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The implications of scope and boundary choice on the establishment and success of metropolitan greenhouse gas reduction targets in the United States

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Abstract

In recent years, cities across the United States have devoted considerable attention and resources to developing greenhouse gas (GHG) inventories and climate action plans (CAPs). Using integrated metropolitan-level GHG estimates from publicly available national datasets, we explore the implications of inventory scope and boundary choices for 41 metropolitan areas across the United States. We quantify emissions from 'under-reported' activities (i.e. emissions from industrial processes and from transportation between urban and suburban areas) and 'under-reported' geographies (i.e. emissions from all activities occurring within the metropolitan area, but outside the city limits), and find that, in most cases, these 'under-reported' emissions constitute a considerable portion of total metropolitan emissions. Given the important role local CAPs continue to play in national-level GHG reduction efforts, there appears to be much to gain from continuing to expand the scope and boundaries of local-level GHG accounting and reduction actions. This analysis helps illustrate why transitions toward policies at the regional (as opposed to the city level) may be warranted, as well as highlights some key issues that may arise as local-level GHG policies continue to evolve and expand. For example, if local decision-makers choose to expand the scope and/or scale of their policies, GHG reduction plans may warrant substantial alterations to baseline emission levels, targeted annual emission reduction rates, overall emission target levels, or the number of years needed to achieve a desired emission reduction. Ultimately, the manner in which these policies evolve will determine their overall contribution to national and international climate mitigation efforts.

1. Introduction

Over the past few decades, cities across the United States have been taking proactive steps to address climate change by developing climate action plans (CAPs). The basic framework for these CAPs is to conduct a greenhouse gas (GHG) emission inventory, establish GHG emission reduction targets, develop strategies for achieving the reduction target, seek to implement those strategies, monitor results and progress, and make modifications as necessary (ICLEI — Local Governments for Sustainability USA 2015a). However, as discussed below, scope and boundary choices related to what is often included or excluded from the emission accounting process can have a meaningful effect on the overall comprehensiveness of GHG inventories and the subsequent emission reduction strategies that are developed. This paper explores these issues more closely and determines the consequence of confining analysis to the city limits and to certain emission producing activities. More specifically, we use metropolitan-level GHG estimates gathered from publically available data sources to determine how the inclusion of under-reported
emissions (i.e. emissions from outside the central city limits, emissions from activities like industrial processes and urban-suburban transportation, etc) affects the ability of different locations to meet their GHG reduction targets.

The remainder of this paper is organized as follows. Section 2 provides additional background on the state of knowledge and practice related to estimating urban GHG emissions and developing GHG reduction targets. Sections 3 and 4 discuss the data and methods used in our analysis. Section 5 quantifies and analyzes the significance of under-reported emissions from industrial processes, on-road transportation, and confining analysis to the city-limits of a given area. Finally, section 6 discusses the applicability of our analysis to non-US locations and elaborates on some policy implications and conclusions.

2. Background on GHG inventories and reduction targets

In an analysis of first generation CAPs for 34 US municipalities, Wheeler (2008) found the most common (i.e. mode and median) reduction target to be 12% below 1990 emission levels by the year 2012. Of the cities in Wheeler’s assessment, Chicago had the least aggressive target of 6% below year 2000 emission levels by 2010, while Chapel Hill, North Carolina had the most aggressive target of 60% below year 2005 emission levels by 2050. More recently, Blackhurst et al (2011) examined the GHG reduction targets of 18 US cities and found reduction goals ranging from 7% to 99%. Eugene, Oregon had the most aggressive target of 99% below 2005 emission levels by the year 2050, while Flagstaff, Arizona and Bloomington, Indiana had the least aggressive targets of 7% below 1990 emission levels by the year 2012 (Blackhurst et al 2011). Currently, over 130 communities have partnered with ICLEI, a non-profit organization focused on climate and environmental sustainability issues at the local level, to develop CAPs and GHG reduction targets—see table A1 in the supplementary material for a full list. Of these communities, 130 have at least one reduction target, 51 have at least two reduction targets, and 27 have at least three reduction targets (ICLEI—Local Governments for Sustainability USA 2015a). Table 1 provides a summary of the typical reduction values, rates, and time frames associated with these targets. For these 130 communities, 2002 typically serves as the baseline year.

