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**The Transportation Greenhouse Gas Inventory: A First Step
Toward City-Driven Emissions Rationalization**

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Abstract: As global warming becomes a leading public policy issue, we find ourselves with a local and regional government structure poorly equipped to deal with emissions from transportation. Reducing transportation emissions will require, among other measures, reductions in how much and how far people drive. Due to a tradition of local self determination, cities hold land use policy levers that in the long run will play an indispensable role in emissions reduction, but commute- and travel-sheds have grown well beyond city borders. In order to encourage cities to induce VMT reduction, some researchers have suggested that cities be included in a carbon economy. In order to be effective, this will require a carefully crafted emissions inventory that rationally guides cities in emissions reduction.

This paper proposes a new inventory methodology with three key features. First, emissions are attributed to trip ends, rather than geographically. Second, new households receive an emissions credit or debit determined by the difference between their projected transportation emissions and the regional average household transportation emissions. Third, full transportation system life cycle emissions are included. Application of this inventory methodology to the City of Berkeley, California reveals that the methodology proposed here generates results substantially different from the presently used methodology.

1. THE NEED FOR THE CITY-LEVEL INVENTORY

As global warming becomes a leading public policy issue, we find ourselves with a local government structure poorly equipped to deal with emissions from transportation. Reducing transportation emissions will require, among other measures, reductions in how much and how far people drive (Ewing et al., 2008). Cities and counties control land use within their confines, but commute- and travel-sheds have grown well beyond city borders.

Across most of the United States and much of the world, city-level government has primary control over land use, and also controls other important policy levers for reducing emissions from transportation. To achieve the 80% emissions reduction by 2050 that scientific consensus prescribes, city action must play a significant role (Ewing et al). A system of accounting for greenhouse gas emissions and attributing them to cities is a critical step in guiding emissions reduction.

ICLEI Local Governments for Sustainability has devised the current “industry standard” greenhouse gas inventory for cities. For mobile emissions, ICLEI’s protocol measures aggregate transportation tailpipe emissions on a geographical boundary basis (i.e. travel that occurs within city limits). Freeways, even when they carry a significant fraction of Vehicle Miles Traveled (VMT), are excluded.

The information such an inventory supplies to a city located within a region of cities can be misleading, in some cases so misleading that it could guide cities to implement policies that actually have the effect of increasing emissions regionally. This paper proposes a method for attributing emissions that would better guide cities’ transportation emissions reduction efforts. It begins with a discussion of features we might want in an effective transportation greenhouse gas emissions inventory at the city level. With these features in mind, it discusses the geographic inventory, proposes an alternative method, and in a case study compares the output of each method for the City of Berkeley, California. Next, it addresses problems of accounting for city growth and incorporating vehicle life cycle emissions. Finally, the limitations of this new method are listed and the need for further research is discussed.

2. FEATURES OF AN EFFECTIVE INVENTORY

In order to craft an effective emissions inventory methodology, objectives for that inventory must first be put forth. Figure 1 proposes a list of objectives for a transportation emissions inventory for a city. The following subtopics discuss each in detail. In crafting an inventory methodology, these objectives must in some cases be balanced against one another.

FIGURE 1 Proposed features of an effective emissions inventory.

1. Catalogs emissions over which a city has influence, and excludes those over which it doesn’t
2. Can be applied feasibly using readily available data
3. Can be generalized to all cities consistently
4. Aggregates across municipalities without double-counting or under-counting
5. Encourages accommodation of population growth where its emissions impact would be smallest
6. Reveals the true relative magnitude of sector emissions, in order to guide the relative magnitude of emissions reduction efforts between sectors
7. Works effectively with state- and local-level policies to reduce emissions

Influence

Cities can influence travel behavior in a multitude of ways. Following is a sampling of programs a city might implement to reduce automobile travel:

