



THE CARBON FOOTPRINT OF RIDE-HAILING: GHG INVENTORY METHODOLOGY

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Abstract

Community greenhouse gas inventories regularly include GHG emissions from local transportation activities, but emissions associated specifically with ride-hailing have not previously been quantified and reported separately. This report reviews the emerging evidence that ride-hailing is quantitatively significant as an emissions source in major urban areas, that it differs from the use of the automobile generally, and that it has impacts on other transportation modes. In sum, these factors suggest that ride-hailing warrants consideration as a distinct transportation mode and emissions source. The report then builds on existing protocols and methods to detail three separate approaches to quantifying GHG emissions from ride-hailing. The approaches depend to varying degrees on data that may or may not be available in a specific community. The closing discussion suggests policy and methodology directions to improve the future insight into the carbon footprint of this emerging mode.

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Introduction

Ride-hailing services such as Lyft and Uber have emerged rapidly as important parts of a fast-changing, technology-enabled urban mobility ecosystem. These services have appeared at a time when our interest in limiting human-caused climate change is at an all-time high, and transportation is well understood as a major emitter of greenhouse gases. So how can jurisdictions that measure their respective carbon footprints quantify the role of ride-hailing in their local emissions?

This research has two parallel goals:

- Establish a hierarchy of methodologies for quantifying these impacts, identifying the likely data sources and gaps for those methodologies
- Assemble guidance, following the structure of a carbon accounting protocol, for local municipalities to include ride-hailing in their GHG inventories.

The research builds on the mosaic of methods, data sources, and disclosure rules – current, in development, or under consideration.

This research has two general sets of outputs, following the project's goals:

- Methodological and theoretical discussion of the quantification issues at hand, as well as an examination of the current practices, policy discourse, and privacy rules surrounding the data in question. We are unlikely to make progress in understanding and contextualizing ride-hailing's role in transportation GHG emissions without a clear view of the surrounding data landscape.
- Clear and simple guidance for practitioners currently engaged in producing, presenting, and using greenhouse gas inventories for public policy and public education. Our aim is to insert ride-hailing into this context appropriately and rigorously.

Our hope is that practitioners working in and on behalf of local jurisdictions will begin to include ride-hailing as a category or sub-category of emissions when conducting greenhouse gas inventories. As the literature review below demonstrates, there is theoretical and empirical rationale to do so, as well as activity by ride-hailing firms and governments to wrestle with this emerging emissions source and its consequences. Calling out these emissions with clear quantification is a step in improving our understanding of the fast-changing landscape of urban mobility and the climate action opportunities therein.

Literature Review

Ride-hailing is still new – Uber and Lyft were founded in 2009 and 2012, respectively – so research on its effects is still nascent. Yet with rides in the billions and drivers in the millions (Zaveri 2018, Bhuiyan 2018), there is no question of the breadth of ride-hailing's impact on urban mobility, and therefore its potential climate impact.

Despite the transportation mode's newness, there has been substantial progress toward understanding the impact of ride-hailing on local transportation systems. Specifically, this early literature addresses key metrics that impact the total carbon footprint of local transportation, namely the direct effects of vehicles, the effects of ride-hailing on traffic congestion and total trip

volumes, and implications for the distribution of rides across transportation modes, i.e., potential changes in modal split. Each deserves consideration here.

First, there is some attention to the direct greenhouse gas emissions from vehicles providing ride-hailing services. This is the focus of a state law in California, SB 1014, that will eventually require average GHG intensity disclosure by ride-hailing firms (CARB 2019a, 2019b). This emerging framework is wrestling with thorny issues such as “deadhead” miles, i.e., miles driven as drivers search for riders or miles driven en route to customers. Ultimately, the California effort seeks to regulate this energy or carbon intensity.

It appears that the ride-hailing duopolists, Uber and Lyft, have clearly recognized the direct greenhouse gas implications of their services as they have jockeyed for position with a wide variety of measures to address their emissions consequences. Lyft has introduced a “Green Mode” with rides in electric vehicles (EVs), and it has begun to rent electric vehicles to its drivers in some markets (Bussewitz 2019, Ohnsman 2019). Uber launched a similar program for EVs (Edelstein 2018), explicitly acknowledging how climate concerns relate both to the direct emissions consequences of the vehicles and the relationship to other modes (Hawkins 2018). And Lyft has gone so far as to claim “carbon neutrality” for its rides, with the purchasing of carbon credits to offset the emissions associated with their rides (Meyer 2018). California’s 2018 baseline adds urgency to these efforts, as average emissions from vehicles driving for Lyft and Uber are estimated to be fifty percent greater than the California fleet average (CARB 2019c). Additional modeling by the Union of Concerned Scientists is consistent with California findings of added VMT from ride-hailing, while also demonstrating that electrification could substantially lower the greenhouse gas emissions from the same trips (Pinto de Moura et al. 2020).