Generally speaking, communities have typically compiled their GHG inventories with the help of the Clean Air Climate Protection (CACP) software produced by ICLEI (Open Energy Information OpenEI 2015). By default, the software uses utility information, vehicle miles travelled estimates, and waste disposal estimates provided by city officials as inputs. Inventories that use the software typically include five categories: energy consumption (electricity and natural gas) in residential buildings, energy consumption in commercial buildings, energy consumption in industrial buildings, transportation energy consumption (typically related to light-duty vehicle gasoline consumption), and emissions related to the production/disposal of waste generated within the city.

In recent years, considerable work has been done to continually improve the quality, accuracy, and consistency of community GHG inventories. ICLEI’s 2013 Protocol for counting and reporting community GHG emissions builds upon the CACP framework discussed above (ICLEI—Local Governments for Sustainability USA 2013). The 2013 Protocol states that all emissions inventories should, at a minimum, include estimates on five ‘Basic Emissions Generating Activities’: (1) use of electricity by the community, (2) use of fuel in residential and commercial buildings, (3) use of fuel for on-road passenger and freight motor vehicle travel, (4) energy use in the treatment and distribution of potable water and waste water, and (5) emissions from the collection and degradation of solid waste generated by the community (ICLEI—Local Governments for Sustainability USA 2013). For on-road transportation emissions, the protocol recommends (and provides guidance for) using an origin-destination demand-based allocation of trips (ICLEI—Local Governments for Sustainability USA 2013). This approach does a better job of capturing the full scale of transportation emissions related to a city, as opposed to the ‘in-boundary’ (i.e. only within the city limits) emissions that were used in previous frameworks.

Building on this protocol, ICLEI also launched the ClearPath online emissions management system in 2014 (ICLEI—Local Governments for Sustainability USA, 2015b). ClearPath essentially replaces the CACP software previously used and makes it easier for practitioners to measure and report emissions, as well as develop projections of future emissions under different scenarios. As of May 2018, nearly 200 local entities and governments have partnered with ICLEI and have

Table 1. Summary of GHG reduction targets for communities across the United States. Adapted from (ICLEI—Local Governments for Sustainability USA 2015a).

| Number of cities | Typical target year | Typical overall reduction target | Average annual reduction rate |
|------------------|---------------------|---------------------------------|-------------------------------|
| 1st reduction target | ~2020 | ~20% | 1.1% |
| 2nd reduction target | ~2025 | ~30% | 1.3% |
| 3rd reduction target | ~2050 | ~80% | 1.6% |
access to the ClearPath software (ICLEI-Local Governments for Sustainability USA, 2018). However, the inventories and forecasts produced by these communities are often not readily available to the public. Thus, the most recent set of inventories that are widely available are still commonly based on the CACP approach. Internationally, the PAS 2070 protocol produced by the British Standards Institute (BSI) provides guidance on developing city-level emissions estimates that include trans-boundary on-road and non-road transportation and industrial activity (British Standards Institution BSI 2013).

The protocols discussed above form a strong foundation for developing reliable community-level GHG inventories. Additionally, these protocols are bolstered by a large body of knowledge related to GHG emission accounting in the US (Brown et al 2009, Glaeser and Kahn, 2010, Hillman and Ramaswami, 2010, Blackhurst et al 2011, Brown and Cox, 2015), Europe (Heidrich et al 2013, 2016, Reckien et al 2014, 2015, 2018), and globally (Kennedy et al 2010). Nonetheless, there still appear to be some issues worthy of consideration. For example, nearly all of the inventories examined were confined to the city limits. However, for activities like on-road commuting between urban and suburban areas, emissions associated with the city but outside the city-limits often go under-reported. Similarly, the under-reporting of emissions from non-electricity fuel consumption and industrial processes also appear to be a common occurrence (Ramaswami and Chavez, 2013).

