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# Preparing US community greenhouse gas inventories for climate action plans

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**Abstract**
This study illustrates how alternative and supplemental community-level greenhouse gas (GHG) inventory techniques could improve climate action planning. Eighteen US community GHG inventories are reviewed for current practice. Inventory techniques could be improved by disaggregating the sectors reported, reporting inventory uncertainty and variability, and aligning inventories with local organizations that could facilitate emissions reductions. The potential advantages and challenges of supplementing inventories with comparative benchmarks are also discussed. While GHG inventorying and climate action planning are nascent fields, these techniques can improve CAP design, help communities set more meaningful emission reduction targets, and facilitate CAP implementation and progress monitoring.

**Keywords:** community greenhouse gas inventories, climate action plans, uncertainty

S Online supplementary data available from stacks.iop.org/ERL/6/034003/mmedia

## 1. Introduction

In alignment with international planning processes, cities and their stakeholders are preparing GHG inventories and climate action plans to support local emission reduction initiatives. ICLEI Local Governments for Sustainability (ICLEI) reports that as of 2009 over 200 member cities have completed GHG inventories, 150 have established a reduction goal, 120 have developed climate action plans, and 30 have completed action plans (ICLEI 2010a). As part of the American Recovery and Reinvestment Act of 2009, the Federal Government appropriated $11 billion for state and local sustainability activities (DOE 2010).

Prior research on GHG inventories has focused on planning methods. Pitt and Randolph (2009) and Bailey (2007) identify GHG inventorying and action planning obstacles, namely difficulty acquiring data, unclear methods, and resource constraints. Wheeler (2008) highlighted major disconnects between GHG reduction targets, safe emissions levels, recommended action items, and implementation.

Several policy organizations have called for clearer and consistent GHG inventory standards tailored for communities (UNEP 2010, Marshall 2011). The United Nations and the World Bank updated their community GHG inventory standards to include some helpful features, such as encouraging uncertainty reporting, reporting heating degree days, and limited sub-sector reporting (UNEP 2010). However, the UNEP standards are limited in that they provide no guidance for how to estimate uncertainty or variability nor does UNEP connect their standards to decision-making during climate action planning.

GHG inventory uncertainty has become increasingly important to policymakers. The IPPC outlines requirements for accommodating GHG inventory uncertainty in macro-level

 


**Figure 1.** Cities included in this study. Dates denote year of baseline greenhouse gas inventories.

analyses (Eggleston *et al* 2006, Penman *et al* 2000). The IPCC guidelines outline the sources of uncertainty in national GHG inventories and analytical methods for modeling such uncertainty, with a particular emphasis on uncertainty and variability associated with fuel composition and combustion. However, the IPCC does not fully address the uncertainty and variability particular to communities.

This paper reviews GHG inventories and climate action plans for eighteen US cities, shown geographically in figure 1. The supplemental information (SI available at stacks.iop.org/ERL/6/034003/mmedia) contains references for each inventory and climate action plan (CAP) shown in figure 1. The cities were chosen based upon the availability of community-level energy consumption and emission estimates by sector and for geographic diversity.

The review evaluates current community GHG inventory methods and supporting resources in light of the technical challenges of estimating GHG inventories at the community scale. GHG inventories were reviewed for clarity, transparency, scope, and major sources of uncertainty and variability. The authors then examine opportunities to improve inventory practices to facilitate planning emission reductions.

Fifteen of the selected inventories were prepared using ICLEI's climate action planning guidance and software tool (ICLEI 2010b, 2010c). The remaining four (Seattle, Chicago, Austin, and New York) followed independent, but similar inventory procedures. When extracting inventory data for comparing inventories, the authors were careful to avoid differences in estimation methods or inventory scope.

Current practice is to evaluate baseline emissions using a single annual GHG inventory. CAPs then use baseline inventories to specify reduction schedules and emissions mitigation alternatives (ICLEI 2010b). Interim single-year inventories are used to monitor progress. Given that CAPs are the dominant approach to planning local emissions reductions, accurate and meaningful GHG inventories are critical to their success.

Section 2 outlines the scope and reporting categories typical of the profiled inventories and includes a discussion of major sources of uncertainty influencing community inventories. Section 3 presents several alternative inventory techniques intended to improve action planning and highlights the merits and challenges associated with comparative benchmarking across cities.

## 2. Greenhouse gas inventories

### *2.1. Scope of inventories*

Community inventories typically include annual emissions from (1) commercial and (2) residential buildings, (3) industrial facilities, (4) on-road transportation, and (5) waste within the city's political boundary. With minor deviations, sixteen of eighteen profiled inventories report emissions from these five sectors. Fifteen of the profiled inventories report GHG emissions by energy source (e.g., natural gas). Only five of the profiled inventories report emissions by sector and consumption sources with each sector.

This study addresses only emissions from electricity and natural gas consumption in commercial and residential buildings and emissions from on-road personal transportation. The industrial and waste sectors were omitted here with the exception of Flagstaff, whose industrial emissions from natural gas use are included in the commercial sector due to the utility metering practices. Industrial emissions stem from facility operations and process fugitive emissions and thus vary by facility, limiting generalized opportunities for characterization. In the profiled cities, industrial emissions accounted for an average of 10% of local emissions, but vary from 3% to 30%. Emissions associated with solid waste management account for approximately 2% of GHG emissions nationally (EPA 2010a).

