City Scale, and Urban Sustainability Directors Network), and also experts on government innovation (such as the US Digital Service).

LITERATURE REVIEW (ACADEMIC AND GRAY)

This literature review starts with an overview of the current field of local GHG measurement, including assessments of how effective it has been in estimating emissions. It will close with two lines of thinking about the future of local GHG estimations. The first line of thinking is driven by advances in measurement capabilities and modeling, particularly in atmospheric data. The second line, orients toward taking immediate action on reducing emissions, centering community input on how to get to carbon neutrality. This approach, which could be called the "next-generation framework," was triggered by the compounding crises of climate disasters, the Covid-19 pandemic, and racial inequities. Both of these emerging conversations are focused on shifting local efforts from measurement to transformational structural changes that will reduce emissions.

Self-reported Greenhouse Gas Inventories

In the 2000s, inspired by international emissions reporting protocols, a critical mass of U.S. cities began tracking their own emissions. The process has formalized

in the intervening years, shifting from a "good-faith exercise that informed local policy development to an expectation of frequent reporting of detailed inventory data to support international standardization[11]."

In a review by Arioli et al.[14], the authors note that "city-scale GHG inventory methods evolved from the Intergovernmental Panel on Climate Change (IPCC) Guidelines to a variety of GHG accounting methods that offer levels of complexity to estimate city-scale emissions." That observation holds for inventory tools available through the EPA, and also for more sophisticated inventory tools provided by the private sector.

The scientific literature and publicly available reports from nonprofits working in this field provide insights into the current resources and barriers for cities building GHG inventories to inform commitments and measure progress[15]. ICLEI USA has the most mature and comprehensive network of local governments in the U.S. working on reducing emissions, with 30 years in operation and 330+ inventories created in their ClearPath tool in the year 2019[16]. ICLEI USA's protocols align to the international standards set by the Global Covenant of Mayors.

The Global Covenant of Mayors has outlined the major steps in a city's climate action journey, described below in Fig. 1. Building a GHG inventory appears in two phases of this planning journey: *Understanding* and *Monitoring*. It is worth noting that a method for building a baseline GHG inventory for the *Understanding* phase may not be sufficiently sensitive to capture progress and setbacks in the

Monitoring phase. For instance, if emissions from the consumption of goods and services is estimated based on population size and average income, deep changes in local consumption patterns would not be reflected in updated inventories because it assumes that the same emission factor applies. In another example, if a city is using data from the EPA Greenhouse Gas Reporting Program for measuring major polluters, if a polluting company dramatically reduces its emissions, that progress will not show up for 1-2 years due to lags in data reporting and compilation.

Fig. 1 | Global Covenant of Mayor's "City Climate Action Planning Journey" [17]

The Global Covenant of Mayors Common Reporting Framework for GHG inventories[18] recommends that jurisdictions update their inventories every two years. Regular inventory updates that can capture and quantify changes due to climate action (e.g., improvements to energy efficiency) and externalities (such as increasing population) are essential to celebrate emissions reductions and make mid-course corrections when falling short. Additionally, cities with a complete perspective on the GHG emissions that actions within their borders are responsible for can better assess where their limited resources are better deployed, for

instance, in swapping out street lights to LEDs or advocating for state policies that will fundamentally shift the energy mix[19].

Types of GHG emissions

GHG inventories are typically divided into three categories of reporting: scope 1 (emissions from within city boundaries), scope 2 (emissions due to grid-supplied electricity, steam, heat, and cooling, often outside a jurisdiction's geographic boundaries), and scope 3 (emissions that take place outside of the city because of activities/demand inside the city, often described as "consumption-based" emissions).

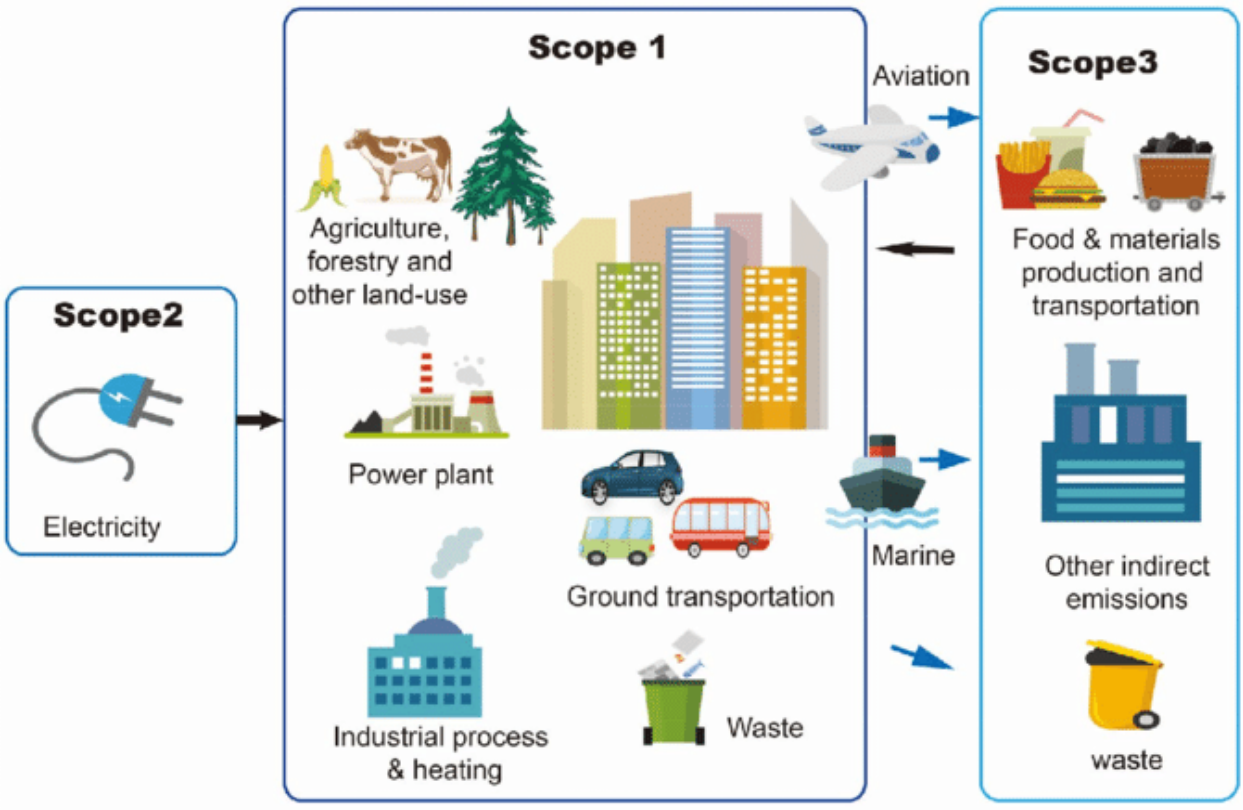

Fig. 2 | Components of scope 1, 2, and 3 emissions reporting from Chen et al.[20]