Additional approaches for estimating emissions have been developed to address some of the scope and boundary challenges mentioned above, as well as remove some of the potential for bias and inconsistency that can emerge from the using different accounting practices in different locations. For example, Baiocchi et al (2015) used regression analysis to form consistent, high resolution household GHG estimates for the entire United Kingdom that are independent of municipal/regional boundaries. Gurney et al (2009) established methods for consistently estimating hourly carbon emissions for 10 km × 10 km grids across the entire United States. These efforts were later refined to allow for the estimation of hourly CO2 emissions at the scale of individual buildings and road segments within an urban area (Zhou and Gurney, 2010, Gurney et al 2012, Patarasuk et al 2016). Blackhurst et al (2011) reviewed the GHG inventories for 18 US communities and explored alternative and supplemental inventory techniques that decision-makers could apply to the climate action planning process. Ramaswami et al (2008) and Hillman et al (2011) developed a methodology for measuring city-scale emissions on a life-cycle basis. This approach allows for a more comprehensive assessment of a city’s emissions by accounting for ‘trans-boundary’ surface transportation (trips that originate or end in a given city but do not necessarily remain with the city-limits for the entire duration of the trip), airline emissions, and embodied emissions for goods consumed within the city (e.g. fuel, food, and water). Overall, it was determined that ‘trans-boundary’ activities like transportation and Scope 3 emissions (i.e. indirect emissions associated with an activity or the use/purchase of a good or service—see section A2 of the supplementary material) contributed nearly 50% more, on average, to a city’s emissions compared to the in-boundary emissions typically reported (Hillman and Ramaswami, 2010).

A majority of the approaches described above rely on bottom-up data collection, which can frequently be resource and time intensive. For example, the approaches proposed in ICLEI’s 2013 protocol and implemented by Hillman et al (2011) for estimating ‘trans-boundary’ transportation emissions rely on relatively detailed travel demand data and modeling software. However, although there are ongoing efforts to increase the consistency between bottom-up and top-down approaches (Newman et al 2016), local practitioners may not always have the access or the ability to use these types of datasets, software, or techniques.

Finally, although there has been an increased call for analysis and planning at the regional or mega-regional level (National Research Council, NRC 2010, 2011, 2013, 2014, 2016, Bongardt et al 2013, Heidrich et al 2013, 2016), implementation to this point has been relatively sparse. However, examples of regional GHG inventories and policies have emerged from the San Francisco Bay Area Air Quality Management District (BAAQMD) and the Sacramento Area Council of Governments (SACOG), and may serve as an indication of a more wide-spread shift toward a regional focus moving forward (BAAQMD 2015, SACOG 2015). The implications of geographic boundary choices on metropolitan-level emissions assessment and planning are highlighted by the fact that central (urban) counties appear to have lower per capita transportation emissions and higher per capita commercial sector emissions compared to nonmetropolitan (rural) counties (Tamaya et al 2014). The expansion to regional emission planning and management is further supported by the fact that a majority of communities within metropolitan areas do not have an established GHG reduction target. For example, of the 122 incorporated cities within the Los Angeles Metropolitan Statistical Area (MSA), only 4 (Hawthorne, Los Angeles, Manhattan Beach, and Santa Monica) have established GHG reduction targets (ICLEI—Local Governments for Sustainability USA 2015a). From a population stand point, this corresponds to only 31% of the people in the Los Angeles MSA living in a municipality with any type of GHG reduction target (US Census Bureau, 2017a, 2018a). This proportion is even lower nationally—on average, the cities that have established GHG reduction targets account for only 13% of the total population of their respective metropolitan areas (US Census
Bureau, 2017b, 2017c, ICLEI—Local Governments for Sustainability USA 2015a). Therefore, to the extent that having the maximum number cities and/or people included in a GHG reduction policy is a desirable goal, there appears to be a large opportunity for communities within metropolitan areas to coordinate and develop comprehensive measurements and policies at the metropolitan and regional level.