- Place neighborhood-serving retail that allows residents to travel to and from their most common shopping needs (e.g. groceries, pharmacy, bank, post office, etc.) on foot.
- Design Transportation Demand Management Programs to shift travel to less-emitting modes and shorten trip distances
- Provide and/or support improvement of transit service
- Provide demand-side transit subsidies (e.g. a universal transit pass)
- Design features into streets which promote use of alternative modes of travel:
 - Traffic calming features
 - Bike lanes, paths, and parking
 - Wide sidewalks, street trees, benches, and other streetscape improvements which increase walkability
- Provide facilities for “bridge” modes (such as Neighborhood Electric Vehicles (NEVs)) such as separated road networks safe from heavier traffic and charging stations at parking spaces)
- Provide a marketing and information campaign educating residents, workers, and visitors, of the full range of transportation options available to them
- Implement pricing measures, including parking pricing, roadway tolling, congestion pricing and cordon pricing

These strategies affect trip generation, distribution, and mode choice. In a region of multiple cities, many of these trips will cross out of the city implementing the strategy. Only roadway tolling strategies might have a significant effect on pass-through traffic, and those are only feasible to implement in very specific, and, in the United States at least, uncommon circumstances.

Readily Available Data

At present, comprehensive measurements of VMT that can be accurately attributed between cities are generally not available. Model data are produced by Metropolitan Planning Organizations (MPOs) and Congestion Management Authorities (CMAs) are typically the best proxy available. These models estimate data using systems of Traffic Analysis Zones (TAZs) and trip ends. Disaggregating these model results to measure travel within the geographic bounds of cities can be a technical challenge; they lend themselves more readily analysis by trip-end.

The practitioner should also note that because models were designed to address congestion concerns, they typically estimate only weekday travel. Because carbon dioxide accumulates in the earth’s atmosphere over decades, total VMT aggregated over long time periods (e.g. a year) is the commonly used metric used to calculate these emissions. Weekend travel can be estimated from weekday models using multipliers derived from Freeway Performance Measurement System (PeMS) data, though this requires an imprecise extrapolation from freeway volumes to the entire street network.

Congestion Management Authorities monitor vehicle inventories at the county level and use these data to construct CO₂ emissions multipliers that can be applied to VMT from a traffic model. A limitation in using these data is that the CO₂ actually emitted from a tailpipe varies significantly with factors such as speed and speed fluctuation; slow speeds, fast speeds, and stop and go driving significantly reduce fuel efficiency. However, modeling such emissions fluctuations for an emissions inventory is, at present, usually impractical.

On the ground, limitations imposed by data availability are not the sole constraint in the feasibility of creating an emissions inventory for a city. Commonly, existing obligations already stretch city staff time and budgets thin. If an inventory method is to achieve widespread application, it must make relatively simple and straightforward use of available data.

Consistency across cities

If emissions inventories are to be part of a larger formalized emissions accounting system, inventories will need to be developed on a level playing field, using a consistent methodology. Tailoring an inventory method to particular circumstances unique to a city will prevent the method from being generalizable to other cities. Methods differing city by city preclude both meaningful aggregation and prospects for use of the inventory in exchange systems such as a cap and trade system.

Aggregation across Jurisdictions

If a city's aim were simply to reduce emissions over which it has influence, it would not be necessary for its inventory to avoid double counting other cities' emissions. However, an inventory method that avoids double counting when applied over multiple cities in a region has the benefit of scale flexibility, enabling analysis at the TAZ or regional level. Further, when a more formal structure such as a cap-and-trade program is put in place, a non-overlapping division of emissions attribution between cities will likely take on economic importance. Importantly, the inventory must not orphan emissions, leaving them unaccounted for by any entity. If emissions are orphaned, then progress measured toward societal targets set to achieve percentage emissions reductions becomes meaningless.

Normalizing/calibrating to the Region using Activity Indicators

Cities within a region can vary significantly in per-capita transportation emissions. A jurisdiction on the urban periphery will tend to have higher per capita transportation emissions than a centrally located jurisdiction. Considering regional transportation emissions, siting infill housing units in a more central city compared with adding them to a city on the periphery can make a several-fold difference in the household's transportation emissions. A city emissions inventory which does not account for this cannot act to rationalize regional emissions reduction, and will lead central cities to simply export emissions outside their borders.