Scope 1 emissions

Scope 1 emissions, although time-consuming to compile, are the most straightforward as they account for emissions coming from within the geographic bounds of the community—waste, transportation, industrial processes, and agriculture. For scope 1 emissions, local GHG inventories are often divided into *local government operations* and *community-scale*. *Local government operation emissions* are emissions due to the operations of local government, such as government-owned buildings and vehicle fleets, and *community-scale* are for all of the emissions within the jurisdictional boundaries.

President Biden's Executive Order 14008 on *Tackling the Climate Crisis at Home and Abroad* specifically directs agencies to use procurement authorities toward "clean and zero-emission vehicles for Federal, State, local, and Tribal government fleets" (Sec 205(b)(ii))[7], an example of policy that would reduce scope 1 emissions at various levels. The first step toward most-effectively achieving this goal is inventorying fleet emissions. Additionally, land use and carbon storage, often a component of Scope 1 community-scale inventories, are also addressed in EO 14008 which directs agencies to recommend "steps that the United States should take, working with State, local, Tribal, and territorial governments, agricultural and forest landowners, fishermen, and other key stakeholders, to achieve the goal of conserving at least 30 percent of our lands and waters by 2030" (Sec 216)." As with vehicle fleets, a high quality inventory of the diversity of land uses in the

jurisdiction will help jurisdictions prioritize conservation efforts toward maximizing the sequestration value of those land uses.

Scope 2 emissions

Scope 2 emissions of grid-supplied electricity, steam, heat, and cooling are more challenging to quantify because utilities tend to be highly decentralized and are often hesitant to produce sufficiently detailed data, for example, to distinguish between commercial, industrial, and residential consumption. Inclusion of scope 2 emissions in local government GHG inventories is critical, as 25% of emissions nationwide are due to electricity production, and given distribution networks, the source of electricity production is often outside city limits. Cities have different "emissions profiles" that determine which actions are going to yield the most substantial emission reductions[21]. Given limited resources, time may be better spent advocating for a shift to renewable energy than upgrading city fleet vehicles to electric (but still charging them from a coal plant). Similarly, knowing the relative electricity consumption of emissions across commercial, industrial, and residential sectors can help a city target actions, including land use zoning to influence industrial emissions or weatherization programs for residential.

Scope 3 emissions

Scope 3 emissions are typically viewed as optional in reporting regimes because within-municipality consumption is difficult to measure in a way that is reproducible and reliable. However, it is a critical category because cities often

outsource much of their carbon emissions through the goods they import. Hoornweg and colleagues observe that although scope 3 data "can be difficult to obtain, the reporting of upstream, consumption-based emissions provides the most comprehensive view of the GHG emissions arising from an urban system for decision-makers.[2]"

International climate action network C40 analyzed the consumption emissions from 79 member cities and concluded that "carbon footprint of some of the world's biggest cities is 60 percent larger than previously estimated" using just scope 1 and 2 emissions[1]. Another analysis of C40 cities found that 80% of them have consumption-based emissions that are larger than those occurring within the city boundaries.[22] Wiedmann et al.[23] analyzed 79 "three-scope" GHG inventories from C40 cities and found that leaving out Scope 3 emissions would result in under-reporting total city emissions by 40%. The authors note that consumption-based emissions provide a crucial "additional perspective with which to engage cities' stakeholders in climate action." This "additional perspective" could lead to both a change in individual consumption behavior and also advocacy for more accountability for emissions in corporate supply chains.

Barriers to producing local-scale GHG inventories

Creating city or county inventories remains a locally-customized, incomplete, bottom-up accounting process, relying on administrative records, ground-level measurements, and estimations of a variety of activities[24]. This information is time-

consuming to assemble, prone to omission, and heterogeneous across jurisdictions. Denny and Pederson, of the EPA team behind the Local Greenhouse Gas Inventory Tool, describe constraints on local government financial resources, time, and technical skills[25]. In a letter to the California Air Resources Board (CARB), 52 local California jurisdictions noted that even localities with the highest capacities to perform detailed inventories "struggle to put their [climate action] plans into action," and they go on to say that "a disproportionate amount of time and effort is directed toward planning and evaluation, rather than direct implementation and action[26]."

In response to these well-known barriers, a growing body of tools[17] (described in the next section) and a global industry of climate change consultants has emerged[27], as has a robust ecosystem of more than 80 national, state, and regional organizations providing a range of support for state and local governments[28]. Membership in ICLEI USA, for instance, provides cities with technical assistance, peer-learning opportunities, and access to tools such as a software-as-a-service called ClearPath to make it easier to produce GHG inventories (described as "TurboTax for GHG inventories[29]". Even with this assistance, an ICLEI-USA[30] analysis of 123 cities using ClearPath tool reveals that one-third have produced only one community-scale inventory, whereas one-quarter have produced five or more inventories. Reams et al.[31] studied 257 ICLEI cities and found that the network's technical assistance and peer support enables members to produce GHG

inventories. However, they note that cities facing greater environmental stressors and those with more workers in carbon-intensive industries such as oil and gas were less successful in making progress, and warranted "targeted assistance to help them make progress toward long-term greenhouse gas reduction".