3. Data

The data sources and emissions estimates in this analysis are based on the same data and methods used in Markolf et al (2017). Production-based GHG estimates were formed from a combination of data from the Environmental Protection Agency’s (EPA) mandatory GHG reporting program, the EPA’s National Emissions Inventory, and the US Energy Information Administration (EIA) (US Energy Information Administration EIA 2017, US Environmental Protection Agency EPA 2014a, 2014b, 2017, 2018a). Overall, we end up with production-based GHG estimates for year 2014 for the 100 largest metropolitan areas in the United States. The estimates include emissions from industrial activity, electricity production, waste generation and disposal, on-road transportation, natural gas consumption in residential buildings, and natural gas consumption in commercial buildings. For the duration of this paper, these data will be referred to as the ‘integrated data.’

Information about the magnitude and timing of various community-level GHG reduction targets was available from ICLEI’s 2015 progress report (ICLEI—Local Governments for Sustainability USA 2015a). Information and data regarding GHG inventories of individual cities was available from the Carbonn Climate Registry (2014), the Carbon Disclosure Project CDP (2015), and the cities themselves. It is important to note that the actual emission data from these local sources are not the primary focus of this analysis. We mainly used these sources to gain a better understanding of the sector scopes and geographic boundaries commonly used in GHG inventories reported by cities. In order to ensure consistent comparisons and allow for the analysis of numerous locations, the integrated data serves as the primary source of quantitative data for this paper. More detailed comparisons between the integrated data and the estimates reported by cities can be found in Markolf et al (2017).

Finally, population data from the US Census Bureau were used to compare the populations of various locations and develop per capita emissions estimates. These population values are for the year 2014 and were available at the city, county, and metropolitan scale (US Census Bureau, 2017b, 2017c, 2017d).

4. Methods

Approximately 130 communities have partnered with ICLEI to form and report their GHG reduction targets. However, we are primarily interested in metropolitan areas, so we limit our analysis to communities that are within one of the 100 largest metropolitan areas as defined by the US Census Bureau. Under this constraint, 87 communities qualified and were contained within 41 Metropolitan Statistical Areas (MSAs)—see section A3 in the supplementary material. The number of communities and MSAs is not a one-to-one ratio because several of the communities that have partnered with ICLEI are within the same MSA. For example, as mentioned above, the communities of Hawthorne, Los Angeles, Manhattan Beach, and Santa Monica have all formed their own GHG reduction targets with ICLEI, but are also all part of the Los Angeles MSA. Thus, all of the results and emission estimates discussed below are developed from the integrated data for the 41 MSAs of interest.

The first part of our analysis focuses on estimating the emissions from specific activities that are frequently under-reported by cities in their GHG inventories: industrial activity and on-road transportation within the metropolitan area, but outside the urban core. We classify total MSA GHG emissions into three categories: (1) ‘Reported’ emissions, (2) ‘Under-reported’ industrial emissions, and (3) ‘Under-reported’ on-road emissions. Although on different geographical scales (i.e. city limits versus MSA level), the ‘reported’ emissions are meant to serve as a proxy for the activities frequently included by cities in their inventories. Thus, for this manuscript, the ‘reported’ emission estimates for the 41 locations of interest are based on the integrated data and include electricity production at the MSA level, waste at the MSA level, residential and commercial natural gas consumption at the MSA level, and on-road transportation within the urban core (i.e. the county containing the primary city of the MSA). The ‘under-reported’ industrial emissions are based on the integrated data and include industrial activity within the urban core. This component was limited to the urban core, because government entities are not generally able to influence industrial facilities outside of their jurisdiction. Finally, the ‘under-reported’ on-road emissions are based on the integrated data and include light and heavy duty vehicle activity within the metropolitan area, but outside of the urban core. These boundaries were chosen to approximate emissions that result from commuting and the transfer of goods between urban and suburban parts of a metropolitan area. In contrast to industrial activity, we believe the entire MSA is an appropriate scale for transportation emissions because planning and policy efforts within the central city or urban core can reasonably be expected to impact transportation activity and emissions throughout a metropolitan area (e.g. increased...
densification, implementation of public transit, etc). Once estimates were formed for each of these three categories, we evaluated how total MSA emissions change when the ‘under-reported’ estimates are added to the ‘reported’ estimates. We then evaluated how the emission reduction plan would need to be altered to accommodate the addition of these added emission sources.