Accuracy in Sector Magnitude

In order to consider emissions reduction measures across sectors on a level playing field, the full magnitude effects of both city policies and individuals' actions on emissions must be known. In the transportation sector, a substantial share of vehicle life cycle emissions comes from sources other than the vehicle's tailpipe. Those emissions, too, are driven by and correlated with the use of those vehicles.

An in-depth discussion of emissions attribution between producers (e.g. auto manufacturers, oil refiners) and consumers (in this case, the city, for its travel needs) is beyond the scope of this paper, but is the subject of increasing attention (see Millard-Ball, 2007 and Bastianoni, Pulselli and Tiezzi, 2004). It is clear, however, that the demand side will respond to price signals. Thus, the emissions inventory proposed in this paper incorporates full vehicle life cycle emissions in its methodology, allowing them to weigh on local transportation decisions.

3. THE GEOGRAPHIC INVENTORY

The California Energy Commission, in a committee report in June 2002 entitled *State of California's Guidance to the California Climate Action Registry: General Reporting Protocol*, directed that emissions from jurisdiction-based vehicles be attributed to the vehicles even when the vehicles travel outside state limits:

The requirement that participants report direct GHG emissions from mobile sources that they own or lease and operate raises the question of how emissions should be accounted for when sources travel across the borders of the state when they are reporting emissions only for California. For the purposes of reporting California emissions to the Registry, participants will report the total GHG emissions for mobile sources based in California regardless of whether the mobile sources travel outside of the state or not.

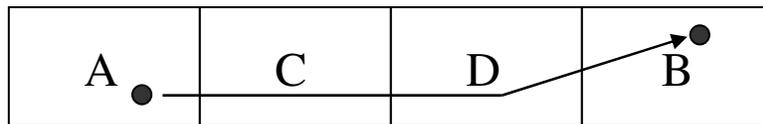
Under these guidelines, an inventory method for cities would be expected to account for travel associated with the city but which occurs outside its physical boundaries. The methodology described in this paper extends this to all vehicles in a city.

The inventory method ICLEI has implemented catalogs all tailpipe emissions within a city's borders. By including emissions from power plants that generate electricity used in the city, an accurate estimate can be made of building energy use in the residential, commercial and (in some cases) industrial sector using readily available data.

However, challenges arise in attributing emissions from transportation, because of the additional complication created by the mobility of emissions sources. People often move across city boundaries in their daily travels, and travel patterns are influenced by the policy decisions of more than one jurisdiction. An inventory method must attribute these emissions between jurisdictions.

If the purpose of an emissions inventory is to guide emissions reduction policy and track its results, then an ideal inventory method would attribute emissions from a vehicle trip by the relative amount of control each jurisdiction has over the trip. However, the geographic method does not necessarily reflect the travel over which a city has control. Consider the following simplified examples:

Example 1: A resident of City A drives from home to her job in City B, and along the way passes through City C and then City D. How should her emissions be attributed between these cities?



Discussion: In Example 1, cities C and D likely have little or no control over travel through their jurisdiction. Except via cordon pricing, which is viable only for the largest, most dense and economically prosperous cities, city C or D can have less effect on the choice to make this trip or the mode by which it is made. Thus, it seems appropriate to attribute emissions instead between cities A and B.

Meanwhile, city D *can* affect regional emissions by filling a deficiency in workforce housing for jobs “excess” jobs in City B. If, by providing this housing, it can shorten the average commute, it should be credited. Section five of this paper presents a crediting method.

Example 2: City B zones vacant land on its periphery for a regional-serving retail (e.g. a “power center”), intending to capture sales tax revenue from dollars spend by residents of A, B and C. A resident from City A drives from his city through City C to the power center to shop.



Discussion: In Example 2, City B makes a land use decision that will increase its revenue stream, but will also increase regional carbon emissions. However, a geographic inventory will attribute to City B only the emissions produced from the city's boundary to the power center, significantly understating the impact of its decision.