Figure 2 shows baseline emissions in the residential, commercial, and transportation sectors per capita for each profiled cities. Figure 2 also shows 2007 US average

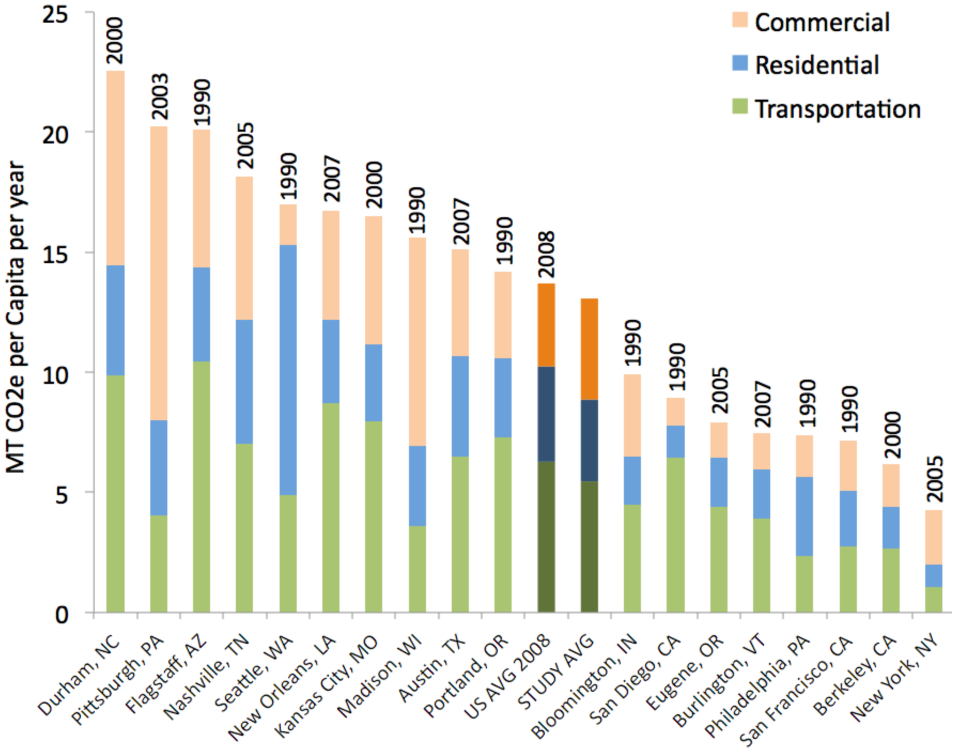


**Figure 2.** Community greenhouse gas emissions per capita for 19 US cities as compared to US average (EPA 2010a, US Census Bureau 2010a, US Census Bureau 2010b; SI (available at stacks.iop.org/ERL/6/034003/mmedia) for inventory references).

emissions. Figure 2 shows considerable variation in total and sector-level emissions. New Yorkers emit around 5 metric tons $CO_2e$ per[5] capita; Durhamites emit around 22 metric tons $CO_2e$ per capita. Residents in fifteen cities profiled were below the 2007 US average residential emissions. Similarly transportation emissions per capita in twelve US cities were below the US average, and commercial emissions per capita were lower than the US average in about half of profiled cities.

Community GHG inventories are rarely reported by scope. Scope 1 emissions are from direct fuel combustion within a geographic boundary, such as natural gas for heating. Scope 2 emissions are from energy consumed within boundaries but generated elsewhere, typical of purchased electricity. Scope 3 emissions are all other indirect emissions, such as emissions associated with producing imported goods or emissions from waste management. Three inventories (New York, New Orleans, and Austin) report emissions by scope.

Each reporting category serves a different purpose. Reporting emissions by sector is helpful when formulating a CAP and for comparative benchmarking. Reporting by fuel type can help identify the influence of regional factors, such as electricity grid emissions and climate. Reporting by scope helps identify cross-boundary impacts of consumptive activities.

For profiled inventories, the transportation boundary is inconsistent. Nine of the profiled GHG inventories report emissions from air travel (Scope 1 or Scope 3 emissions, depending on airport locations), three indicate that air travel is out of scope, and the remainder are not explicit (may or may not include them). Results are similar for public transportation and freight emissions. The cities profiled exclude Scope 1 emissions from on-road regional commuting outside the city limits, with the exception of San Francisco's GHG inventory.

[5] The term $CO_2e$ designates 'equivalent carbon dioxide', which represents the cumulative radiative forcing impact from several greenhouse gases expressed in an equivalent concentration of carbon dioxide.

### 2.2. *Uncertainty and variability in inventories*

The considerable uncertainty and variability demonstrated by community GHG inventories is not reflected in current practice. Three major sources of uncertainty and variability are discussed here: the influence of uncertain electricity power systems operations on emissions from electricity demands (often called 'grid emissions'), weather impacts on building energy use, and measurement and sample errors associated with on-road personal transportation emissions. Other sources of uncertainty not discussed here include the direct and indirect emissions associated with the combustion of fuels used to supply the energy needs of cities (Jaramillo *et al* 2007).

The use of the term 'uncertainty' herein is consistent with policy applications (Morgan *et al* 1990). However, the taxonomy applied to uncertainty differs across experts and fields. For example, policy analysts often treat future inter-temporal variation as uncertainty, while others define uncertainly as only inherent randomness.

*2.2.1. Electrical power systems operations.* The US electricity grid is highly interconnected, with demand centers drawing from multiple and varying power generators. The