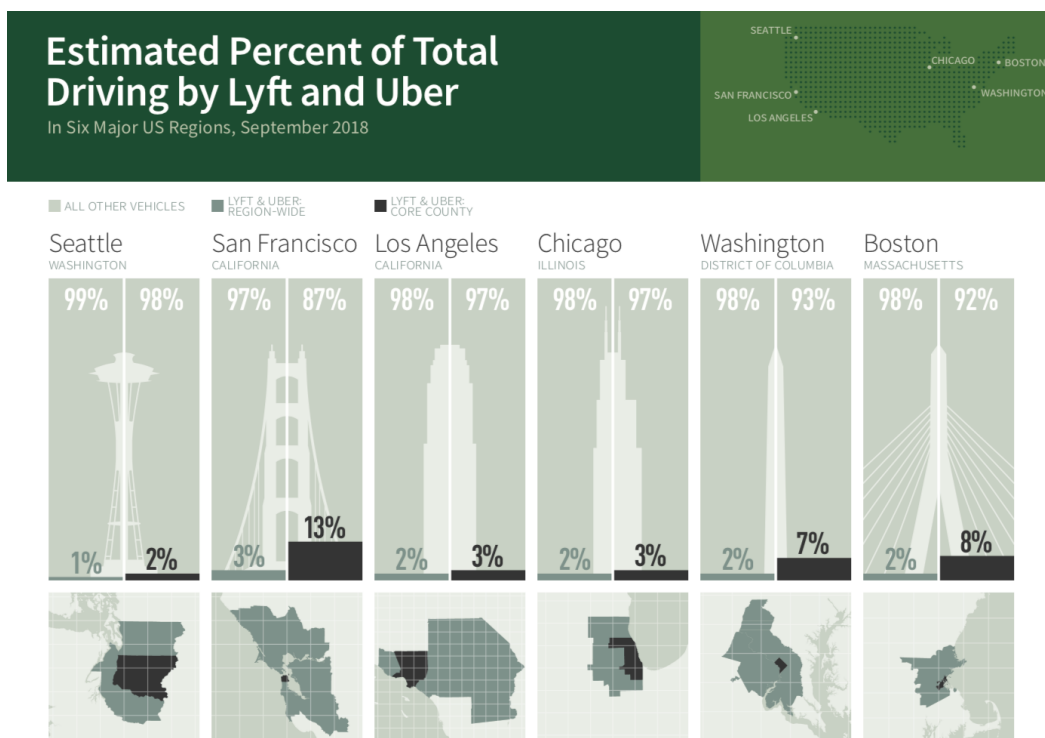
The emergence of vehicle automation adds complexity to this picture. Vaidyanathan (2019) speculates that energy use (and greenhouse gas emissions) could rise or fall, with the open questions stemming from diverse policy paths and the use of other modes. Arbib and Seba (2017) have provocatively suggested a potentially rapid transition to electric autonomous vehicles (AVs) provided by ride-hailing platforms, with an associated massive decrease in total greenhouse gas emissions. The analysis, however, does not model congestion, despite the prediction of a fifty percent increase in passenger-miles.

Second, there is a now a large and growing body of evidence suggesting ride-hailing is adding vehicle-miles traveled (VMT) to U.S. roads. Schaller (2018) finds a considerable shift toward ride-hailing as a mode in New York City, and SFTA (2017, 2018) finds the same phenomenon in San Francisco. Studying Austin, Wenzel et al. (2019) find considerable additional miles from deadheading and between-fare travel, estimating total energy consumption to be 41-90% higher than in the pre-ride-hailing baseline of personal travel. In the most extensive modeling to date, Erhardt et al. (2019), also studying San Francisco, establish a detailed comparison between current conditions and a counterfactual without ride-hailing. While congestion would have increased by over 20% in the 2010-2016 period without ride-hailing, congestion has in fact risen by over 60% in the presence of rapid adoption of ride-hailing. Others estimate that—in Denver, and accounting for dead-heading and modal shift, which we discuss in later sections—ride-hailing adds 83.5% more VMT than would have been driven absent ride-hailing (Henao and Marshall 2019).

Transportation modeling is also starting to acknowledge the importance of ride-hailing as a distinct mode and emissions source. Oregon Department of Transportation’s Regional Strategic Planning Model has evolved to incorporate ride-hailing deployment level within the City and the average age of the ride-hailing service fleet (ODOT 2020).

Disentangling ride-hailing's impacts from other sources of congestion is challenging. Chase (2018) sounds a note of caution that some trends, such as a steady increase in many metropolitan areas' traffic congestion and a gradual decline in transit ridership, precede ride-hailing's emergence, so ride-hailing cannot be blamed for the full magnitude of changes. Nonetheless, in a large longitudinal study, Graehler et al. (2018)—while finding potential support for transit service cuts and low gasoline prices as contributing factors to lackluster transit ridership—identify ride-hailing as a source of gradual decline in transit usage, suggesting concomitant increases in VMT.

Ride-hailing may conspicuously add millions of vehicle-miles (with inevitable associated GHG emissions), but observers have questioned whether the share of total vehicle-miles is significant relative to total miles driven across all types of vehicles. In a study commissioned by Lyft and Uber and using data supplied by the companies, Fehr & Peers (2019) finds that—across Boston, Chicago, Los Angeles, San Francisco, Seattle, and Washington, D.C.—ride-hailing VMT comprised less than 3 percent of regional VMT and between 2 and 13 percent of core county VMT. Combined with previously cited work on congestion, these findings suggest that while ride-hailing does contribute to VMT, its effects on congestion are relatively concentrated in urban cores and only part of a broader trend of gradually rising VMT nationally (BTS).



Source: Fehr & Peers (2019)

Third, and by definition, new modes cause both modal shift—i.e., people change modes thus altering the overall modal composition of trips—as well as potentially changing the total number of trips. Research suggests that ride-hail travelers would have taken a variety of modes, or not traveled at all, absent ride-hailing. Most commonly, ride-hail users report that they would have taken transit (15-42%) for their most recent ride-hail trips (Clewlow and Mishra, 2017; Henao and Marshall 2019; Gehrke et al. 2018). Notably, however, others (3-16%) report using ride-hailing to *connect* to transit (Feigon and Murphy 2017), and transit agencies around the country are piloting ride-hail partnerships to increase travelers' access to transit stations (FTA, Schwieterman et al.