4. A PROPOSED ALTERNATIVE INVENTORY: TRIP END ATTRIBUTION

Instead of counting emissions within a geographic boundary, an inventory might count emissions from entire vehicle trips, and split them between the city that produced the trip and the city that attracted it. Such an inventory would count emissions from travel induced by a city's policy choices but which take place outside its geographical boundary. Because trip end attribution better captures the true total magnitude of the emissions generated as a result of city policy, it allows emissions repercussions of city decisions to be weighed more rationally during policymaking.

In the case of a metropolitan area composed of only a single city, this inventory will produce a similar magnitude, and guide policy in a similar manner, to the geographic inventory. However, for cities within urbanized regions that include a number of other cities, the difference in both magnitude and policy influence can be substantial. To illustrate this, a subsequent section applies each inventory discussed here to the city of Berkeley, California, and the results are compared.

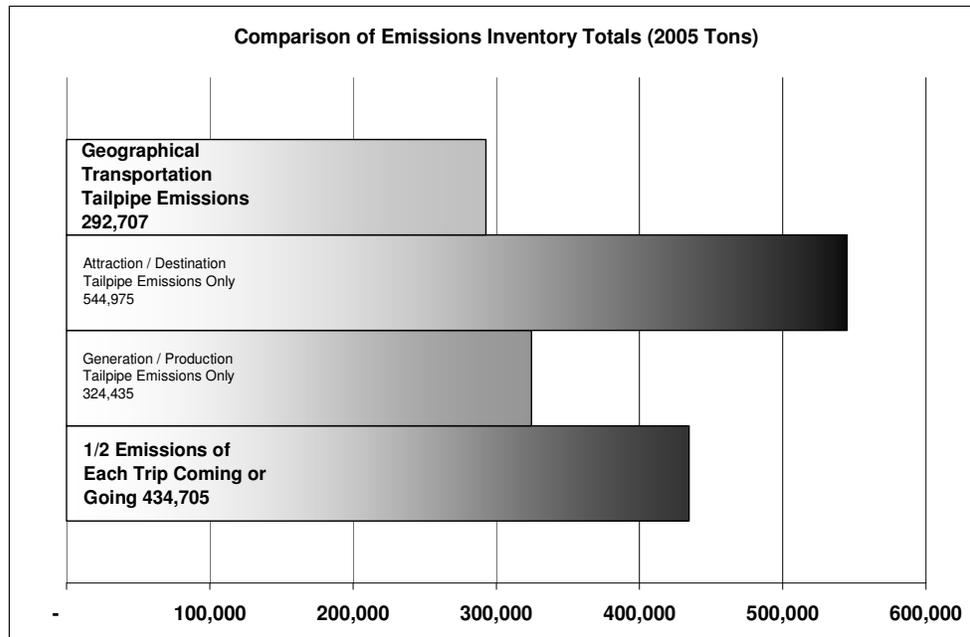
Half Trip End Attribution

Including tailpipe emissions from all trips that originate or are destined for a city in an inventory better captures those emissions over which the city has influence. However, when aggregating these city inventories to a regional level, all intercity trips become double counted. Attributing half of the emissions associated with each trip to the city at each end provides a straightforward solution to this problem. Conveniently, this method automatically attributes the full emissions from an intra-city trip to that city without double counting the city's emissions. By eliminating both double counting and under counting between cities, it scales transportation emissions attribution fairly against the other sectors (e.g. residential, commercial) and leaves no orphaned emissions.

Case Study: A Comparison of Inventory Models for the City of Berkeley

Results of application of the geographic attribution and trip end attribution methods to the city of Berkeley are given in Figure 2. Tallies of emissions from all trips starting or ending in Berkeley are provided for comparison.

FIGURE 2 Emissions inventories comparison for the City of Berkeley.