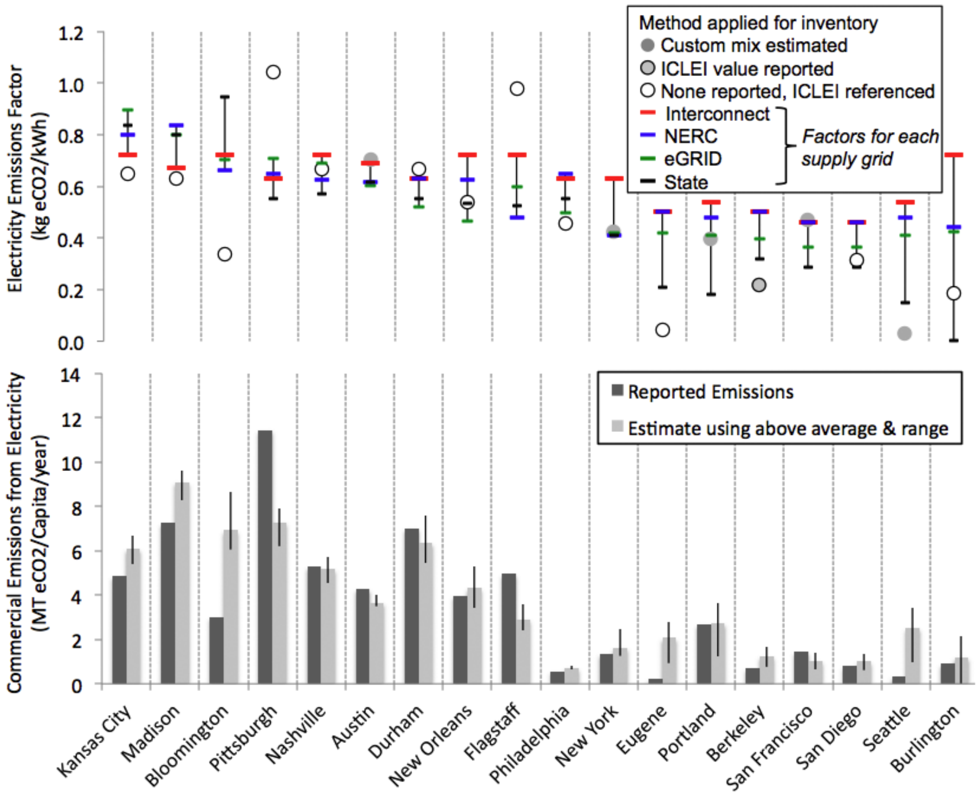


**Figure 3.** (top) Electricity emission factors for profiled cities (EPA 2010b); (bottom) commercial electricity greenhouse gas emissions per capita for profiled cities (SI available at stacks.iop.org/ERL/6/034003/mmedia; US Census Bureau 2010a, US Census Bureau 2010b). eGRID data were aligned with baseline inventory years within limitations associated with eGRID benchmark publication years. Thus, some of the differences between reported and estimated emissions factors may be inter-temporal (e.g., grid emissions data are unavailable for inventories in the 1990s).

generators used to meet local demands are determined by an uncertain relationship between demand activity relative to available transmissions and generation capacity. Generators may be meeting demands located across city, state, regional, and US borders (Marriott and Matthews 2005). It is not currently possible to specify which generators (and therefore which fuels) are used to meet local demands due to the inability to trace the flow of electrons (Weber *et al* 2010).

The EPA provides power systems emissions estimates for the following electricity supply service areas (EPA 2010b):

(i) US states;
(ii) Twenty-six continental US eGRID sub-regions (varying in size from New York City to almost all of the six states in the northwest US);
(iii) Eight North American Electric Reliability Council (NERC) sub-regions (varying in size from the six New England states plus New York to the entire 11-state region west of the Rocky Mountains).

The EPA data can be used to estimate emissions for the three continental US interconnects (the eastern US, the western US and Texas). The EPA uses power plant operations data (fossil and non-fossil sources) to estimate regional power system emissions factors without reflecting potential transmission across supply regions (EPA 2008). While transmission across the US interconnects is limited (Blumsack 2007, Marriott and Matthews 2005) shows that inter-state electricity flows are often higher than 25% and can be as high as 70% of in-state demand or consumption. Figure 3 shows power systems emissions factors associated with assuming different supply service areas (referenced above) for each profiled community.

The above discussion indicates that geographic proximity alone is not a sufficient predictor of the fuels used to supply local electricity consumption. However, five of the profiled inventories assume most or all consumed electricity is supplied locally, using local power plant fuel mixes with some potential supply from the broader grid. Twelve inventories do not report a power systems emissions factor but imply emissions factors in ICLEI's software were used. Berkeley explicitly reports ICLEI's emissions factor used for their inventory.

Figure 3(top) shows the electricity power systems emissions factor used to assess each community's baseline inventory. The ICLEI software tool assumes emissions from the eGRID sub-regions apply locally (ICLEI 2010c). However, figure 3 indicates many ICLEI clients use emission factors inconsistent with eGRID data. Thirteen of the nineteen community inventory emissions factors are near the extreme or outside of the range, suggesting communities may be using inappropriate factors. The reasons for these discrepancies are unclear but may be related to poor software version control, software errors, or users overriding default emission factors when using ICLEI's software.

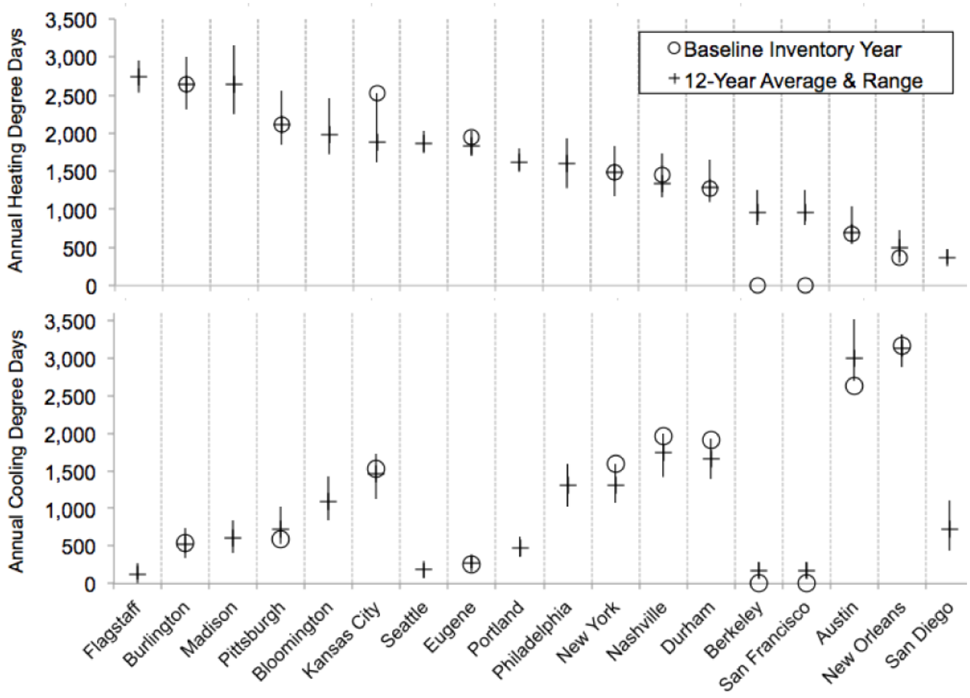


**Figure 4.** (top) Heating degree days for profiled cities (NWS 2010); (bottom) cooling degree days for profiled cities (NWS 2010); degree days use a base of 65 °F. Baseline inventory data for some cities not shown because local degree data is not available for baseline year.

Grid emissions also change over time as a result of changes in infrastructure, operations, and fuel sources. The electricity power systems emissions factors for EPA's eGRID sub-regions vary by more than 10% for some regions between 2004 and 2005, and many US states have aggressive renewable portfolio standards (Wiser 2008). Only two (Seattle and New York) of the CAPs profiled recognize potential supply-side changes in formulating reduction schedules and strategies.