Data and tools to improve quality and reduce reporting burden

One core characteristic of the field of self-reported GHG inventories is that it is continuously improving. Much of that improvement has been in the form of tools intended to lighten the load for local jurisdictions. For instance, ICLEI USA, World Resources Institute, Woodwell Climate Center, recently built a tool called LEARN (Land Emissions and Removal Navigator) that customizes USGS National Land Cover Database to local geographies to quantify sequestration benefits[32,33]. However, digital tools do not automatically solve problems; city climate planners need to be aware that a tool exists, recognize that it fits their need, and have the staff expertise and resources to implement the tool.

In a white paper entitled "Understanding data and tools to accelerate city climate action" researchers surveyed and interviewed more than 300 city representatives globally, and found that a city that was using such a tool was 2.5 times more likely to be taking on large-scale climate actions, although causality remains elusive[17]. For the white paper, researchers started with a list of 600+ climate-related tools, and winnowed them down to 59 priority tools to support cities in their GHG mitigation work. They matrixed the tools across 75 "city needs"

across the four phases of climate action (outlined in Fig. 1) and found that the majority of tools addressed city needs related to processing data (as in GHG inventories). However, they found no tools currently supporting consumption-based (scope 3) inventories, and insufficient "streamlined" tools for easy GHG inventorying for lower capacity jurisdictions. On that last point, despite the utility of these tools for many jurisdictions, the researchers concluded that "widespread use [of tools] is thwarted by complexity, lack of awareness, and a high technical capacity threshold."

Data quality

ICLEI USA caveats that the data in GHG inventories are "self-reported and should be considered in light of the typical data challenges that many communities face when conducting an inventory, such as inconsistencies in utility data and the fact that most transportation data is modeled, not measured[30]". For instance, if jurisdictions use measured transportation emissions data such as Google's Environmental Insights Explorer (EIE)[34] rather than modeled data, then their inventories will be more sensitive to interventions such as increased access to public transit. Conversely, modeled or proxy data can mask progress or setbacks in emissions.

While city participation in creating self-reported inventories is well-documented, research on the quality or accuracy of the GHG inventories is nascent, due to the challenges of benchmarking the inventory data against an

independent source of truth. Gurney and colleagues[35] compared GHG inventories from 48 U.S. cities to estimates from an independent integrated platform (called *Vulcan*) for measuring fossil fuel carbon dioxide emissions. (Vulcan emissions estimates are consistent with direct atmospheric measurements of $^{14}CO_2$[36]). They found that city GHG inventories differed from the benchmark by -145.5% to +63.5%, for an average under-reporting of 18.3%. Self-reported GHG inventories in the study often did not include fuel use and point source emissions for industry and commercial facilities. This accounted for the greatest variance from the benchmark, along with differences in estimation methodology and accounting of marine and airborne emissions.

An Inflection Point in the Field of Local Climate Action

Inherent quality limitations of the self-reported GHG inventories and perceived diminishing returns of assigning more local resources to refining the inventories are fueling a growing call for a shift in the field. Armstrong and colleagues describe GHG inventories as "a resource-intensive yet invariably low-quality exercise that generates a badly lagging indicator of progress" due to the inherent complexity of the process and assumptions/estimations that feed into the final numbers.[11] In an assessment commissioned by the Global Covenant of Mayors on the "recent evolutions and opportunities" in the field of local climate action domestically, analysts at the Urban Sustainability Directors Network and City Scale remark that the "work is evolving in ways that depart from the longstanding model of

inventories and carbon-centered standalone climate plans[10]." Gurney and Shepson[13] contend that voluntary GHG inventories and self-reporting from emitters have resulted in a "patchwork" of emissions data that is insufficient to prioritize action where it is most needed. And a Global Covenant of Mayors, Bloomberg Associates, and World Resources Institute survey of nearly 300 cities globally confirmed that assessment with a finding that although 60% had completed GHG inventories, only 22% had moved from planning to execution (such as securing funding for plan implementation)[17].

The inflection point in the field, shifting away from the current accounting-based self-reported inventories, reflects two distinct movements described in more detail in the following sections.

Nationwide Integrated GHG Estimates: Scientific architecture

Recent advances in the science of carbon monitoring systems and atmospheric inversion techniques enable researchers to connect near real-time, measured atmospheric concentrations to their emission sources[37]. These types of estimates are often thought of as verification for GHG inventories, but recently researchers have been using them for climate action planning and tracking in pilot cities[38]. Such an approach offers more geographic granularity across city neighborhoods and across time than a traditional GHG inventory. For example, the *Hestia Project*, which is currently being implemented in four cities: Baltimore, Indianapolis, Los Angeles, and Salt Lake City, is a standardized system that quantifies scope 1

emissions down to the level of individual buildings and roadway segments. Gurney likens this level of precision to using a "scalpel rather than a hammer" to prioritize climate actions[39]. He explains that in the Greater Los Angeles area, "about 60 percent of roadway emissions come from 10 percent of the roads. With Hestia, I can tell them which roads those are, and they can develop specific policies to address just those roads."

Integrated GHG estimates require significant investment, however, in *in-situ* and aircraft measurements of GHG gasses. A sensor can cost up to $100,000, with 8 to 12 at a minimum required to cover a typical metropolitan region, and is therefore currently cost-prohibitive for most local governments[40]. The field also needs further development of standards, to refine the techniques used for atmospheric inversion, and to develop methods for attributing emissions to consumption (scope 2 and 3 emissions). Additionally, data inputs such as assessor information on building square footage or regional traffic information are key elements to the model, but require local collaborations to procure[38].

In a recent opinion piece in the Proceedings of the National Academy of Sciences, Gurney and Shepson[13] advance the case for a "US Greenhouse Gas Information Service" through which "all citizens should be able to see a daily map of detailed emissions across the US landscape, much like viewing daily weather." And, in their inventory of climate mitigation tools, GCoM and colleagues recommend that the future development of tools go in a direction that allows for easy

slicing/dicing of data by different geographic areas, timeframes, and other factors[17]. They additionally recommend lowering the barriers for cities to use tools and more of a focus on decision support.