The trip end inventory is greater than the geographical inventory for two reasons. First, the geographical inventory excludes emissions on freeways and thus leaves out a substantial portion of travel. Second, as an employment center and regional destination, the City of Berkeley carries a disproportionately high share of trip ends and, conversely, a disproportionately low share of pass-through travel. Because most of what a city can do to manage transportation emissions must be leveraged at the trip ends, Berkeley, a destination city, has greater leverage in influencing travel behavior compared with pass-through cities. Attributing emissions by trip end more rationally allocates the responsibility that comes with that leverage.

5. ACCOUNTING FOR THE ADDITION OF HOUSING

Accommodating more population would cause a city's emissions inventory to rise, all else equal, because more residents' travel will add emissions. However, a city's choice to accommodate more residents does not generate population, it merely redistributes it. This is important because the placement of new development is fundamental in determining the travel behavior it induces.

Population growth in a region provides both opportunities and challenges in emissions reduction. Strategic infill can reduce per capita travel distances and average emissions by creating a denser network of destinations. Meanwhile, adding growth on the urban periphery will increase average travel distances and emissions. In order to help a city rationalize its policies in reducing regional carbon emissions, its inventory must account for this.

Expressing emissions on a per capita basis is a step in the right direction. Basing policy on per capita emissions would lead the city to discourage land uses that would generate per capita emissions higher than *its* average, and conversely encourage only those land uses which reduce *its own* intensity. It would encourage the city to develop infill projects rather than build on *its own* periphery.

However, tracking per capita emissions does not provide the city all the information it needs to optimize its emissions as part of the region. For example, a per capita inventory would guide a centrally located city with low per capita emissions to reject additional housing that would emit greater than *its own* emissions intensity. In the case where that additional housing

would instead be built in a peripheral city with a higher emissions profile, this policy would have the perverse effect of emissions. In order for inventory method to provide the information necessary to optimize growth for a region, it would need to compare the expected per capita emissions from a new dwelling unit in a city with the per-capita emissions for *the region*.

Traditionally in most places, cities, not regions, states, or federal governments, control land use. This arrangement allows local self-determination, but does not lend itself to optimization of the regional transportation system. However, an emissions inventory that credits cities for growth policies that reduce net regional emissions would help optimize both emissions and travel patterns. Without incorporating such credits, a city's inventory would overstate the emissions reduction induced by its policies, and would very likely induce greater emissions elsewhere.

The following is a method of accounting for transportation emissions effects of regional housing allocation via a city emissions inventory. This method determines the net effect of adding a dwelling unit on transportation emissions, then credits (or debits) the city for that amount multiplied by the number of housing units it adds. The method relies on the following two assumptions:

1. If a new dwelling unit is built within the city to satisfy housing demand, residents that move into it will have travel behaviors like those households already there, on average.
2. If the demand for a new dwelling unit is not satisfied within the city, the dwelling unit will be built elsewhere in the region, and its new residents will exhibit travel behavior like the average household in the region, on average. (This "baseline" could be replaced with a marginal analysis for the region, and/or be matched by housing type or income level, where data can be feasibly obtained.)

Each new household would receive a credit (or debit) equal to the difference between its expected emissions and the average household emissions in the region. Under the first assumption, the expected emission would be set to equal those of households in the same TAZ. The net effect of adding a unit of housing within a city in a given year would therefore be described by the formula below.

Let $E_{r,n}$ = emissions per year per household in the region in year n
 $E_{c,n}$ = emissions per year per household in the city in year n
 X_n = number of households added by the city in year n
 C_n = emissions credit city should receive for building housing in year n

Then $C = X_n \times (E_{r,n} - E_{c,n})$

A more fine-grained credit/debit calculation would examine emissions by Traffic Analysis Zone (TAZ). This would require simply replacing aggregate city data with Traffic Analysis Zone (TAZ) data. The credit earned by the city would be the sum of the credit earned by all of its TAZs.

Housing Credits Case Studies for Berkeley and Selected Other San Francisco Bay Area Cities

Berkeley is a centrally located city within the San Francisco Bay Area region, well served by transit. In 2006, the average household in the region emitted 6.1 tons of tailpipe CO₂ from home-based vehicle trips, while the average household in Berkeley emitted 2.6 tons. Therefore, each additional household built in the City of Berkeley in 2006 should have earned the city a credit of 6.1 tons – 2.6 tons = 3.5 tons in that year's inventory. Moreover, because the unit continues to

provide emissions reduction benefits indefinitely, that unit of housing should continue to earn the City a similarly calculated credit in future years. Table 5.1.1 displays per-household annual credits calculated for four other cities in the region.