Eight of the profiled cities follow the Kyoto protocol in establishing a baseline year of 1990. However, electricity power systems emission factor data are generally not available for 1990. With the exception of Seattle, these cities assume 1990 grid emissions match current levels, an arbitrary and likely inaccurate assumption. Seattle used fuel consumption data from its municipal electricity generator to estimate fuel switching accounted for nearly 60% of their estimated electricity emissions reduction from baseline.

*2.2.2. Weather variability.* Weather can significantly affect energy consumption for buildings. For example, New York City reports that monthly local natural gas consumption can vary fivefold depending on winter weather (SI available at stacks.iop.org/ERL/6/034003/mmedia). Similarly, Sailor and Pavlova (2003) and Amato (2004) demonstrate strong variations in annual local energy use with temperature. Figure 4 shows annual degree days for baseline assessments years, 12-year ranges, and per capita energy use for profiled cities. Figure 4 shows heating and cooling degree days vary by more than 50% for most of the profiled cities. While several of the inventories report temperature or degree day data, none reflect potential weather variation when establishing a baseline inventory.

*2.2.3. Measurement and sampling errors for transportation emissions.* The most common method for estimating on-road personal transportation emissions is to estimate local vehicle miles traveled (VMTs) and apply nationally average fuel efficiencies and fleet distributions to estimate fuel consumption. Thirteen of the profiled inventories used this method within ICLEI's software tool. Local VMT data were provided by state, local, or regional planning authorities. Two inventories (Portland and Flagstaff) used surrounding county fuel sales to estimate on-road transportation emissions. Flagstaff scaled county estimates by population. Portland's emissions include all of those associated with its surrounding county. The remainder (three) do not specify their methods

While a general characterization of the uncertainty in on-road transportation emissions is not as tenable as characterizing uncertainty in emissions from buildings, the on-road emissions inventory methods described above clearly introduce many sources of uncertainty through sampling errors and biases. For example, VMT data are commonly estimated by household surveys or traffic count samples, which are known to demonstrate such errors (Wolf *et al* 2004, Erlbaum 2005).

The above analysis of inventory uncertainty suggests that current inventory practices may lead to unrepresentative and thus inappropriate emission baselines. As a result, the action planning that rests on such baselines—such as setting reduction targets and designing action items—may be misguided. For example, figure 4 suggests that Austin's baseline inventory represents a relatively mild summer, and thus Austin may be underestimating typical cooling needs. This skewed baseline may lead to inappropriate action items, especially given the significance of building cooling in Austin.

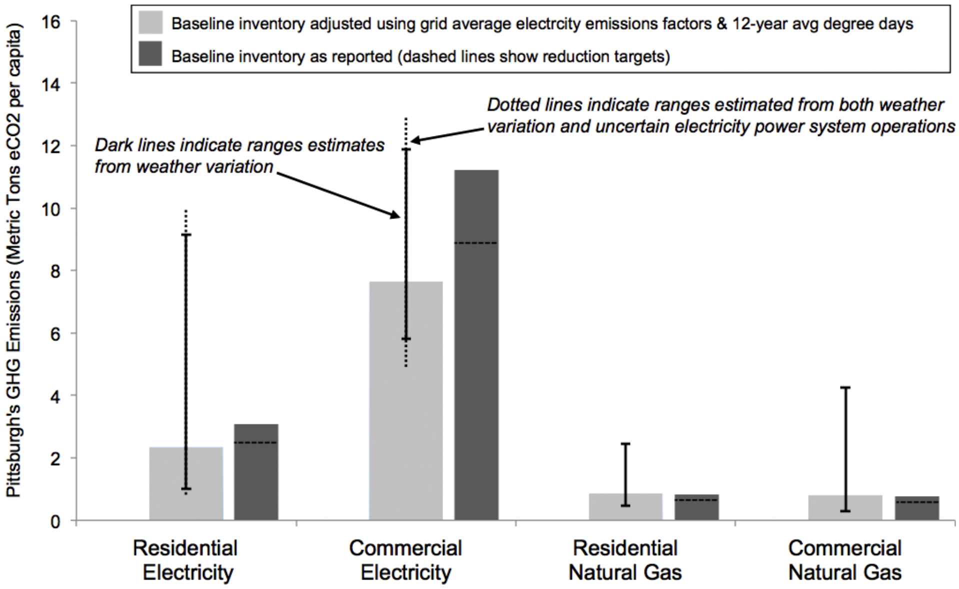


**Figure 5.** Residential and commercial electricity greenhouse gas inventories by energy source for Pittsburgh, PA. The inventories and ranges shown in light gray have been adjusting using degree day data (NWS 2010), expected emissions factors (EPA 2010b), and regression results (Amato 2004). Dark gray inventories show baseline inventory with reduction targets shown in dashed lines.

## 3. Alternative and supplemental inventorying practices

The following alternative and supplemental inventorying techniques are proposed to improve decision-making during climate action planning. The techniques are designed to help action planners prioritize emissions sources, select meaningful reduction targets, design actionable mitigation measures, strategize reduction plans, measure progress, and learn from other practitioners. The profiled techniques are not meant to be comprehensive nor are they necessarily 'best' practices, as the data and perspectives required to prepare a comprehensive benchmark review remain limited.

### *3.1. Reporting categories*

Inventories that report emissions both by sector and by the energy sources consumed within each sector provide more resolution and thus help scope and prioritize action items. Solely reporting emissions by sector without reporting fuel consumption data obscures the influence of electricity emissions, weather, and other regional factors. Figure 5 shows an example inventory reported by fuel for the residential and commercial sectors in Pittsburgh.

Figure 5 also shows estimates of the sources uncertainty and variability discussed in section 2.2. The influence of weather variability on the inventories shown in figure 5 was estimated by regressing the reported baseline inventory energy use against 12-year historical degree day data (Amato 2004, NWS 2010). The range in emission factors shown in figure 3 were then applied to these regression results to estimate the influence of uncertain electrical power systems emissions shown in figure 5.