Next-generation framework for local climate action: Social architecture

In an impassioned call to rethink the current path from emissions measurement to action, eleven local climate action practitioners self-published "The State of Local Climate Planning: Observations by Local Climate Action Practitioners" in May of 2021[11]. The paper was the culmination of conversations started 2019 but interrupted by the Covid-19 pandemic—a time of compounding crises that included racial injustices, exposed inequities, and climate-fueled disasters. In contrast to the proposed adoption of a new science architecture described in the previous section, this discussion focuses on a new social architecture for emissions measurement, planning, and action.

They are aiming to continue the dialogue on how to "co-create a next framework," with a focus on centering community needs (rather than GHG emissions data), building leading indicators to track progress toward a future "carbon neutral world," and influence larger systems change. They argue for a move to regional inventories that more completely capture the emissions dynamics and range of solutions, and that the bulk of the work of creating GHG inventories should be centralized via state and federal "climate services and capacity building programs." One of the biggest shifts is toward acknowledging the limited range of

scientifically known necessary actions to design for carbon-neutral communities (such as decarbonizing the grid, designing complete communities that make vehicle travel unnecessary, and cultivating more carbon sinks in forests and urban trees[41,42]), and engaging communities (especially those most vulnerable) in how to move toward that carbon-neutral future in a way that builds opportunity for all[42].

The dialogue around this new social architecture of local climate action is perhaps most lively in California due to its complex GHG regulatory environment that has incentivized the widespread production of local self-reported GHG inventories. Fifty-two local California jurisdictions recently asked the California Air Resources Board (CARB) to enable the State of California to take over the major efforts of creating city and county GHG inventories, so local governments can focus on action[26].

Similarly, in a review of the evolving state of climate action planning on behalf of the Global Covenant of Mayors, authors from the Urban Sustainability Directors Network (a community of practice across 180+ cities/counties in the U.S. and Canada) and City Scale (a collective of former city sustainability practitioners) make a range of recommendations[10], including one specifically designed for local jurisdictions with lower data capacity; They contend that "the field must improve access to climate data and develop an integrated data, planning, and reporting platform that eliminates the need for practitioners to sort among the current multitude of tools and approaches." More broadly, they recommend that local

climate action be integrated throughout city functions (not just the sustainability office), centered on the needs of community members rather than emission-reduction commitments and measurements, and with an eye toward "collective influence" on larger systems at the state, regional, and federal levels.

Additional Considerations for Local GHG Estimates

Engagement and collaboration.

Independently of whether cities are producing GHG inventories, in a meta analysis of the determinants of cities adopting climate policies, Yeganeh and colleagues[43] found that the largest predictor of climate policy adoption is public support, and Haugen et al.[44], found that public concern for climate change was a key driver in local commitments for 100% renewable energy policies in three case studies. With that finding in mind, Haugen and colleagues recommend that cities use multiple methods to engage the community (such as collaborations with community organizations, workshops, and social media campaigns) with an emphasis on including populations most vulnerable to the impacts of climate change. They also suggest that GHG estimates can provide a useful baseline before making a commitment.

In their analysis of data from 376 Florida cities over five years, Yi and colleagues[45] found that cities that were larger and with municipal neighbors that have adopted environmental/climate protection policies were more likely to take

action themselves. They comment that more research is needed on the mechanisms of "policy diffusion" across cities and whether it is due to cross-city learning, competition, or both. Of note, the literature does support the premise that "strong-tie" networks such as ICLEI USA de-risk climate action for local jurisdictions.

More research is also needed on how to best enable a politically palatable path toward emissions reduction for conservative local elected officials. Such research would inform the ultimate design of a GHG Information System, including what it is called, how it is described, who it is targeted to (members of the public versus elected leaders), and the role it plays in collaboration between and across levels of government. In an analysis of the nation's 100 largest cities' participation in 10 prominent climate action networks, Gunkel found that conservative mayors were four times less likely to affiliate with climate action networks[46]. However, those mayors are still in many cases willing to take climate action—although only seven Republican mayors in those largest cities publish an emissions inventory and six of those are effectively required by the State of California.

Importance of data choices and geography of solution

In an analysis of contributions to changes in GHG emissions over time, ICLEI USA analysts observe that with the rising application of performance management to climate action, "it is becoming clear how important data choices are"[30]. Part of this movement toward performance management may also be prioritizing collecting

data for emissions that cities can influence, somewhat inverting the maxim "what gets measured gets done" into "what can *be* done gets measured." Armstrong and colleagues[11] observed that "practitioners experience tension between the obligation to use the levers that they do control and the need to contribute to larger changes that they do not control, though in some cases can influence."[11] They note that regional collaboratives including multiple cities and counties may be better suited to deliver on climate commitments. These types of collaboratives are already starting to form. In their 2019 annual report[16], ICLEI USA describes the "Wilton Manors-Oakland Park Joint Climate Action Plan"—a collaboration of two neighboring cities in Florida, and in their 2020 report[47], note the Metropolitan Washington Council on Government's joint climate action plan across 24 jurisdictions[48].

Mirabella and Allacker[49] warn that if production and consumption emissions are not both included, "'climate neutral' targets can be misleading and impact negatively on decision-making and behavioural change of producers and consumers." Choosing not to measure significant sources of emissions like consumption of goods and services means that policies to reduce those sources of emissions are unlikely to be implemented.

Full scope emissions to inform priorities

"Full scope" inventories that include emissions caused by both production and consumption are by definition more work to produce, especially the consumption

aspects of scope 2 and 3 emissions. Not surprisingly, in their review of city-level carbon inventories that looks at all three scopes, Chen and colleagues[24] make the case that local practitioners building GHG inventories "require support in conducting carbon accounting, so as to explore the potential in mitigation and adaptation from a number of perspectives."