The second part of our analysis focuses on the implications of cities confining their inventories and planning to the city limits. Expanding on the central, outlying, and rural levels of aggregation employed by Tamayao et al (2014), we establish three different geographic categories for evaluating a given metropolitan area: (1) the urban ‘core’ county/counties, (2) the ‘central’ counties surrounding the urban core, and (3) the ‘outlying’ counties of the MSA. For our analysis, we classify the urban ‘core’ as the county (or counties) that house(s) the primary city of an MSA. We maintain the central and outlying classifications specified by the Census Bureau, where a ‘central’ county contains all (or a substantial portion) of the urbanized area and ‘outlying’ counties have one-quarter or more of their employed residents working in central counties (or vice versa) (Mackun, 2009). Using the San Francisco–Oakland–Fremont, CA MSA as an example, San Francisco County serves as the urban core; Alameda, Marin, and San Mateo counties serve as the central counties outside the urban core, and Contra Costa County serves as the outlying county. Once estimates were formed for each of these three categories, we evaluated how total MSA emissions change when the ‘central’ and ‘outlying’ estimates are added to the ‘urban core’ estimates. We then evaluated how the emission reduction plans might need to be altered to accommodate the emissions from the expanded geographic areas.

5. Results

5.1. ‘Under-reported activities’ based on integrated data

As mentioned above, there are two emission producing activities that we classify as commonly under-reported in inventories produced by cities: (1) on-road transportation that occurs within the MSA but outside the urban-core, and (2) emissions from industrial processes (i.e. non-utility energy consumption) that occur within the urban core. We denote these emissions as ‘under-reported activities,’ and quantify them using the integrated data.

Based on emissions estimates from the integrated data, the under-reported activities accounted for between 0.1% (in the Bridgeport, CT MSA) and 57% (in the Portland, OR MSA) of total production-based emissions within an MSA, and average roughly 25% of the total production-based emissions across the 41 evaluated MSAs. Similar percentages hold on a per capita basis, and emissions from under-reported activities range from roughly 0.1 metric tons CO$_2$e per person (in the Bridgeport, CT and San Diego, CA MSAs) to roughly 9.1 metric tons CO$_2$e per person (in the Madison, WI MSA). On average, the under-reported activities result in a 38% increase in per capita emissions compared to just the reported activities. Given these results, it appears that by not fully accounting for these activities, certain metropolitan areas may be missing key opportunities to reduce their overall GHG emissions.

Figure 1 uses the integrated data to depict the ‘under-reported’ and ‘reported’ production-based emissions for 41 metropolitan areas in the United States. As discussed earlier, the ‘reported’ emissions represent a proxy for the activities/sectors that are most frequently included in the GHG inventories produced by the cities, while the ‘under-reported’ emissions represent the activities/sectors that cities do not commonly include in their inventories. The figure also includes per capita emissions for each MSA.

Figure 1 shows that emissions from ‘under-reported’ activities can vary widely between metropolitan areas and can be rather large in certain cases. For a majority of the MSAs, on-road transportation outside the urban core comprises the largest portion of total under-reported emissions. However, for places like Los Angeles, Cleveland, Pittsburgh, and San Jose, emissions from industrial activity within the urban core are roughly as large as (or larger than) on-road transportation emissions. The large contribution from industrial activity in these locations is somewhat surprising given that industrial activity is typically expected to be located outside of the urban core of an MSA — particularly in the United States.