Figure 5 shows that Pittsburgh's baseline natural gas inventory aligns well with historical winter weather, as demonstrated in figure 4. However, Pittsburgh's baseline electricity inventory is likely unrepresentative as a result of weather influences and the assumed emissions associated with electricity consumption (see figure 3). The ranges shown in figure 3 demonstrate the limitations of using single annual inventories for decision-making. For example, figure 5 indicates ranges in Pittsburgh's baseline inventory overshadow their reduction target of 20%. For example, an annual inventory for commercial electricity consumption in Pittsburgh can be expected to vary from around 5 to 13 metric tons per capita (+14%/−56% from Pittsburgh's selected baseline of 11.4 metric tons per capita). Finally, figure 5 demonstrates that electricity emissions in Pittsburgh are likely to be much higher than natural gas emissions even under extreme conditions, which helps action planners prioritize mitigation measures.

### *3.2. Sector disaggregation*

The sector resolution currently in place (residential, commercial, industrial, and transportation) is often too broad and open ended for designing and implementing climate action plans. Increased disaggregation would improve decision-making. For example, the level of resolution in Los Angeles' commercial accounting as shown in table 1 is helpful when prioritizing action items, as opposed to reporting a single commercial total. Decision-makers in Los Angeles know that restaurants are a GHG-intensive sub-sector and account for a majority share (20%) of Los Angeles' commercial footprint. Restaurants would provide a focused target for CAP initiatives.

Sector disaggregation also has the benefit of identifying accessible jurisdictions over emissions. For example, the education sector may be more easily influenced as a result of centralized decision-making, public value stewardship, and educational co-benefits than the retail sector might be.

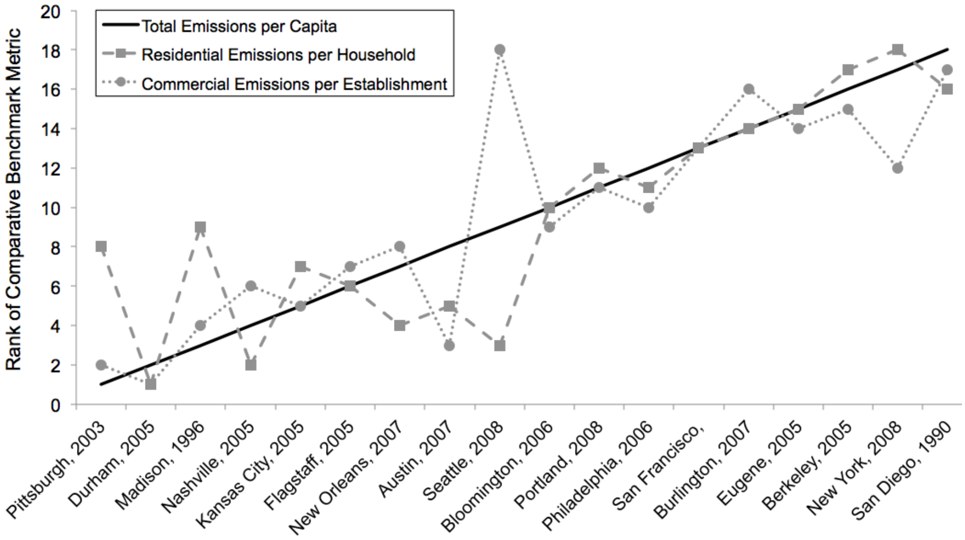


**Figure 6.** Relative rank of comparative metrics for profiled cities (rank 1 = highest emissions per capita, rank 19 = lowest). Year designates inventory, which may be baseline or interim. (SI available at stacks.iop.org/ERL/6/034003/mmedia; US Census Bureau 2009, US Census Bureau 2010a, US Census Bureau 2010b).

**Table 1.** Emission and energy intensities for Los Angeles Commercial Sub-sectors (City of Los Angeles 2010).

| Commercial sub-sector | Energy intensity (kBtu ft$^{-2}$) Los Angeles | California | Emissions (metric tons eCO2) |
|---|---|---|---|
| Restaurant | 2.8 | 2.4 | 2.1 |
| Health | 0.77 | 0.86 | 1.3 |
| Hotel | 0.47 | 0.48 | 0.63 |
| College | 0.27 | 0.39 | 0.66 |
| Other | 0.27 | 0.26 | 3.2 |
| Food store | 0.25 | 0.32 | 0.38 |
| School (K-12) | 0.14 | 0.18 | 0.49 |
| Office | 0.12 | 0.20 | 1.9 |
| Wholesale | 0.03 | 0.04 | 0.32 |
| Retail | 0.03 | 0.05 | 0.25 |
| | | Total | 11.2 |

Disaggregation also helps identify emission reduction opportunities associated with public sector programs, such as public housing efficiency programs and expanding transit. For example, Pittsburgh's first inventory excluded public transit because the transit authority is a county entity (Pittsburgh in SI available at stacks.iop.org/ERL/6/034003/mmedia). However, Pittsburgh's commercial activities and land use affect transit ridership; thus city-related transit emissions are included in both their updated 2010 inventory (GBA 2010). If transit emissions are excluded from inventories, communities will not be able to leverage transit GHG mitigation programs.

Utility consumption data may not be readily available to support such resolution, but, with guidance through a community GHG protocol, communities could use proxy data such as county real estate data and state and federal planning tools (for examples see DOE 2005, 2008, CPUC 2005). New energy tracking tools, such as EPA's Portfolio Manager, support sub-sector inventorying.

### *3.3. Comparative benchmarking and peer analysis*

Comparative benchmarking can provide quality control, inform reduction goals, identify reduction strategies, and integrate influential regional factors into CAP design. For example, figure 2 suggests local $CO_2e$ emissions should fall between 4 and 25 metric tons per capita, with narrower ranges expected for similar cities. For example, New York's inventory recognizes that its transportation emissions are already very low relative to other US cities. As a result, building emission reductions are prioritized during action planning.

Comparisons are more meaningful when contrasting inventories follow appropriate baseline definitions and are similar in scope (see section 2). Identifying peers in similar energy service areas can also improve comparisons. Factors such as the carbon intensity of local energy supplies, climate, energy pricing, and organizational capacity are useful peer criteria.