Despite the additional burden of producing full scope inventories, having a complete picture of baseline emissions can help jurisdictions customize their priorities to their emissions profile. Different local jurisdictions have different dominant sources of emissions across and within the three scopes. In an analysis of 100 city GHG Inventories, ICLEI found that within scope 1/2, for 56% of the cities, transportation was the dominant emissions source with commercial activities in second place, but for 29% of cities, residential emissions were secondary to transportation[21]. Beyond scope 1/2 emissions, Chen et al.[24] found that more than half of emissions in two Chinese megacities could be attributed to scope 3 activities (emissions embedded in goods and services produced elsewhere), whereas emissions for two other Chinese megacities tended to be more in scope 1.

Value of "double-counting" emissions

Arioli et al.[14] describe a movement over the last decade or more toward including consumption emissions in city GHG inventories, and Ibrahim et al.[50] outline the need to avoid double-counting. That is, if an emission is counted by the jurisdiction where a product is manufactured, and also by a different jurisdiction where it is

consumed, then that emission would be double-counted when the jurisdictions' emissions are added together. Not surprisingly, Chen and colleagues[24] observe in their study of 3-scope GHG inventories across four Chinese megacities that the likelihood of double-counting some emissions increases as more cities are added together.

Including more scope 2 and scope 3 emissions in an inventory complicates the ability to roll up GHG inventories to larger geographic levels because the same emissions would be counted as scope 1 in the geography where they occured (e.g., a landfill in City A), and as scope 2 or 3 in the geographic area where the activity that spurred the emission occurred (e.g, household garbage created in City B). Therefore, in order to combine the inventories for City A and City B into a regional picture of emissions, the duplicate emissions need to be reconciled.

However, the double counting that occurs by including scope 2 and 3 emissions can itself increase the ability of local stakeholders to reduce the emissions for which they are responsible. In other words, each double-counted emissions source has "specific and complementary implications associated with carbon emission mitigation"[24]. When consumption emissions are counted in both scope 1 or scope 2/3 inventories across different jurisdictions, stakeholders in each community can approach mitigation from the production side (for scope 1) or consumption side (for scopes 2 and 3) as appropriate. Not surprisingly, when Chen et al. modeled mitigation strategies across four Chinese megacities, a hybrid model of increased

efficiency *and* reduced consumption emerged as the clear winner in reducing emissions[51]. Rather than being problematic, "double-counting" can be viewed instead as a means for approaching emissions reduction from both the supply and demand side.

Current Role of Federal Data in Informing Climate Action

The EPA produces one national GHG Inventory, and provides spreadsheet-based tools for state and local governments to produce their own inventories. Different agencies like EIA and the Census Bureau provide additional data that are often used in third party inventories.

National GHG Inventory. The EPA produces the National GHG Inventory every year in compliance with IPCC reporting requirements. Although it relies in part on point source data such as EPA's Greenhouse Gas Reporting for emitters of more than 25,000 metric tons of CO2e annually, it is not currently produced with disaggregation to the city-level[52]. Even if the national data were disaggregated, the "current IPCC framework of national accounts [designed to be added together without duplication] does not match with standard approaches to city-level carbon accounting[24]." Specifically, the spatial density of cities by definition requires that they outsource many more of their emissions (scope 2 and 3) than the nation as a whole does.

***EPA State Inventory and Projection Tool*[53].** This top-down interactive spreadsheet inventory comes pre-loaded with state-level estimates from the National GHG

Inventory. States can use it as a starting place for a rough GHG emissions estimate that improves with the addition of state or local data.

***EPA Local (and Tribal) Greenhouse Gas Inventory Tool*[54].** EPA's peer-reviewed Local Greenhouse Gas Inventory Tool and Tribal Greenhouse Gas Inventory Tool are also pre-populated with existing emissions factors and assumptions, into which local governments input data on population and other local data as available (US EPA 2021). The intent of these tools is for jurisdictions without the resources or staff capacity to do a more robust inventory through a member organization like ICLEI-USA can still have access to a tool that builds a basic GHG inventory.

Individual Federal data sets. The production and curation of Federal data to inform estimates of subnational GHG emissions has lagged behind data to inform local adaptation. For example, Federal data—such as NOAA's data on sea level rise and FEMA's Flood Maps—have informed local climate adaptation planning in the form of building codes and evacuation zones for years. However, building a local GHG inventory to inform emissions mitigation currently gains little assistance from Federal data sources. Some notable exceptions include:

- ***EPA eGrid data.*** The EPA's eGrid (Emissions & Generation Resource Integrated Database) data is an average multiplier for emissions per kWh, aggregating emissions data from the EPA and electricity generation data from the Energy Information Administration on power plants by region. However, there is a geographic mismatch between the 24 sub-regions and the boundaries of the

local jurisdiction being inventoried, and also a two year lag in updating the emissions factors. As a result, data are outdated and too broad, so that local progress in choosing cleaner energy sources may not be accounted for[29,55].

- ***Census Bureau data.*** The U.S. Census Bureau's data on households and population sizes are the gold standard for demographic aspects of GHG inventory accounting (ICLEI-USA 2020). Such data are critical for establishing *per capita* emissions, as well as characterizing the populations that are contributing the most to carbon emissions in order to design effective interventions.
- ***EPA Greenhouse Gas Reporting Program (GHGRP)*[56].** The GHGRP contains point source data for polluters above the threshold of 25,000 mtCO2e per year, so it covers only about half of U.S. facility emissions and also has a reporting lag of one to two years.
- **The Multi-Resolution Land Characteristics (MRLC) Consortium's National Land Cover Database (NLCD)**[57]. The MRLC is a collaboration of Federal agencies that produces the NLCD, which is a thematic analysis of LandSat images and other data sets that categorizes land into categories such as "deciduous forest" or "high-intensity developed." The NLDC is published annually, with data going back 18 years, and has a reporting lag of two years. Land use data is important for quantifying the sequestration value of nature. For instance, if a community restores an ecosystem within their borders, that land cover will absorb GHG

emissions, affecting the net emissions for that geographic area. And conversely, if a forest is cut down to build a parking lot, then the forest can no longer be included in the local GHG inventory to offset emissions.