As a reminder, the integrated data is only granular to the county level, so care should be taken when interpreting results for industrial activity. In cases where the central city is much smaller than the core county it is within (e.g. Pittsburgh within Allegheny County), there is the potential for an over-estimation of the industrial emissions attributable to the central city. Less concern is warranted in instances where the city comprises all (or a majority) of the county for which emissions are reported (e.g. Denver County, Miami-Dade County, etc). Similarly, if county-level industrial emissions are low or negligible, city-level industrial emissions can also be considered to be low or negligible.

Although they have been shown to be significant (Matthews et al. 2008, Hillman and Ramaswami, 2010), Scope 3 emissions are frequently described as outside the bounds of analysis in most GHG inventories. Thus, even if one does not fully agree with the boundary of analysis employed here, the emissions
estimates for otherwise omitted activities can at least serve as an initial lower-bound estimate of the Scope 3 emissions for various cities and help allow for their inclusion in the inventory and CAP process.

5.2 ‘Under-reported geographies’ based on integrated data
In addition to quantifying emissions from under-reported activities, we also quantified metropolitan emissions that are under-reported due to cities confining their analysis and planning to the city limits. In order to gain a better understanding of the implications that geographic boundary choices have on the emissions profile of a given area, we use the integrated data to estimate and compare three different categories of emissions: (1) the ‘urban core’, (2) the ‘central’ counties outside the urban core, and (3) the ‘outlying’ counties within the MSA. For this analysis, the estimates for the ‘urban core’ are assumed to be comparable to those reported by a given city, while the ‘central’ and ‘outlying’ estimates are assumed to be under-reported by cities due to their boundary choices.

Figure 1. Profile of year 2014 total and per capita CO2e emissions for 41 metropolitan areas as estimated with the integrated data. Emission estimates for ‘reported’ activities (i.e. the activities commonly reported by cities in their GHG inventories) are shown in blue and the ‘under-reported’ emissions are shown in red (on-road transportation outside the urban core) and gold (industrial activity within the urban core). The left side of the figure reports total emissions in million metric tons of CO2e and the right side of the figure reports per capita emissions in metric tons CO2e per person.
Based on the estimates from the integrated data, the ‘non-urban core’ MSA emissions (i.e. emissions from central and outlying MSA counties) account for between 0 metric tons CO$_2$e (in the New Haven, CT, Bridgeport, CT, San Diego, CA, and Tucson, AZ MSAs) and 119 million metric tons CO$_2$e (in the Chicago, IL MSA), with an average of roughly 25 million metric tons of CO$_2$e per MSA across the 41 evaluated MSAs. These non-urban core categories account for between 0% (in the New Haven, CT, Bridgeport, CT, San Diego, CA, and Tucson, AZ MSAs) and 97% (in the St. Louis, MO MSA) of total production-based emissions within an MSA, and average roughly 56% of the total production-based emissions across the 41 evaluated MSAs.

Figure 2 uses the integrated data to depict the production-based emissions for the ‘urban core’, ‘central’ counties (surrounding the urban core), and ‘outlying’ counties for 41 metropolitan areas in the United States. The ‘urban core’ emissions represent a proxy for the emissions that are reported by cities in their GHG inventories, while the ‘central’ and ‘outlying’ emissions represent ‘under-reported’ emissions. In contrast to past work (e.g. Tamayao et al. 2014), the results presented here are for specific locations (as opposed to generalized results for the entire US), focus exclusively on MSA emissions (rather than metropolitan and nonmetropolitan emissions), are for total emissions (rather than per capita emissions), and are entirely production-based emission estimates (rather than a hybrid of production-based and consumption-based estimates).