Comparative benchmarking is also applicable to sector-level emissions. While current practice is to compare total emissions per capita, different normalization metrics (e.g., per establishment or square footage) may be more insightful for sector and sub-sector comparisons. Figure 6 shows the relative rank of the profiled cities for different metrics. Berkeley demonstrates the third lowest total emissions per capita, but the highest commercial emissions per establishment. It should be noted that regional commercial activity will influence a fair comparison of commercial emissions per establishment. Combining this metric with the disaggregation techniques discussed above would provide more meaningful comparisons.

### *3.4. Reduction strategies*

The profiled CAPs suggest that selecting reduction targets, schedules, and baseline inventories are currently arbitrary and unstructured practices. Eight cities follow the Kyoto protocol

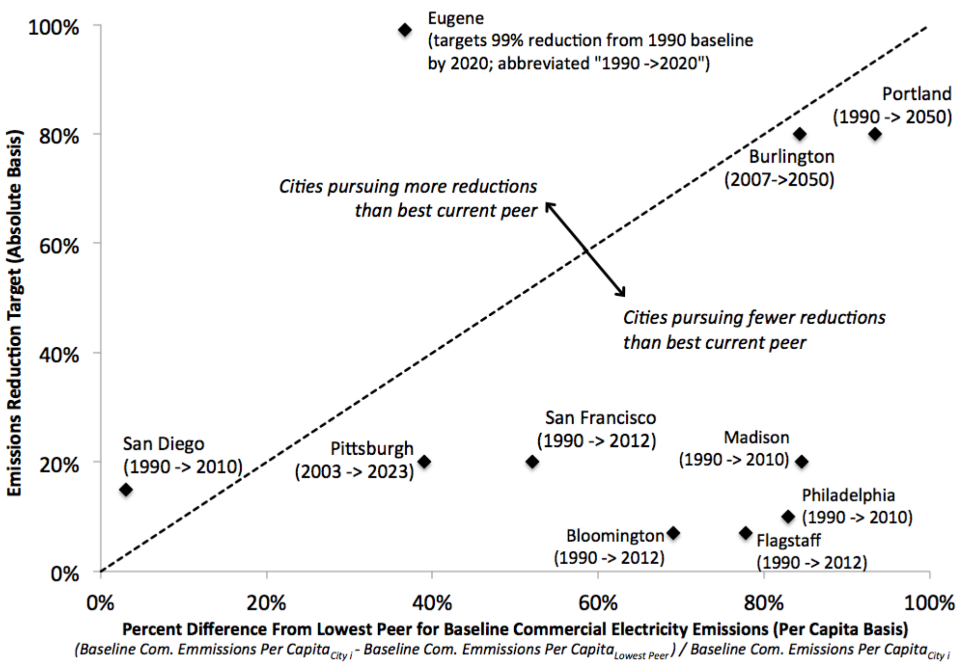


**Figure 7.** Commercial electricity emissions reduction targets relative to peer with fewest emissions. Some cities are not shown because they have no peers, no peers with lower emissions, or do not publish reduction goals. Peer criteria include electricity power systems grid emissions (EPA 2010b) and climate zone (NWS 2010, EIA 2010).

baseline year of 1990; however, the reduction goals for these cities range from 7% to 80% from baseline. The remaining nine use baselines from 2000 to 2007 and reduction targets range from 20% to 99%. Eugene, OR has the most aggressive goal of a 99% reduction from 2005 levels by 2050 (an average annual reduction of 2.2%). Flagstaff, AZ and Bloomington, IN are the least aggressive with a 7% reduction from 1990 levels by 2012 (an average annual reduction of 0.3%).

Reduction targets and schedules are not typically reported by sector. Each sector and sub-sector demonstrates divergent opportunities, feasible project time horizons, and strategies for emissions reductions. For example, building energy efficiency demonstrates substantial, short-term GHG mitigation and financial savings opportunities (for examples see NRC 2009, Azevedo 2009, Blackhurst 2011), while mitigation through transit-oriented development requires long-term, capital-intensive planning and investment. The inventory techniques profiled above promote a more careful consideration of these issues.

Comparative benchmarking can also help plan reduction targets and strategies. Figure 7 compares commercial electricity power systems emission reduction targets relative to lowest emissions from peer cities. The supplemental information lists peer cities and peer criteria (power systems emissions and climate zone). In figure 7, two cities are pursuing more reductions than their best peer's baseline emissions; eight are pursuing fewer. Given Eugene's emissions are 35% higher than their lowest-emitting peer (Seattle), targeting a 99% reduction below 1990 levels by 2050 seems extreme. Given the limited city sample size, few peer criteria, uncertainty of emissions, and disparities of baseline and target years, figure 7 is intended to be conceptually illustrative, not analytically precise.

With the exception of Durham, all profiled cities use total per cent reductions below a baseline year for reduction targets. This approach may not be appropriate for communities with divergent growth patterns. Areas experiencing significant growth are more challenged by total per cent reductions than slow-growth areas. Moreover, effective CAP planning strategies are likely to differ regionally, such as prioritizing retrofitting infrastructure in slow-growth areas or targeting new construction in growing regions. Per capita diagnostics are helpful and could be aligned with other planning metrics—such as land use, transportation planning, and economic development strategies.

Given the short- and long-term aspects of CAPs, interim targets and supporting implementation plans are critical to achieve CAPs and tracking progress. However, interim targets are typically not established (six profiled inventories set one interim target; four set two interim targets). More importantly, few CAPs provide an implementation schedule. Field experience highlights how poor planning stalls implementation (Pitt and Randolph 2009). Without interim targets little feedback and course correction will be possible.

It should be noted that the alternative benchmarking practices discussed herein should be considered supplemental, scoping techniques to facilitate decision-making as opposed to a comprehensive analyses.

## 4. Discussion

Administration of the 2009 American Recovery and Reinvestment Act suggests that state and local governments may be primary decision-makers in broader GHG mitigation efforts (DOE 2010). Of ICLEI's membership, the number of communities conducting GHG inventories nearly doubled in the last five years (from around 100 to 200) (ICLEI 2010a). CAPs also doubled (from around 50 to 100). Many more inventories and CAPs are likely imminent given that over 1000 mayors have committed to reducing emissions.