ANALYSIS & DISCUSSION

Compounding crises of the Covid-19 pandemic, flailing economy, racial inequities, and climate-fueled disasters have created a sense of urgency in communities around the nation to find a more sustainable path forward. In the field of local measurements of GHG emissions to inform climate action, a cursory look at the current dialogue might lead one to believe that there is intractable disagreement on the role of local estimates of GHG emissions in charting that path. There are those who want to incrementally improve the methods of self-reported city-wide GHG inventories; those who want to use atmospheric science and sensors to create more timely estimates down to the city block (with more science infrastructure); and those who want to center community needs rather than emissions (with different social infrastructure). However, all of these approaches have one thing in common: minimizing the level of effort for local governments to measure their emissions so they can devote more resources to taking action. The purpose of this paper is to lay out policy recommendations for the development of a Federal GHG Information Service to support just that.

A Federal solution to helping local communities understand their emissions is important in jurisdictions with low local data capacity or political will, those

jurisdictions who have mastered the GHG inventorying process, and those in between. In the last two years in particular, local governments have been stretched thin by factors such as civil unrest, disaster response, and revenue losses due to Covid. Those shocks are on top of the fact that many local jurisdictions in the U.S. lack the capacity under normal circumstances to produce GHG inventories with fidelity as part of a climate action process. In addition to these capacity challenges are political sticking points, where conservative local leaders are less likely to explicitly pursue climate mitigation agendas, including assessment of their communities' emissions. With cities distracted by other priorities, or walking the line of political agendas, it makes sense to focus on emissions reduction more as a co-benefit to solving pressing community priorities such as equitable access to opportunity or climate resilient agriculture, rather than the primary goal. Regardless of ideology, this concept of "centering community needs" is a strong foundation for building a carbon-neutral future.

A Federal GHG Information Service could ultimately produce a nationwide, three-scope map of GHG emissions down to the census tract level. A solution to GHG estimates that covers the entire nation would benefit jurisdictions with the will but not the resources to create a self-reported inventory, and it would ensure homogeneity, durability, and inter-jurisdictional transparency. It would enable cities with robust mitigation assessment and policy capacity to direct their efforts toward implementation instead of assessment. For cities without existing

mitigation structures and initiatives, a transparent, automatic, external accounting of emissions could shift public opinion and spur action. All of these outcomes mean more resources for community engagement and identifying policies that both address community priorities and are on the path to decarbonization.

CONCLUSIONS AND POLICY RECOMMENDATIONS

Climate journalist Umair Irfan captures the reality succinctly when he writes "the atmosphere doesn't care where the emissions are coming from or where they go, just the overall quantity that makes it into the sky[58]." Bringing an integrated GHG emissions framework to scale will allow local governments to focus on identifying new leading indicators of progress toward carbon neutrality — indicators that are more meaningful and visible to citizen-stakeholders. Additionally, a national, multi-scale, low-latency system for estimating GHG emissions would allow local leaders to engage in solutions at multiple levels, such as reducing building emissions at the local level, decarbonizing the energy mix at the metropolitan level, and advocating for market-based cooperatives at the state and multi-state level.

The following seven policy recommendations would yield an information system that sub-national governments could rely on to provide the basic information on GHG emissions to inform planning and emission-reducing actions.

1. **Expand the plan for Climate Services** to emphasize data and information services in support of mitigation as an equal partner to those in support of

adaptation. A Federal GHG Information Service would fall under the umbrella of Climate Services as detailed in the October 2021 report from OSTP, NOAA, and FEMA on *Opportunities for Expanding and Improving Climate Information and Services for the Public*[8]. Though the report frames Climate Services primarily for adaptation, including mitigation in Climate Services would be advantageous; local adaptation efforts (driven by urgent, relevant climate issues such as the effect of drought on farming) can be a gateway to planning for emissions reduction and adaptation and mitigation actions have high potential to be mutually reinforcing[59].

2. **Identify high-value data to continuously improve a GHG Information System** (such as more granular consumption reporting from power companies, private sector data sources on consumption of goods and services, supply chain carbon emissions data, and downscaling of remote sensing data), and pursue those data through legislation, regulation, research investment, procurement, and voluntary commitments.
3. **Further develop research on the GHG Information Services** to refine scope 1 emissions and include scope 2 and scope 3 emissions as well as ecosystem carbon emission sources and sinks. To improve relevance for planning and action, research and development should also refine integrated modeling methods to produce comprehensive estimates of GHG emissions for smaller

areas with low latency. This could be led by USGCRP and implemented by member agencies and academic researchers.

4. **Increase the density of carbon sensors nationwide** to enable the scaling of collection programs such as NOAA's Carbon Tracker[60] that could feed into a GHG information system. This might include direct funding for deployment of carbon sensors at meso- and micro-net stations, deployment of mobile carbon sensing stations[61], or actions to reduce the cost of sensors so communities can deploy them themselves. On that final point, a grand challenge[62], led by NIST or another entity with prize authority, for low-cost in situ carbon sensors could advance the field.
5. **Enlist the U.S. Digital Services[63] or other design expertise to bring a human-centered approach** to Climate Services so they meet the decision-making needs of domestic State, Tribal, and local governments. The Federal government has a Digital Services Playbook[64] that applies to the concept of a Climate Data Service, although not all of the Service will be digital. To date, climate data produced by the Federal government has been largely driven by research priorities and compliance with the United Nations Framework Convention on Climate Change (UNFCCC) reporting requirements[65], not the needs of State or local climate planners. Taking a human-centered approach can build a bridge between existing research and data streams and applications at the local level to plan for and act on reducing carbon

emissions. Specifically, a human-centered approach would not only inform the development of tools and technical assistance, but also would influence the Federal research agenda itself (recommendations 2-4 above).

6. **Identify an inter-agency home for mitigation-oriented Climate Services** (including the GHG Information Service). Using a mix of traditional and flexible hiring mechanisms, build the capacity of the identified organization to deliver Climate Services as spelled out in the Global Change Research Act (GCRA) of 1990 that are "readily usable by policymakers attempting to formulate effective strategies for preventing, mitigating, and adapting to the effects of global change[66]." The EPA, given their current role in compiling the National GHG Inventory and building tools to enable State, local, and Tribal governments to conduct their own inventories, would be a central player in this effort. And, any such inter-agency home should also be charged with engaging boundary organizations already convening local jurisdictions around climate adaptation and mitigation to maintain a strong demand signal for Climate Services writ large, and the GHG Information Service specifically.