TABLE 1 Tailpipe Emissions from Four Cities in the San Francisco Bay Area

	Distance to Downtown San Francisco	Average household home-based trip tailpipe CO ₂	
		Emissions Per Existing HH	Credit Per Additional HH
San Francisco	–	2.6 tons/year	– 3.5 tons/year
Berkeley	13.6 mi	2.6	– 3.5
Palo Alto	32.4 mi	4.0	– 2.1
Pleasanton	40.0 mi	6.9	+ 0.8
Vallejo	32.1 mi	7.1	+ 1.0

Calculated from *Metropolitan Transportation Commission 1454 Travel Analysis Zone* model output VMT. Interregional travel and air travel are excluded. (1 mile = 1.61 kilometers)

A better analysis would calculate credits at the TAZ level. For example, the TAZ representing Berkeley’s city center showed an average emissions rate of 1.1 ton per household. Such a finer grain analysis thus reveals that each additional household added specifically to that TAZ in 2006 should earn the city a credit of 6.1 tons – 1.1 tons = 5.0 tons.

6. VEHICLE LIFE CYCLE ADJUSTMENTS

All of the inventory methods discussed thus far, including the geographic model, the trip-end based model, and land use credits, tally only vehicle tailpipe emissions. However, other emissions induced by vehicle manufacture and operation comprise a significant fraction of total vehicle life cycle emissions (Figure 4.5.1). Including vehicle life cycle emissions in an inventory provides a more complete measure of the impact of the city’s transportation sector, and thus helps the city to better weigh potential emissions reduction strategies rationally.

FIGURE 3 Vehicle life cycle emissions for cars, SUVs, Pickups, and Buses.