Achieving meaningful reductions will take careful analysis, skilled decision-making, and dedicated implementation. In summary, the inventory recommendations documented herein call for a paradigm shift from standards that mimic a 'calculator' to those that facilitate decision-making and improve climate action plan implementation.

The alternative and supplemental practices documented herein are not intended to discourage cities from committing to the significant reductions required to meet safe GHG levels. They are intended to help decision-makers strategize and prioritize under the influence of previously documented organizational and financial constraints (Pitt and Randolph 2009, Bailey 2007, Wheeler 2008).

Our recommendations also complement more rigorous financial analyses of action items, such as technical, economic, and organizational feasibility. For example, energy efficiency planning resources—such as those estimating the costs and benefits of efficiency interventions (CPUC 2005, REEEP 2010, DSIRE 2010)—would be easier to integrate into action planning with inventory techniques that prioritize inventory sources and identify local jurisdictions over emissions.

The practice of using a single baseline year for action planning may lead to unrealistic reduction targets, misrepresent progress, and obscure local emissions profiles. The range of uncertainty discussed herein (often greater than 50%) is well within the reduction goals of some communities. As a result, communities could currently claim credit for reductions not due to action planning but instead due to mild weather or renewable portfolio standards (see figure 5 as an example). Conversely, leading communities may not meet their stated goals using current methods.

In the short-term, inventories could be supplemented with annual or seasonal heating and cooling degree day data (as is done in New York's 2009 inventory) or use existing regression studies to adjust for weather (for examples see SI available at stacks.iop.org/ERL/6/034003/mmedia; Amato 2004, Sailor and Pavlova 2003).

In the long-term, community GHG inventories would benefit from more formal treatment and awareness of major sources of variability and uncertainty. As community-scale inventory practices mature, the IPPC provides helpful guidelines and intuition for modeling GHG emissions uncertainty at the national scale (Penman *et al* 2000). For example, the IPCC would likely recommend expert judgment be used to address uncertainty from local electricity consumption emissions given empirical and measurement limitations (Eggleston *et al* 2006). Similarly, improved local GHG inventories and associated methods would offer insights into uncertainty and variability in national scale inventories. Collaboration between appropriate agencies and organizations (e.g., IPCC, EPA, UNEP, and ICLEI) and research merging national and local inventory methods would help. (We thank a reviewer for identifying these opportunities.)

Collecting long-term, local annual energy and degree day data would improve baseline and interim accounting for weather variability. Accounting for such variability would promote more meaningful monitoring using formal statistical techniques (such as $t$-tests).

Communities also need additional resources for accounting for 'business as usual' in the context of climate action planning. Current methods do not adequately account for population and economic growth, energy supply-side changes (such as state renewable portfolio standards), technology improvements (such as fuel economy standards for automobiles), and state and federal standards that influence energy and greenhouse gas emissions within communities. Effective GHG reduction strategies and levels of effort will differ significantly for high- and low-growth areas (Blackhurst 2011). In states making aggressive investments in renewables, local demand-side strategies for electricity may do little to mitigate GHGs.

About half of the profiled cities have conducted interim-year inventories. There are no updating standards nor are there provisions or mechanisms to ensure updating. Also missing is information sharing between inventory practitioners regarding lessons learned in regularly acquiring and tracking data from utilities, various government departments, and other entities. Many of the community GHG inventory recommendations above could easily be incorporated into common community inventory software tools, lessening the burden on inventory practitioners.

Recent work encourages inventorying scope 3 emissions embodied in goods and services (Hillman and Ramaswami 2010, Kennedy *et al* 2009, UNEP 2010). Scope 3 accounting is a challenging, developing field that demonstrates significant uncertainty for products let alone community imports. Scope 3 emissions include not only the uncertainty in upstream emissions (scopes 1 + 2 discussed above) but also supply chain and aggregation variability (Huang *et al* 2009). Huang *et al* (2009) document that hundreds of suppliers must be tracked to estimate reasonable fractions of scope 3 emissions for products. At the community scale, these data requirements seem impracticable given known methodological challenges (Pitt and Randolph 2009, Bailey 2007). The discussion herein suggests that improvements to inventorying scopes 1 and 2 may be higher research priorities. Communities motivated to inventory and manage scope 3 emissions may consider inventorying scope 3 separately from scopes 1 and 2.

Our recommendations were shared with practitioners in Austin, TX, Pittsburgh, PA, and Kansas City, MO. Practitioners in Austin indicated they are more likely to practice comparative benchmarking after reviewing our work. They further noted that while uncertainty may skew their baseline assessment, inventory timing was politically decided. Noting a lack of adequate inventory tools, Pittsburgh practitioners suggested our recommendation would help standardize inventories in ways that better support action planning and noted that our recommendations provide useful insights into what local factors influence inventories. While these action planners indicated our recommendations would significantly improve decision-making, they all emphasized resource constraints in preparing inventories and action planning and called for improve decision support tools that reflect the issues documented herein. States, the EPA, and support organizations like ICLEI are well positioned to provide such support.

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**Brief**

A review of community greenhouse gas inventories highlights methodological challenges when planning and measuring local emissions reductions. The authors present alternative and supplemental inventory techniques that better facilitate local climate action planning.

## References

Amato A D 2004 Energy demand responses to temperature and implications of climatic change *PhD Dissertation* University of Maryland at College Park, USA

Azevedo I 2009 Energy efficiency in the US residential sector: an engineering and economic assessment of opportunities for large energy savings and greenhouse gas emissions reductions *PhD Dissertation* Carnegie Mellon University, USA

Bailey J 2007 *Lessons from the Pioneers: Tackling Global Warming at the Local Level* (Minneapolis, MN: Institute for Local Self-Reliance)

Blackhurst M 2011 Achieving Realistic Energy and Greenhouse Gas Emission Reductions in US Cities *PhD Dissertation* Carnegie Mellon University, USA

Blumsack S 2007 Measuring the benefits and costs of regional electric grid integration *Energy Law J.* **28** 147–84

City of Los Angeles 2010 Personal communication with Jose Gutierrez, Environmental Supervisor, City of Los Angeles, CA

CPUC (California Public Utilities Commission) 2005 Database for Energy Efficient Resources (available at www.deeresources.com, accessed 6 October 2009)