Figure 2 shows that, in most cases, the majority of emissions within a metropolitan area come from outside the urban core. Thus, although it is important for the central cities to develop CAPs and GHG reduction plans, failure to expand and develop analysis and policies at the metropolitan level could lead to sub-optimal results in terms of achieving desired emission reduction targets. The figure also indicates that the central counties appear to have a much larger contribution to total emissions than the outlying counties—on average, 85% of emissions come from central counties (including the urban core). Thus, if steps were taken to expand CAPs beyond city limits, it might be more effective in the short-term to focus on central counties before expanding to outlying counties.

Figure 3 compares the per capita emissions for the urban core, the central counties within the MSA, and the outlying counties within the MSA for all 41 locations analyzed. In this case, the emissions were estimated for each component—‘core’ per capita emissions represent total emissions from the core counties of a given MSA divided by the total population of the core counties of the MSA; ‘central’ per capita emissions represent total emissions from central counties divided by total population from central counties; etc. On a per capita basis, the ‘non-urban core’ emissions range from 0 metric tons CO$_2$e per person (in New Haven, CT, Bridgeport, CT, San Diego, CA, and Tucson, AZ where the MSA consists of only one county, and thus there are no central or outlying counties—i.e. all emissions are attributed to the urban core) to roughly 100 metric tons CO$_2$e person (in the Madison, WI MSA). On average, urban core emissions were roughly 8 metric tons CO$_2$e per person, central county emissions were roughly 12 metric tons CO$_2$e per person, and outlying county emissions were roughly 17 metric tons per person. For reference, US 2016 per capita emissions were roughly 20 metric tons CO$_2$e per person (US Census Bureau, 2018b, US Environmental Protection Agency EPA 2018b). The average per capita emissions we found are comparable to the average Scope 1 per capita emissions that Tamayao et al. (2014) found for central and outlying counties across US MSAs. Thus, from the perspective of production-based emissions, there appears to be a relationship between the centrality of a county within an MSA and its per capita GHG emissions. However, the fact that Tamayao et al. (2014) found that scope 1 and 2 emissions do not statistically significantly differ by geographic type, further highlights the importance of clearly and consistently stating scope and boundary choices when estimating local-level GHG emissions (e.g. Scope 1 versus Scope 1 + Scope 2 + Scope 3; production-based estimates versus consumption—based estimates).

6. Discussion and implications

The analysis above helps illustrate how under-reported emissions can be estimated and incorporated into GHG inventories and CAPs. It also helps highlight possible opportunities and implications that may arise from adding these ‘under-reported’ emissions into the analysis and planning process. Due to data availability and familiarity with local processes, the manuscript primarily focuses on urban areas within the United States. Nonetheless, the methods and insights from this analysis can translate beyond the US. In particular, our discussion of under-reported and trans-boundary transportation GHG emissions appears to be highly relevant to ongoing trends in global transportation demand, urbanization, and urban form. The combination of rising income levels, growing populations, and increased urbanization (especially in Asia, Africa, and South America) is expected to result in a substantial increase in vehicle ownership, vehicle kilometers traveled, and transportation related GHG emissions over the next several decades (Schafer et al. 2009, Bongardt et al. 2013). In fact, under baseline scenarios, the International Energy Agency (IEA) projects that global CO$_2$ emissions from light-duty vehicles will roughly double by year 2050 (IEA 2009). As international climate goals and policies continue to evolve, addressing this potentially rapid rise in transportation GHG emissions will become increasingly
important. Thus, the analysis and framing presented in this manuscript could serve as a possible starting point for cities in Asia, Africa, and South America to begin developing regional mechanisms for estimating and mitigating GHG emissions—and avoid some of the jurisdictional and governance barriers that often inhibit efforts in US and European cities.

Although transportation is perhaps the most intuitive and congruent sector for regional GHG assessment and climate action, the results in section 5.2 (i.e. on average, 56% of metropolitan GHG emissions come from outside the urban core) highlight the large opportunity (and arguably need) for taking steps to implement regional-scale analysis and action across all sectors. In addition to more effectively accounting for traditionally under-reported activities, moving to a regional scale approach for all sectors can also help provide additional resources, guidance, and support that are often lacking in smaller cities and suburban towns (Reckien et al 2015, Heidrich et al 2016).