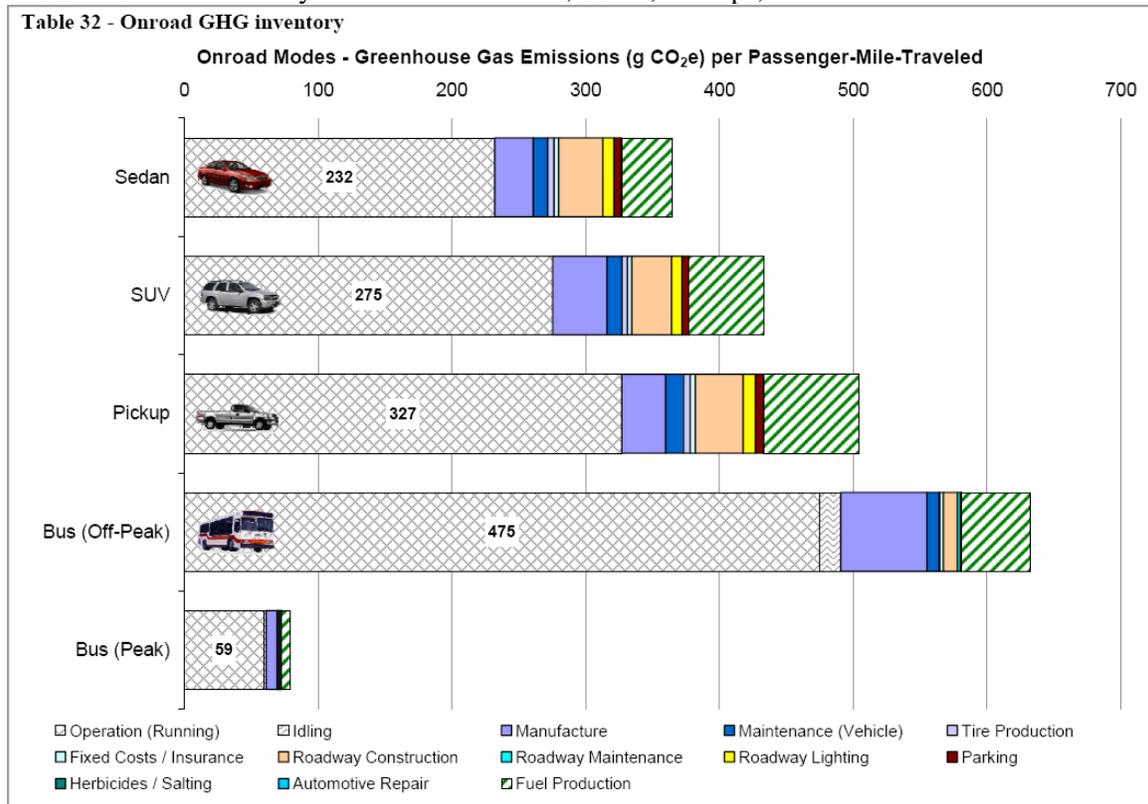


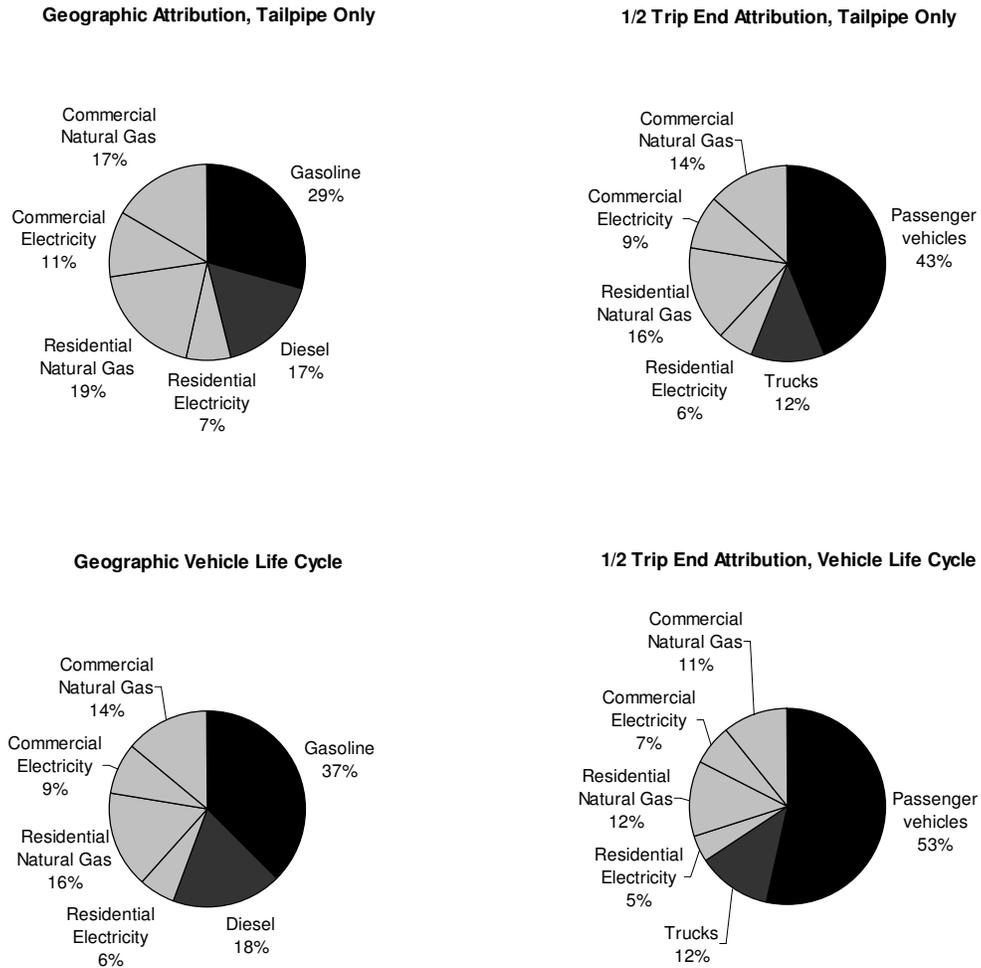
Figure taken from Chester, Mikhail and Arpad Horvath, *Environmental Life-cycle Assessment of Passenger Transportation: A Detailed Methodology for Energy, Greenhouse Gas and Criteria Pollutant Inventories of Automobiles, Buses, Light Rail, Heavy Rail and Air v.2*, Working Paper, UCB-ITS-VWP-2008-2, 2008.