2018, Shurna and Schwieterman 2020). In addition to transit, ride-hail riders report that they would have driven their own car (18-39%), biked or walked (12-23%), hailed a taxi (10-22%) or not made a trip at all (5-22%) (Clewlow and Mishra, 2017; Gehrke et al. 2018; Henao and Marshall 2019). Hall et al. (2018) find that ride-hailing is on average a complement to transit, but with considerable heterogeneity of outcomes. The net effects of these modal shifts on either total trips or VMT remains uncertain. Additional research is also needed to understand the longer-term effects of ride-hailing such as potential effects on car ownership. For example, sampled ride-hailing users report decreased household car ownership and single occupancy vehicle trips, though with uncertain net effects on VMT (Clewlow and Mishra, 2017; Feigon and Murphy, 2017). Of greatest relevance to the work here, the aforementioned modeling by Pinto de Moura et al. (2020) further confirms the substantial greenhouse gas emissions reduction potential of shared ride-hailing and of combining ride-hailing with lower-carbon modes such as transit, car-pooling, and micromobility.

The relationships among these various shared-use modes are by definition new and surely still evolving, and ultimately the net effects of ride-hailing in a particular place may depend a great deal on the menu of modes available. Early research by the Shared Use Mobility Center (SUMC 2016) has suggested the possibility of modal shift as a result of ride-hailing usage. In seven large metropolitan areas, so-called “supersharers” using a variety of shared-use modes were more likely than others. For example, with data from a major Chinese metropolitan area, Qin et al. (2019) show how the introduction of a bike-sharing system, with first-mile/last-mile access to transit, raised transit ridership and reduced the use of ride-hailing.

Finally, our analysis does not include, but could potentially be extended to, delivery services that represent an increasing share of many metropolitan areas’ VMT. These include delivery by national online or mixed online/brick-and-mortar retailers such as Amazon and Walmart, and food delivery services such as Grubhub, UberEats, and DoorDash. There is preliminary analysis and evidence suggesting disproportionate congestion effects from increased urban freight volumes (Butrina 2018), as well as projections of “significantly faster growth in freight shipments and truck VMT” (Federal Highway Administration 2019). Such factors lie beyond this current work.

Going from the literature to practitioner work: inventories vs. action

Ultimately, the practitioner realm pursues better and better greenhouse gas inventories in order to inform priorities for action. In other words, our concern here is with protocols and norms for quantifying and reporting greenhouse gas emissions, but not for the sake of analysis. Rather, the goal is better informed climate action planning.

This distinction – between greenhouse gas inventories and climate action planning – poses challenges in this particular setting because new transportation modes both (a) require quantification and (b) pose opportunities and challenges for efforts to reduce emissions. The focus in this current work is clearly on the first point, providing a foundation for action. That said, ride-hailing is interesting because it fits in both challenges us to do better greenhouse gas inventories and increasingly demands inclusion in climate action planning.

The next section begins to build toward a method for including ride-hailing impacts in greenhouse gas inventories by laying out the common protocols that compose the context for existing inventories and therefore any addition to an inventory.

Greenhouse Gas Inventories: Overview

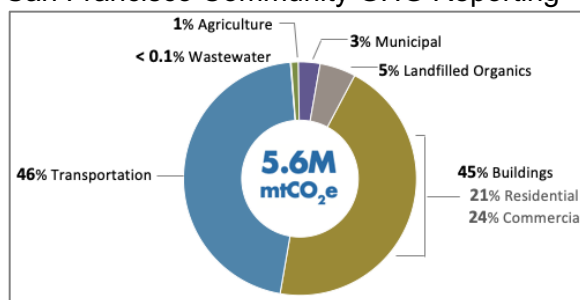
Communities around the globe regularly conduct community-scale greenhouse gas (GHG) inventories by following internationally recognized, voluntary greenhouse gas protocol and annually report results to various bodies, such as CDP Cities Survey¹ or for compliance purposes to the Compact of Mayors.² Inventories are used to better understand sources of community emissions for climate action planning activities and to track progress toward related community climate goals over time. The boundaries of a community GHG inventory include the transportation sector over a wide geographic boundary and range of transportation modes, including ride-hailing services.

The impetus for including individual emissions sources is straightforward: we measure them in order to manage them. Given the newness of ride-hailing, it is unsurprising that it has not yet appeared in protocols. But given the findings discussed in the literature review – it is likely time for communities with high rates of service to consider including ride-hailing as a distinct emissions source.

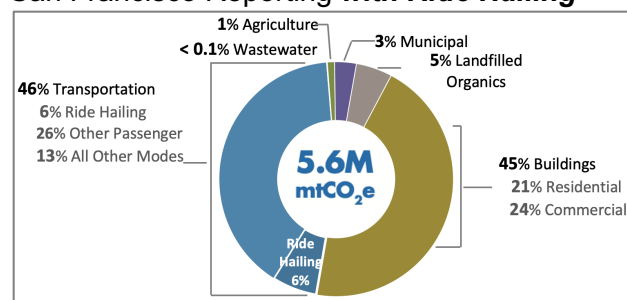
A single reporting example quickly demonstrates the basic motivation behind this effort to include ride-hailing services as a distinct source of emissions in community protocol. In the side-by-side pie charts below, we have juxtaposed the results of San Francisco's most recent community inventory with estimated emissions from ride-hailing vehicle-miles, based on research commissioned by Lyft and Uber. The left-hand graph is what appears in the City of San Francisco's 2018 community GHG inventory summary. San Francisco's community GHG emissions in 2018 total 5.6 million metric tons of carbon dioxide equivalent (MT CO₂e), by emissions sector.

The right-hand graph uses San Francisco inventory results but displays a separate carve-out for ride-hailing emissions. This carve out uses publicly available, self-reported ride-hailing company data and related analysis by Fehr & Peers.

San Francisco Community GHG Reporting



San Francisco Reporting *with Ride Hailing*



Sources: San Francisco Department of Environment (2018)³; Fehr & Peers (2019)⁴

¹ CDP, Cities Survey, <https://www.cdp.net/en/guidance/guidance-for-cities>

² Compact of Mayors, C40 Cities, <https://www.c40.org/researches/compact-of-mayors>.

³ San Francisco Department of Environment, Climate Change (2018). 2016 San Francisco Geographic Greenhouse Gas Emissions Inventory (2018). Downloaded 02/2020 at https://sfenvironment.org/sites/default/files/fliers/files/sfe_cc_2016_community_inventory_report_2.pdf.