REFERENCES

1. Leahy, S. Cities Emit 60% More Carbon Than Thought in Embodied Consumption, C40 Report Says. *National Geographic* https://www.nationalgeographic.com/science/article/city-consumption-greenhouse-gases-carbon-c40-spd (2018).
2. Hoornweg, D., Sugar, L. & Gomez, C. L. T. Cities and Greenhouse Gas Emissions: Moving Forward. *Urbanisation* **5**, 43–62 (2020).
3. Climate Mayors. 446 US Climate Mayors commit to adopt, honor and uphold Paris Climate Agreement goals. (2017).
4. United States Climate Alliance. *2019 Fact Sheet*. https://static1.squarespace.com/static/5a4cfbfe18b27d4da21c9361/t/5f1f0b2cf13e090f828e58dc/1595869997700/USCA+Factsheet_Dec+2019.pdf (2019).
5. Stilson, D., Kiely, P. & Zakaria, R. *Turning Climate Commitments into Results: Progress on State-led Climate Action*. https://www.edf.org/sites/default/files/documents/FINAL_State%20Emission%20Gap%20Analysis.pdf (2020).
6. Heath, R. & Boudreau, C. Biden to surf new wave of global climate action. *POLITICO* (2020).
7. Executive Office of the President. Tackling the Climate Crisis at Home and Abroad. (2021).
8. Office of Science and Technology Policy, National Oceanic and Atmospheric

Administration, Federal, & Emergency Management Agency. *Opportunities for Expanding and Improving Climate Information and Services for the Public.* https://downloads.globalchange.gov/reports/eo-14008-211-d-report.pdf (2021).

9. Krause, R. M. & Martel, J. C. Greenhouse Gas Management: A Case Study of a Typical American City. *Palgrave Handb. Sustain.* 119–138 (2018) doi:10.1007/978-3-319-71389-2_7.
10. Urban Sustainability Directors Network & City Scale. *Local Climate Action Field Evolution in the U.S.* (2021).
11. Armstrong, M. *et al. The State of Local Climate Planning*. https://cityscale.org/wp-content/uploads/2021/05/State-of-Local-Climate-Planning.pdf (2021).
12. Morrison, T. H. *et al.* Mitigation and adaptation in polycentric systems: sources of power in the pursuit of collective goals. *WIREs Clim. Change* **8**, e479 (2017).
13. Gurney, K. & Shepson, P. Opinion: The power and promise of improved climate data infrastructure. *Proc. Natl. Acad. Sci.* **118**, (2021).
14. Arioli, M. S., D'Agosto, M. de A., Amaral, F. G. & Cybis, H. B. B. The evolution of city-scale GHG emissions inventory methods: A systematic review. *Environ. Impact Assess. Rev.* **80**, (2020).
15. Ghaemi, Z. & Smith, A. D. A review on the quantification of life cycle greenhouse gas emissions at urban scale. *J. Clean. Prod.* **252**, 119634 (2020).

16. ICLEI USA. Leading with Local Action: Annual Report 2019. 29 (2020).
17. Global Covenant of Mayors. *Understanding data and tools to accelerate city climate action*. https://www.globalcovenantofmayors.org/wp-content/uploads/2021/07/21-0715-White-Paper-GCoM-Decision-making-and-Tools-Project.pdf (2021).
18. Global Covenant of Mayors. *Global Covenant of Mayors Common Reporting Framework*. https://www.globalcovenantofmayors.org/wp-content/uploads/2019/04/FINAL_Data-TWG_Reporting-Framework_website_FINAL-13-Sept-2018_for-translation.pdf (2018).
19. Freeh, R. Telephone interview. (2021).
20. Chen, J., Zhao, F., Zeng, N. & Oda, T. Comparing a global high-resolution downscaled fossil fuel CO2 emission dataset to local inventory-based estimates over 14 global cities. *Carbon Balance Manag.* **15**, (2020).
21. ICLEI USA. Local Government High-Impact Pathways to Zero Emissions. (2021).
22. C40 Cities Climate Leadership Group. Exploring the benefits of consistent and comparable city-wide greenhouse gas emission inventories. https://www.c40knowledgehub.org/s/article/Exploring-the-benefits-of-consistent-and-comparable-city-wide-greenhouse-gas-emission-inventories (2018).
23. Wiedmann, T. *et al.* Three-scope carbon emission inventories of global cities. *J. Ind. Ecol.* **25**, 735–750 (2021).

24. Chen, G. *et al.* Review on City-Level Carbon Accounting. *Environ. Sci. Technol.* **53**, 5545–5558 (2019).

25. Denny, A. & Pederson, L. Local Greenhouse Gas Inventory Tools for Government Operations and Communities. *Environmental Protection Agency* https://gaftp.epa.gov/Air/nei/ei_conference/EI21/session9/denny.pdf (2015).

26. Multiple signatories. Letter to California Air Resources Board: Request for GHG Inventories for California Local Governments. (2021).

27. Coherent Market Insights. Global Climate Change Consulting Market is estimated to account for US$ 8,653.7 Mn by end of 2028. *GlobeNewswire News Room* https://www.globenewswire.com/en/news-release/2021/04/12/2208423/0/en/Global-Climate-Change-Consulting-Market-is-estimated-to-account-for-US-8-653-7-Mn-by-end-of-2028-Says-Coherent-Market-Insights-CMI.html (2021).

28. Freeh, R., DeLorenzo, M. & Seville, A. All Reporting and No Action Makes Climate Planning a Dull Deploy. (2019).

29. Fyfe, A. Telephone interview. (2021).

30. ICLEI-USA. *What's Driving Changes in Local GHG Emissions? Results from Contribution Analysis*. https://icleiusa.org/wp-content/uploads/2018/09/ICLEI_GCAS-Contribution-Analysis-Report.pdf (2018).