DOE (US Department of Energy) 2005 *Commercial Buildings Energy Consumption Survey, 2003* (Washington, DC: Energy Information Administration (EIA)) (available at http://www.eia.doe.gov/emeu/cbecs/)

DOE (US Department of Energy) 2010 Recovery and Reinvestment: Breakdown of Funding (available at http://www.energy.gov/recovery/breakdown.htm, accessed 20 February 2010)

DOE (US Department of Energy) 2008 *Residential Energy Consumption Survey, 2005* (Washington, DC: Energy Information Administration (EIA)) (available at http://www.eia.doe.gov/emeu/recs/)

DSIRE (Database of State Incentives for Renewables and Efficiency) 2010 DSIRE is funded by the US Department of Energy and administered by the NC Solar Center and Interstate Renewable Energy Council (available at http://www.dsireusa.org/summarytables/index.cfm?ee=1&RE=1, accessed 29 December 2009)

Eggleston S *et al* 2006 *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (Hayama, Japan: Institute for Global Environmental Strategies) (available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html, accessed 5 May 2011)

EIA (Electricity Information Administration) 2010 Details of US climate zones (available at http://www.eia.doe.gov/emeu/cbecs/climate_zones_explanation.html, accessed 16 September 2010)

EPA (US Environmental Protection Agency) 2008 *The Emissions & Generation Resource Integrated Database for 2007: (eGrid2007) Technical Support Document*

EPA (US Environmental Protection Agency) 2010a *Inventory of US Greenhouse Gas Emissions and Sinks: 1990–2008* Washington, DC (available at http://www.epa.gov/climatechange/emissions/usinventoryreport.html, accessed 28 December 2009)

EPA (US Environmental Protection Agency) 2010b *eGRID* (available at http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html, accessed 12 April 2010)

Erlbaum N 2005 Assessment of 2001 New York State NHTS Add-On Data Using Empirical and Auditable Data Sources *J. Transport. Stat.* **8** (3) 1–24

GBA (Green Building Alliance) 2010 2008 Pittsburgh Greenhouse Gas Emissions Inventory: a five-year benchmark Pittsburgh, PA (available at http://www.pittsburghclimate.org/resources.htm, accessed 14 January 2011)

Hillman T and Ramaswami A 2010 Greenhouse gas emission footprints and energy use benchmarks for eight US cities *Environ. Sci. Technol.* **44** 1902–10

Huang Y A *et al* 2009 The role of input–output analysis for the screening of corporate carbon footprints *Econ. Syst. Res.* **21** 217

ICLEI 2010a *ICLEI USA 2009 Annual Report* (available at http://www.icleiusa.org/about-iclei/annual-reports, accessed 14 April 2010)

ICLEI 2010b *The five milestone process* (available at http://www.iclei.org/index.php?id=810, accessed 30 December 2010)

ICLEI 2010c *CACP Software 2009* (available at http://www.icleiusa.org/action-center/tools/cacp-software, accessed 30 December 2010)

Jaramillo P, Griffin W M and Matthews H S 2007 Comparative life-cycle air emissions of coal, domestic natural gas, LNG, and SNG for electricity generation *Environ. Sci. Technol.* **41** 6290–6

Kennedy C *et al* 2009 Greenhouse gas emission baselines for global cities and metropolitan regions *Proc. 5th Urban Research Symp. (Marseille, June)* (available at http://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1256566800920/6505269-1268260567624/KennedyComm.pdf)

Marriott J and Matthews H S 2005 Environmental effects of interstate power trading on electricity consumption mixes *Environ. Sci. Technol.* **39** 8584–90

Marshall C 2011 International coalition searches for a standard way to track urban emissions *Climate Wire* (available at http://www.eenews.net/climatewire/2011/06/06/2/, accessed 11 June 2011)

Morgan M G, Henrion M and Small M 1990 *Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis* (Cambridge: Cambridge University Press)

NRC (National Research Council) 2009 *Realistic Prospects for Energy Efficiency in the United States* (Washington, DC: National Academies Press) (available at http://www.nap.edu/catalog.php?record_id=12621, accessed 29 December 2009)

NWS (National Weather Service) 2010 *Monitoring & Data: Degree Days Statistics* National Oceanic and Atmospheric Administration (available at http://www.cpc.noaa.gov/products/analysis_monitoring/cdus/degree_days/, accessed 13 April 2010)

Penman J *et al* 2000 *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (Hayama, Japan: Institute for Global Environmental Strategies)

Pitt D and Randolph J 2009 Identifying obstacles to community climate protection planning *Environ. Planning* C **27** 841–57
REEEP (Renewable Energy and Energy Efficiency Partnership) 2010 Compendium of best practices: sharing local and state successes in energy efficiency and renewable energy from the United States, Vienna, Austria (available at http://www.reeep.org/16672/compendium-of-best-practices.htm, accessed 21 September 2010)
Sailor D J and Pavlova A A 2003 Air conditioning market saturation and long-term response of residential cooling energy demand to climate change *Energy* **28** 941–51
UNEP (United Nations Environment Program) 2010 International standard for determining greenhouse gas emissions for cities *Version 2.1* (available at http://www.unep.org/urban_environment/PDFs/InternationalStd-GHG.pdf, accessed 3 December 2010)
US Census Bureau 2009 *2007 Economic Census* (available at http://www.census.gov/econ/census07/, accessed 17 June 2009)
US Census Bureau 2010a *American Community Survey* American FactFinder, population and housing data for appropriate benchmark years (available at http://factfinder.census.gov/, accessed 19 April 2010)
US Census Bureau 2010b *Decennial Census (1990 & 2000)* American FactFinder (available at http://factfinder.census.gov/, accessed 19 December 2010)
Weber C L *et al* 2010 Life cycle assessment and grid electricity: what do we know and what can we know? *Environ. Sci. Technol.* **44** 1895–901
Wheeler S M 2008 State and municipal climate change plans: the first generation *J. Am. Planning Assoc.* **74** 481–96
Wiser R 2008 *Renewable Portfolio Standards in the United States-A Status Report with Data Through 2007* Lawrence Berkeley National Laboratory (available at http://www.escholarship.org/uc/item/1r6047xb, accessed 20 September 2010)
Wolf J *et al* 2004 Advances in the application of GPS to household travel surveys *Conf. National Household Travel Survey* (Washington, DC)