⁴ Fehr & Peers (2019). Estimated TNC Share of VMT in Six US Metropolitan Regions/ Downloaded 2/2020 at <https://www.fehrandpeers.com/what-are-tncs-share-of-vmt/>.

At first blush, the graphs seem identical. Yet upon close examination, disaggregating ride-hailing shows it to be quite a substantial category. The self-evident point here is that ride-hailing emissions can, and in certain circumstances already do, represent a category that warrants separate quantification. While San Francisco clearly provides the extreme example, it is the direction in which other communities may be moving. Furthermore, even where GHG emissions related to ride-hailing might be on the order of 3-5%, that magnitude may still be larger than some standard categories that are routinely included according to protocol. In short, ride-hailing emissions may be worth calling out separately in order to draw attention to their relative and absolute scale.

With that motivation in hand, we proceed to consider the protocols into which one would insert a consideration of ride-hailing emissions.

Standard GHG Inventory Methodology as Starting Point: the GPC and USCP

There are two commonly used GHG reporting protocols for community-scale inventories:

- Global Protocol for Community-Scale Inventories (GPC). <https://ghgprotocol.org/greenhouse-gas-protocol-accounting-reporting-standard-cities>
- U.S. Community Protocol (USCP). <http://icleiusa.org/publications/us-community-protocol/>

Conceptually, these protocols are very similar. Both include the transportation sector, and specifically on-road passenger transportation, and both provide similar conceptual guidance. The GPC is more recent and is the recommended protocol for reporting to the Climate Compact of Mayors. The USCP provides a complement to GPC and offers more detailed accounting guidance than is available in GPC, including alternative estimation methods when the ideal data is not readily available.

The following figure provides a summary of the transportation emissions sources that are required reporting in the GPC.

Figure 1: Transportation Emissions Sources Required by Protocol

GHG Emission Source	Scope 1	Scope 2	Scope 3
TRANSPORTATION	Emissions from fuel combustion for transportation occurring in the city	Emissions from consumption of grid-supplied energy for in-boundary transportation	Emissions from portion of transboundary journeys occurring outside the city, and transmission and distribution losses from grid-supplied energy
On-road transportation	II.1.1	II.1.2	II.1.3
Railways	II.2.1	II.2.2	II.2.3
Water transport	II.3.1	II.3.2	II.3.3
Aviation	II.4.1	II.4.2	II.4.3
Off-road transportation	II.5.1	II.5.2	

■ Sources required for BASIC reporting
 + ■ Sources required for BASIC+ reporting
 ■ Sources included in Other Scope 3

Source: Table 1, Transportation Overview, from Global Protocol for Community Scale Inventories (GPC), GHG Protocol / World Resources Institute.

Within these protocols, ride-hailing services are implicitly a subset of the on-road transportation source, but to this point, no guidance is provided by WRI's Greenhouse Gas Protocol (the entity that developed and maintains the Global Protocol for Community-Scale GHG Inventories) or other protocol development organizations to disaggregate ride-hailing from the on-road-transportation sector total. That said, the same methodological approaches already outlined in existing community protocol may be modified to focus on GHGs from ride hailing services.

The next sections of this document introduce the methodologies required by existing community protocols, leading into our team's proposed guidance related to ride-hailing GHG accounting.

This report is intended as a first attempt to provide community GHG practitioners with a simple, high-level screening method to assess whether ride-hailing is a significant source of on-road transportation emissions based on community-level information. And for those communities where ride-hailing likely represents a significant fraction of GHG emissions, we provide data collection and calculation guidance for three distinct methodologies based on availability of ride-hailing company data. We hope that our framework will allow practitioners to add ride-hailing to the list of emissions sources in community inventories.

Overview of On-Road Transportation GHG Methodology

There are two commonly used methods for calculating community-scale transportation emissions – referenced in the protocols:

- **Top-down fuel sales data** within a geographic boundary as a proxy for travel behavior within the community. This method multiplies fuel data (e.g. gallons) by fuel specific emissions factors to calculate emissions.
- **Bottom-up** which uses detailed data on trips, distance, mode, fuel economy and fuel type to calculate or model transportation emissions. The following figure, also from GPC, shows the Activity-Share-Intensity-Fuel (ASIF) calculation framework used to calculate bottom-up emissions. See Figure 3 for a summary of the ASIF method. There are a variety of data sources that may provide values for the ASIF calculation.

Figure 2 provides a comparison of the top-down versus bottom-up methods.

Figure 2: Comparison of top-down and bottom-up calculation methods

Methodology	Advantages	Disadvantages
Fuel sales	• More consistent with national inventory practices • Well suited to aggregation with other city's transportation inventories if all fuel sold in boundary is classified as scope 1. • Less costly • Less time-consuming to conduct • Do not require high level of technical capacity	• Does not capture all on-road travel, as vehicles may be fueled at locations outside the city boundary but driven within the city • Does not disaggregate the reasons for travel emissions, e.g., origin, destination, vehicle efficiency changes, modal shift, etc. • Does not comprehensively demonstrate mitigation potential • Does not allow for allocating emissions by scope (unless additional steps are taken)
VKT and model-based (induced activity, territorial, resident activity)	• Can produce detailed and more actionable data for transportation planning • Integrates better with existing city transport models and planning processes	• More expensive, time consuming, and less comparable between cities due to variation in models used

Source: Table 7.3, Comparing top-down and bottom-up methodologies for on-road transportation, Global Protocol for Community Scale Inventories (GCP), GHG Protocol / World Resources Institute.

The process that California Air Resources Board (2019b, 2019c) is pursuing involves a bottom-up calculation, involving primary data from the ride-hailing firms.