Of course, life cycle emissions might be attributed elsewhere. For example, emissions from petroleum refining to make vehicle fuel could be attributed to the refineries rather than downstream users. Alternately, the emissions attribution could be divided between “upstream” manufacturers and “downstream” users (see Simone Bastianoni, Federico Maria Pulselli and Enzo Tiezzi, *The Problem of Assigning Responsibility for Greenhouse Gas Emissions*, 2004). However, in many cases upstream sources have limited potential to reduce emissions. Cities, meanwhile, have substantial potential to affect changes in mode share and VMT. Therefore, attributing life cycle vehicle emissions at the city level will likely affect the most effective policy response.

Precise calculation of embedded and induced emissions is typically dauntingly complex, so these emissions are often grossly misrepresented as being zero for policy purposes, though even a rough estimate of these emissions would much better inform policymaking. In order to make such an estimate feasible, all vehicle life cycle emissions could be assumed to occur in proportion to tailpipe emissions. Life cycle emissions can then be included by using simple multipliers supplied in *Chester and Horvath, 2008*.

Figure 6.1 compares sector emissions shares for the city of Berkeley calculated from geographic and from ½ trip end attributions, and from tailpipe only and from full vehicle life cycle emissions. For Berkeley, considering trip end and vehicle life cycle emissions grows transportation’s share of emissions from 47 percent of the city’s total to 65 percent. This demonstrates that the inventory presently used significantly under-represents the transportation emissions over which the city has influence, leading the city’s emissions reduction policy to deemphasize transportation measures.

FIGURE 4 Comparison of inventoried sector shares under four transportation attribution methodologies.



7. DATA AVAILABILITY AND METHODOLOGY CONSTRAINTS

Household mileage data can be obtained, by vehicle, from smog check records. However, vehicle transfer between owners, changes of owner address, and low reporting frequency render these data problematic for use in an inventory. Further, smog check data sheds no light on trip attraction VMT. Fueling station sales data are available, but cannot discern whether drivers who fueled their vehicles are city residents, workers, visitors, or entered the city solely to access the fueling station.

The application of the methodology presented in this paper to the City of Berkeley uses VMT outputs from the traffic model of the San Francisco Bay Area's Metropolitan Planning Organization (MPO), the Metropolitan Transportation Commission (MTC). In counties with Congestion Management Authorities (CMAs), outputs from those models could be used instead.

As stated above, this methodology relies upon the assumption that new residents in a TAZ will exhibit travel behavior similar to existing residents there. In some cases, however, new development is of a very different character than the existing development within a TAZ. For example, residents of new Transit Oriented Development along a suburban rail line tend to drive

less than their established neighbors. Here, the assumption that new resident will exhibit travel behavior similar to existing residents does not hold. In such a case, modeling tools (such as URBEMIS) should be used to calibrate the new project's expected emissions, and the location credit should be determined from this "post processed" emissions value.

8. CONCLUSION

City actions to reduce greenhouse gas emissions are not just stopgap measures to tide us over as we wait for climate action policy to be formed at higher levels of government. Because of their unique control of key policy levers, especially land use, cities must play a fundamental role in emissions reduction.

Different methodologies used to inventory cities' transportation emissions report significantly different results, and can guide, or significantly misguide, emissions reduction policy. Because the choice of inventory method will have such a large bearing on the set of strategies chosen in building a city's climate action plan, care should be taken to ensure that the inventory accurately depicts the emissions over which the city has influence. The methods presented in this paper can be used to produce inventories that guide regionally-rationalized city action.

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