31. Reams, M. A., Clinton, K. W. & Lam, N. S. N. Achievement of Climate Planning Objectives among U.S. Member Cities of the International Council for Local Environmental Initiatives (ICLEI). *Low Carbon Econ.* **3**, 137–143 (2012).
32. ICLEI USA. Land Emissions and Removals Navigator -. *LEARN Tool (Land Emissions And Removals Navigator)* https://icleiusa.org/tools/learn/ (2021).
33. Multi-Resolution Land Characteristics (MRLC) Consortium. Data. https://www.mrlc.gov/data?f%5B0%5D=category%3ALand%20Cover (2021).
34. Google. Google Environmental Insights Explorer - Make Informed Decisions. https://insights.sustainability.google/ (2021).
35. Gurney, K. R. *et al.* Under-reporting of greenhouse gas emissions in U.S. cities. *Nat. Commun.* **12**, 553 (2021).
36. Basu, S. *et al.* Estimating US fossil fuel CO2 emissions from measurements of 14C in atmospheric CO2. *Proc. Natl. Acad. Sci.* **117**, 13300–13307 (2020).
37. Mueller, K. L. *et al.* An emerging GHG estimation approach can help cities achieve their climate and sustainability goals. *Environ. Res. Lett.* **16**, 084003 (2021).
38. Gurney, K. Telephone interview. (2021).
39. Bennett, K. & Phillips, A. Press Release: NAU scientist maps CO2 emissions for entire Los Angeles Megacity to help improve environmental policymaking. (2019).
40. Martin, C. *et al.* Evaluation and enhancement of a low-cost NDIR CO2 sensor.

Atmospheric Meas. Tech. Discuss. 1–25 (2017) doi:10.5194/amt-2016-396.

41. Brown, M. A. *et al.* A framework for localizing global climate solutions and their carbon reduction potential. *Proc. Natl. Acad. Sci.* **118**, (2021).
42. McCormick, M. Email exchange. (2021).
43. Yeganeh, A. J., McCoy, A. P. & Schenk, T. Determinants of climate change policy adoption: A meta-analysis. *Urban Clim.* **31**, 100547 (2020).
44. Haugen, M., Swaroop, K., Troost, S., VanDyke, S. & Vivian, S. *Investigating City Commitments to 100% Renewable Energy: Local Transitions and Energy Democracy*. http://deepblue.lib.umich.edu/handle/2027.42/155017 (2020).
45. Yi, H., Feiock, R. C. & Berry, F. S. Overcoming collective action barriers to energy sustainability: A longitudinal study of climate protection accord adoption by local governments. *Renew. Sustain. Energy Rev.* **79**, 339–346 (2017).
46. Gunkel, N. Many Republican Mayors Are Advancing Climate-Friendly Policies Without Saying so. *DeSmog* https://www.desmog.com/2018/06/05/republican-mayors-advancing-climate-friendly-policies-quietly/ (2018).
47. ICLEI USA. Pressing Forward: 2020 Annual Report. https://icleiusa.org/resources/pressing-forward-2020-annual-report/ (2021).
48. Metropolitan Washington Council of Governments. *Metropolitan Washington 2030 Climate and Energy Action Plan.*

https://www.mwcog.org/documents/2020/11/18/metropolitan-washington-2030-climate-and-energy-action-plan/ (2020).

49. Mirabella, N. & Allacker, K. Urban GHG accounting: discrepancies, constraints and opportunities. *Build. Cities* **2**, 21–35 (2021).

50. Ibrahim, N., Sugar, L., Hoornweg, D. & Kennedy, C. Greenhouse gas emissions from cities: comparison of international inventory frameworks. *Local Environ.* **17**, 223–241 (2012).

51. Chen, S., Long, H., Chen, B., Feng, K. & Hubacek, K. Urban carbon footprints across scale: Important considerations for choosing system boundaries. *Appl. Energy* **259**, 114201 (2020).

52. US EPA. *Inventory of U.S. Greenhouse Gas Emissions and Sinks*. https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-main-text.pdf?VersionId=wEy8wQuGrWS8Ef_hSLXHy1kYwKs4.ZaU (2021).

53. US EPA. State Inventory and Projection Tool. https://www.epa.gov/statelocalenergy/state-inventory-and-projection-tool (2017).

54. US EPA. Local Greenhouse Gas Inventory Tool. https://www.epa.gov/statelocalenergy/local-greenhouse-gas-inventory-tool (2021).

55. US EPA. eGRID Questions and Answers. https://www.epa.gov/egrid/egrid-

questions-and-answers (2015).

56. US EPA. Greenhouse Gas Reporting Program (GHGRP). https://www.epa.gov/ghgreporting (2021).

57. Multi-Resolution Land Characteristics (MRLC) Consortium. NLCD 2019 Products Now Available. https://www.mrlc.gov/card/nlcd-2019-products-now-available (2021).

58. Irfan, U. Are 'net-zero' climate targets just hot air? *Vox* https://www.vox.com/22737140/un-cop26-climate-change-net-zero-emissions-carbon-offsets (2021).

59. Klein, R. J. T. *et al.* Inter-relationships between adaptation and mitigation. in *Climate Change* 2007: *Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* 745–777 (Cambridge University Press, 2007).

60. US Department of Commerce, N. Global Monitoring Laboratory - Carbon Cycle Greenhouse Gases. https://gml.noaa.gov/ccgg/carbontracker/goals.php#ct_who.

61. Cornwall, W. On eve of climate summit, researchers sharpen emissions tracking. *Science Insider* https://www.science.org/content/article/eve-climate-summit-researchers-sharpen-emissions-tracking (2021).

62. US General Services Administration. Challenge.Gov. *Challenge.Gov* https://www.challenge.gov/ (2021).

63. US Digital Service. How we work. *United States Digital Service* https://usds.gov/how-we-work (2021).
64. US Digital Service. The Digital Services Playbook. https://playbook.cio.gov/.
65. UNFCC. Reporting requirements. *Unfccc.int* https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/reporting-requirements.
66. US Global Change Research Program. Legal Mandate. *GlobalChange.gov* https://www.globalchange.gov/about/legal-mandate (1990).