The methods outlined by protocol can be applied to a variety of geographic boundaries depending on local context. Many times, the method and geographic boundary are selected based on what data is available to support each individual method. The GPC and USCP are not overly prescriptive about what geographic boundary is used, and both acknowledge the challenges inherent in tracking an emissions source whose activities cross local jurisdictional boundaries. There will continue to be legitimate methodological questions about the share of transboundary emissions to allocate to the inventory community versus to neighboring communities.

Allocation of fuel or energy data is relatively straightforward, i.e., include emissions from all fuel or other transportation energy sold within the geographic boundary. In the Top-Down method there likely will not be any additional data from which to allocate fuel combusted within the jurisdiction boundary versus fuels purchased inside the boundary and therefore the most straightforward accounting approach is to account for 100%.

There are four trip types that are commonly considered in on-road passenger transportation:

- In-boundary trips that originate and terminate in the jurisdiction
- Trans-boundary trips that originate in the jurisdiction and terminate outside of it
- Trans-boundary that originate outside the jurisdiction and terminate in it
- Out-of-boundary trips that pass through the jurisdiction, with both origin and destination outside the jurisdiction

If a bottom-up methodology is used, protocols provide guidance on how to allocate respective shares of these trip types to a community's inventory.⁵ We provide guidance below on calculations that draw on this total vehicle miles traveled (VMT) quantity.

In addition to the VMT activity data, bottom-up calculations include a measure of vehicle energy efficiency (Intensity) and the emissions factor for local fuels used for on-road transportation (Fuels). There are two approaches to these parts of the ASIF formula.

On-Road Emissions Factor

An on-road emissions factor (or rate per VMT) may be calculated using EPA's MOVES (or a similar model). MOVES estimates an average emissions rate for a defined geographic boundary taking into account fleet composition, age, fuel economy, fuel types, road types, speeds, and ambient temperature data for a specific time period. The model may be used to generate an average annual emissions rate (kg CO₂e / VMT) or to inventory transportation emissions (MT CO₂e) using activity data (community VMT) and the other data described. The outputs from modeling may be used to calculate on-road emission by multiplying community VMT by the MOVES estimated emissions rate or the user may take the additional step to use MOVES to inventory community emissions by inputting additional community VMT data.

Average Fuel Economy and Fuel Type

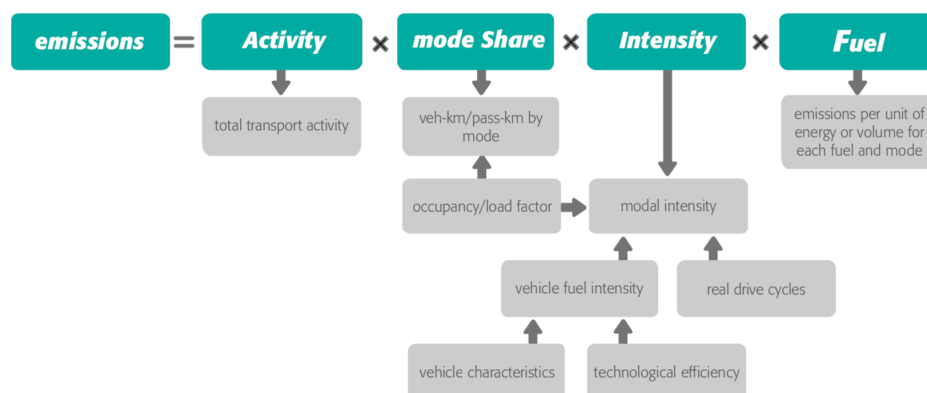
An average fuel economy may be used instead of an on-road factor but does not appropriately account for speed and congestion when estimating fuel use from VMT. Average fuel economy can be found in the following sources:

- Bureau of Transportation Statistics – <https://www.bts.gov/browse-statistical-products-and-data>
- Energy Information Administration's Annual Energy Outlook – <https://www.eia.gov/outlooks/aeo/>
- (for certain states) Census block-level average fuel economy, based on state vehicle registration data – for Oregon, <https://www.oregon.gov/ODOT/Data/Pages/Passenger-Vehicle-Fuel-Economy.aspx>

Of the available methods, ride-hailing companies likely have greater access to data to support bottom-up calculations given existing examples of publicly available data.

⁵ Constructing a total VMT quantity in the bottom-up method is necessarily a mixture of methodology and opportunism. Methodologically, when data for all four trip types is available, one can follow the GCP guidance: include all trips that both begin and end in the geography; allocate 50% of all trips that either begin or end; and ignore all pass-through trips. We recommend this method path. However, practitioners may be forced to choose a simplified method of total VMT, depending on data availability.

Figure 3: Diagram of Activity-Share-Intensity-Fuel (ASIF) Framework



Source: Figure 7.1, ASIF Framework, Global Protocol for Community Scale Inventories (GCP), GHG Protocol and World Resources Institute.

Methodology in practice: two Oregon communities, and beyond

It is impossible to overstate the importance of practical barriers of data availability in conducting local greenhouse gas inventories. What is possible in different locations? What are the data options of communities in different circumstances? To highlight different circumstances, we consider two communities that have conducted community carbon footprints: Eugene, Oregon (the largest city in a small metropolitan area) and Milwaukie, Oregon (an inner suburb in a larger metropolitan area) in assessing the viability of this methodology.

From the methods summarized in Figure 2 – the two most common in Oregon are the (1) Fuel Sales Approach and (2) Induced Activity Method using regionally modeled VMT and either an On-Road Factor calculated with EPA’s MOVES model or an U.S. or local average fleet fuel economy.

The fuel sales approach is available for the large subset of Oregon cities that have local fuel taxes. For these communities, the State of Oregon publicly reports fuel cost and volume data on a monthly basis for all sales within jurisdictional boundaries. This data source provides a low-cost means of calculating transportation emissions. The downside of this approach is that it does not provide detailed information about trip origins and destinations to support detailed climate action planning that address specific routes and trip types.