Although not explicitly dedicated to GHG mitigation, the Greater London Authority (2018), the Southeast
Florida Regional Compact on Climate Change (2017), the Sacramento Area Council of Governments (SACOG) (2015), and the San Francisco Bay Area Air Quality Management District (BAAQMD) (2015) can all serve as templates for successfully developing accounting practices and climate action at a regional scale.

As organizations like ICLEI continue to provide updated protocols and inventory software, and more communities adopt a regional planning approach similar to those of SACOOG and the San Francisco BAAQMD, decision-makers will need to plan for incorporating these changes and possibly revaluate how they develop and implement their GHG reduction targets. To further demonstrate this point, figure 4 provides an illustrative example of potential GHG reduction pathways for Baltimore that could occur with and without the inclusion of the ‘under-reported’ emissions.

The City of Baltimore has pledged to reduce its GHG emissions to 15% below 2010 levels by the year 2020 (ICLEI—Local Governments for Sustainability
USA 2015a). Based on the integrated data, this equates to moving from roughly 17.6 million metric tons CO₂e in 2010 to roughly 14.9 million metric tons in 2020—note 2010 integrated data adapted from Markolf et al (2017). This level of reduction equates to roughly a 1.6% annual reduction rate over the ten year period (this baseline scenario is depicted by the dashed black line in figure 4). If Baltimore decided to more closely align with the ICLEI 2013 protocol and expand their scope to include emissions from industrial processes within the city limits and on-road transportation within the metropolitan area but outside the city limits, baseline emissions would undergo a 1.6 fold increase. Under this new emission regime, the decision makers would then have to decide what emission reduction rate they want to pursue. Considering that the vast majority of cities establish percentage reduction targets, this transition will likely be relatively straightforward and will primarily require a one-time acknowledgment of any disconnect between ‘initial’ baseline emissions and ‘updated’ baseline emissions (e.g. 17.6 million metric tons CO₂e versus 28.5 million metric tons CO₂e in the Baltimore example above). However, if certain cities decide to be more aggressive and pursue a target level of emissions (rather than a percent reduction), expansion of geographic scope and/or inclusion of additional emission-producing activities may warrant changes to GHG reduction plans in terms of annual reduction rates, the overall emission level targeted, or the number of years in which to achieve the desired emission reduction.

Ultimately, the continued expansion of the scope and boundaries of local GHG reduction plans can play a major factor in national-level GHG emissions reduction efforts—especially considering the leadership role cities continue to take in the wake of the US Federal Government’s withdrawal from the Paris Climate Agreement in 2017. For example, the sum of the emissions from

![Figure 4](image_url). Illustrative example of GHG reduction policies for Baltimore under different scope/boundary scenarios for an emissions reduction target. The dashed black line represents the status quo scenario. The solid black line represents a scenario incorporating ‘under-reported’ emissions and maintaining the percent reduction target (15%), baseline year (2010), and end year (2020) established in the status quo scenario. The red dashed line represents the emission reduction trajectory for a scenario incorporating ‘under-reported’ emissions and establishing an emission reduction target equivalent to the end-point emission levels established in the status quo scenario (14.9 MMT CO₂e in year 2020).
under-reported activities in the 41 metropolitan areas analyzed (~407 MMT CO$_2$e) was roughly 6% of total US GHG emissions in 2014 (US Environmental Protection Agency EPA 2016). Similarly, the sum of the ‘non-urban core’ emissions from the 41 metropolitan areas analyzed (~1022 MMT CO$_2$e) was roughly 15% of total US GHG emissions in 2014 (US EPA, 2016). Therefore, there appears to be much to gain from continuing to expand the scope and boundaries of local-level GHG reduction policies, and the manner in which these policies evolve will help determine their overall influence on efforts to mitigate global climate change.

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