Most residents are in cities or counties that are part of a Metropolitan Planning Organization (MPO); in Oregon, MPOs typically provide member communities with vehicle miles traveled (VMT) data from a regional planning model. Regional models are often able to provide VMT for multiple geographic boundaries by trip type *related to those boundaries*. For example, Portland Metro is able to provide member communities with the quantity of VMT that happens only within the community’s geographic boundaries, i.e., community and community-induced travel that starts in, ends in, or goes through the geographic boundary. (Aggregating the sum of these trip types’ VMT constitutes the *geographic* or *territorial* method specified in protocol.) Oregon communities that conduct community GHG inventories that have access to and benefit from MPO transportation modeling include the City of Portland, the City of Beaverton, Multnomah County, and Clackamas County.

There are also many small to mid-sized communities in Oregon that do not have either of these options available and therefore choose one of the remaining alternatives. They can contract for

transportation activity modeling services; use State-level data to estimate emissions (i.e. total and state highway VMT with average fuel economy for census tracts); or use a big data service provider that use geospatial navigation data as a means to estimate on-road VMT activity data. Communities in Oregon that fit this circumstance include Corvallis, Bend, and Ashland.

This modeling capability and the corresponding data depend largely on scale in Oregon, but that reality may or may not be transferable to other states. Not all states and not all large and medium-sized metropolitan areas have detailed transportation modeling. Only a small subset of state departments of transportation, much less MPOs, have their own models with the capacity to spin off city- or county-level data for use in GHG inventories. Therefore, data gaps due to a lack of consistent availability of modeling must be filled before GHG estimates derived using the methods described herein can become commonplace.

Ride-Hailing GHG Methodologies: Hierarchy, Guidance, and Rationale

This section proposes a hierarchy of methodologies, with accompanying data needs, for quantifying the impact of ride-hailing in a municipality's or metropolitan area's carbon footprint.

A higher place on the hierarchy denotes preference, for precision and usefulness, and generally requires data that are more onerous to gather, and in our current circumstances, less likely to be available. In addition to an axis of precision and availability, we propose another axis related to the spatial and conceptual extent of the boundaries. Setting appropriate and meaningful boundaries is a common fundamental challenge in many carbon accountings tasks.

Using the accounting framework detailed in the GPC – the following data could be collected to calculate emissions using the top-down or bottom-up methodologies.

Caveat on Availability of New Mobility Data (including Ride-Hailing)

This work takes place in a broader environment characterized by a battle over data disclosure for a variety of new mobility businesses, including but not limited to ride-hailing. Our interpretation of the current landscape is as follows. In general, ride-hailing firms rarely disclose trip-level or aggregate travel data. In fact, there has been strong pushback against disclosure attempts and requirements in a variety of locations, from attempts at pre-empting local legislation by lobbying in state legislatures to filing lawsuits against local disclosure rules (Nelson 2020). Even the previously cited research by Fehr and Peers (2019) was possible only because Uber and Lyft commissioned the study and provided the data. Finally, there is some encouraging heterogeneity of disclosure, and that too warrants review.

As of this writing (April 2020), it is highly unlikely that a ride-hailing company will respond to a data request from an individual municipal or county government unless there exist regulations that codify operational reporting requirements. Ride-hailing companies have successfully defended against a public records request from the Portland newspaper, The Oregonian (Njus 2016a, 2016b, 2016c). Similarly, staff from the City of Beaverton, Oregon (part of the Portland metro area) submitted a request to Lyft on behalf of this project and did not receive any response, despite multiple follow-ups.

There are several points of light in this darkness.

Cities may find an opportunity in disclosure requests that conform to emerging data reporting standards, as this will both likely ease their ability to get data (they can point to other cities that have successfully implemented disclosure requirements) and also allow comparisons across urban areas. The City of Los Angeles, for example, has created a Mobility Data Specification (MDS) aimed at creating a data standard for new mobility, including micromobility options such as e-scooters and shared bikes: <https://github.com/CityOfLosAngeles/mobility-data-specification>. Los Angeles has successfully defended a legal challenge from Uber against the City's MDS, albeit only over Uber's shared bikes and e-scooters for now (Nelson 2020).

The City of Chicago currently has the most the comprehensive disclosure requirements and the most public disclosure of the resulting ride-hail data through its Open Data Portal.⁶ The City requires trip-level reporting of all trips to, from, and within the City of Chicago, with twenty-one required variables describing trip geography, trip timing, fares and tips, and the authorization of a shared ride.⁷

Finally, California's Clean Miles Standard (CMS) will provide reference points of direct usefulness in the state and potential relevance beyond (California Air Resources Board 2019b, 2019c). The CMS outputs will, in effect, provide general-purpose emissions factors for ride-hailing everywhere, and potentially these emissions factors could act as a "safe harbor" assumption while other local and state values are not available.

The authors of this work acknowledge current difficulties in requesting data from private ride hailing companies, as well as the considerable limitations on municipal governments as a result of non-disclosure agreements between the private companies and local governments. It is notable and discouraging that the only encouraging examples herein involve large cities with unusual technical capacity, financial resources, political will, and market power. That said, the following section outlines data options available to include ride-hailing in inventories, as well as guidance for future efforts towards policies and systems for data disclosure.

Hierarchy, Guidance, and Rationale for Three Methods

The table below provides a summary description of the various levels of the hierarchy, each of which we discuss in detail in this section. The method selected should be consistent with the data and calculation methodology used in the community inventory to calculate other sources of on-road passenger vehicle emissions.

Method 1 is consistent with best practice as articulated in protocol: bottom-up calculations with high-quality primary data.

Method 2 essentially would move the calculations from municipal entities working on GHG inventories to the ride-hailing firms; in California, under a CARB-supervised process, Method 2 could potentially provide high-quality data, but such a regulatory mandate and accompanying process doesn't exist elsewhere yet.

⁶ City of Chicago Open Data Portal, data.cityofchicago.org.

⁷ Ibid. "Configure Visualization" page, <https://data.cityofchicago.org/d/m6dm-c72p/visualization>.

In the event that Method 2 is “chaperoned” by regulators and thereby made transparent, it could be equivalent to Method 1. In that sense, readers should not see Method 1 as necessarily inferior to Method 2. At least in California from 2021 onward, Method 2 could achieve the same outcomes as Method 1, especially where there are only a few large ride-hailing firms.

Method 3 extrapolates from recent research to estimate the ride-hailing share of local VMT and corresponding emissions. It will appear to practitioners as a bold departure from normally cautious GHG accounting methodology, but we believe we have made a well-reasoned case for this direction. We predict that Method 3 will be the method utilized by most users of this guidance given current data availability circumstances. We also hope that the method will give momentum to discussions of what data ride-hail firms should disclose in order to support community GHG inventory efforts.

Figure 4: Summary of Calculation Methods and Data Needs

Methods	Data Needs
METHOD 1: Fuel Purchases	Fuel purchases (\$) or volume (gallons) within geographic territory from ride-hailing companies Company reported electricity purchases in- geographic boundary
METHOD 2: Ride-Hailing Company Data	Company reported in-geographic boundary vehicle miles traveled (VMT), passenger miles traveled (PMT), and average fleet fuel economy Company reported electric vehicle registrations as percentage of total service fleet Company reported out-of-boundary vehicle miles traveled, passenger miles traveled, and average fleet fuel economy
METHOD 3: Extrapolate from Emerging System Parameter Averages	Local, regional, or state in-boundary VMT, PMT, average fleet fuel economy, and fuel types Local, regional, or state out-of-boundary VMT, PMT, average fleet fuel economy, and fuel types Local, regional, or state data on electric vehicles registrations as percentage of total passenger fleet

Methodologies in Detail

This section details three distinct methods, with various preference tiers by data quality and precision.

Method 1: Fuel Purchases

Primary data for fuel use has long been the preferred reporting unit for vehicle emissions calculations in greenhouse gas inventory protocols. Volumes (liters or gallons) of various fuel types are multiplied by readily available fuel-specific emissions factors to calculate emissions.

The benefit of this methodology is that it is straightforward and does not require any additional information about vehicle fuel economy, occupancy, and local congestion. The downside is that it does not provide the additional trip-level detail that may be available with vehicle and passenger-mile data.

For Method 1, collect fuel or energy volume (gallons, liters, or kWh), or fuel or energy cost data, within the community's geographic territory for a consecutive 12-month period:

- Annual vehicle fuel purchases (volumes or cost) within appropriate inventory geographic boundary (e.g., city or county limits), categorized by fuel type or blend
- Annual vehicle electricity consumption or purchases (kWh or cost) within appropriate inventory geographic boundary (e.g., city or county limits), categorized by electric utility or grid region

For those that have detailed analytical needs related to ride hailing, consider the Method 2.

Note: The authors acknowledge that, at this writing, it is highly unlikely that ride-hailing companies will centrally collect or have access to direct fuel use data at present. That said, GHG inventory protocols have long prioritized fuel data as the most accurate means for emissions accounting and therefore that approach is suggested here as the ideal data form for use in a community GHG inventory. It is possible fuel data may be available as part of programs such as Lyft's Fuel Reward Programs.

Furthermore, it is important to acknowledge the potential role of vehicles owned and operated by the ride-hailing firms. Lyft and Uber both have ambitions of owning fleets of autonomous vehicles, and Waymo already operates a fleet of 600 vehicles with the country's first "driverless" ride-hailing service (Waters 2020). At the point that such private fleets achieve a significant scale in a local transportation system, the emissions associated with their operation could be quantified with data from the ride-hailing firms. For that reason, it is important to include Method 1 as a potential eventuality.

Method 2: Vehicle Mileage and Fuel Economy Data

Ride-hailing companies are known to collect detailed trip-level vehicle mileage data and for a reluctance to share it publicly due to concerns related to intellectual property and proprietary business data. There are examples where trip data has been shared, but as of this writing the examples are limited to communities that have established detailed local data reporting requirements (e.g., Chicago) or when the companies have voluntarily shared information for company-sponsored research (e.g. the Fehr and Peers memo previously mentioned) or for non-sponsored research with limited data-sharing agreements (e.g., Brown 2019).

Data may be requested at various levels of detail, depending on desired inventory and related analytical goals. For example, some users of this guidance may be interested in streamlining data collection by simply requesting annual totals while others may have interest in detailed trip-level data for the community inventory as well as to provide information towards local or regional transportation planning. Detailed trip level data would allow for greater understanding of the geographic areas, times of day, times of year that ride-hailing services peak in order to better understand the reason for these trips and local effect on congestion.

For first time data collection it is often beneficial to ask for less as data systems are developed over time. It is common in GHG inventory data collection that an overly detailed data request can slow the data collection process. More detailed data often times becomes easier to collect over time as systems develop.

The following two sections outline two possible data request – simple and detailed. The simple data request is consistent with the minimum data required to calculate community GHG emissions under the GPE, while the detailed request would include additional information for transportation system and community climate action planning.

Method 2 uses the ASIF formula. Suggestions for the source of each variable are below for both the simple and detailed data sets:

Simple Company Data Request:

Activity (A):

- Total vehicle-miles traveled (VMT) for trips with an origin OR destination for appropriate geographic boundaries (city limits)
 - Total VMT for trips with an origin AND destination for appropriate geographic boundaries
 - Total number of trips with an origin OR destination for appropriate geographic boundaries
 - Total number of trips with an origin AND destination for appropriate geographic boundaries

Share (S):

- Total passenger-miles traveled for trips with an origin OR destination for appropriate geographic boundaries (city limits)
 - Total passenger-miles for trips with an origin AND destination for appropriate geographic boundaries

Intensity (I):

- Tier 1: On-road factor – This factor calculated using EPA’s MOVES model (or similar) takes into account vehicle fuel economy; speeds; and local congestion to calculate an average GHGs / VMT for the community for the specific time period.
- Tier 2: Average fuel economy of the Lyft vehicles for appropriate geographic boundaries, or calculated on-road factor as described in California’s emerging requirements (CARB 2019b)
 - Percentage of VMT served by a fully battery electric or hybrid electric vehicle

Fuel (F):

- It is unlikely the company will be able to provide data on various fuel types in use. As a proxy use local, regional, or State level data on community fuel sales by fuel type. If proxy data is unavailable assume the fuel type is E10 (10% ethanol blended with 90% gasoline).

Method 2 Example

Emissions = Activity (A) x Mode Share (S) x Intensity (I) x Fuel (F)

Emissions = Ride-Hailing VMT (A) x Occupancy Factor (S) x Miles per Gallon (I) x Passenger Vehicle Fuel Emissions Factor (F)

Ride-Hailing VMT: Company data described above provided by local ride-hailing service providers. See GPC or USPC for detailed method on allocation of community induced transboundary trips.

Occupancy / Load Factor: Simple company data described above as reported by local ride-hailing service providers. Calculated factor with company data:
Ride Hailing Occupancy/Load Factor = Total Vehicle Miles Traveled / Passenger Miles Traveled

Miles per Gallon: Simple company data described above by local ride-hailing service providers.

Fuel Emissions Factor: Local, regional, or State data on community fuel sales by fuel type. If proxy data is unavailable assume the U.S. average fuel type of E10 (10% ethanol blended with 90% gasoline).

Method 3: Extrapolate from Emerging System Parameter Averages

Method 3 will likely be the method utilized by most users of this guidance given current data availability circumstances. Method 3 is provided as a means to estimate the contribution of ride-hailing trips to total community's total vehicle miles traveled.

This method provides a simple, cost-effective means of estimating the ride-hailing share of local vehicles miles traveled and greenhouse gas emissions using commonly available transportation data, combined with publicly available ride-hailing sector statistics.

Method 3 uses the ASIF formula – suggestions for the source of each variable are below. Data sources are shown by accuracy tier. Data sources with greater accuracy are presented as a higher-level tier (e.g., Tier 1a has a greater accuracy than Tier 2b). (Users may download the accompanying Ride Hailing GHG Method 3 Excel-based calculator that supports this guidance along with the following to estimate ride-hailing VMT and fuel use.)

The section below represents, in our view, the most likely path for current inventories and an important advance over current practices. It provides a bridge between recent evidence on the prevalence of ride-hailing and existing transportation models that capture all on-road activity. We offer it as a substantive placeholder until some future world in which ride-hailing firms' voluntary and mandatory disclosures make possible a more rigorous assessment.

Activity (A):

Activity data for Method 3 utilizes data already collected for the on-road transportation source in the community inventory, specifically total vehicle miles traveled. A fraction of this activity

data is allocated to ride-hailing using population density and the table below, based on Fehr and Peers (2019).

Total In-Boundary Vehicle Miles Traveled (Geographic / Territorial)

- Tier 1: Local VMT (from MPO or “big data” service provider)
- Tier 2: State-reported VMT (downscaled by population)

Ride-Hailing VMT Allocation Estimation Method

- Tier 1: Use company-provided data
- Tier 2: County / City population density (people / square mile) and currently available public data.

Here we suggest estimating ride-hailing data with the following formula and tables. Please note that this methodology has a high level of uncertainty given the limited publicly available data. However, available literature indicates the use of ride-hailing service use is strongly related to metro area size and density. This method is recommended for communities with population densities between 2,500 and 18,000 persons per square mile. This method applies only to geographically defined VMT⁸ for core metropolitan areas (i.e., “core” city or county with greatest population and employment density). The relationship between population density and ride-hailing service is not well documented for smaller communities and communities with fewer than 2,500 people per square mile. This methodology should therefore be used with caution in such situations.

Figure 5: Lookup Table for Ride-Hailing Share of VMT, by Population Density

Population Density (people / square mile)	Ride Hailing % of Territorial VMT
18,000	11.7%
15,000	9.8%
12,500	8.3%
10,000	6.7%
7,500	5.2%
5,000	3.6%
4,000	3.0%
2,500	2.0%
1,000	1.1%

Calculated based on the correlation of community population density and ride-hailing’s share of local VMT, as presented in Fehr & Peers (2019).

Although this approach is somewhat simplistic, the Fehr & Peers research shows a high correlation between population density and ride-hailing prevalence for selected large U.S. cities. This table is provided to help community GHG inventory practitioners use those preliminary findings to generate a preliminary answer to the questions, “How big of a climate impact is ride-hailing in our community?” The method is not intended as a precise, long-term measurement, but

⁸ See the previous comment guiding practitioners toward the use of GPC guidance for VMT calculation.

rather a sense-of-scale proxy based on best available information for use until more accurate data is readily available.

There are clear limitations to this highly simplified method. It does not account for local differences in important factors such as transit access, urban and suburban form, and local attraction or aversion to ride-hailing. If one were to consider ride-hailing in a setting that differed from U.S. cities in many of these characteristics, this estimation methodology would no longer be appropriate.

Calculation example: estimating ride-hailing for Harris County, Texas

Harris County is, in Fehr and Peers' (2019) terminology, the "core county" of the Houston metropolitan area, a large metropolitan region whose urban and suburban form generally resembles that of many major cities in North America. It is therefore a reasonable candidate for this methodology, with a population density of 2,732 per square mile. Calculating the linear combination of the ride-hailing trip share values on either side of Houston's population density:

$$2\% + \left(\frac{2732 - 2500}{4000 - 2500} \right) \times (3\% - 2\%) = 2.15\%$$

Thus, our guidance suggests using 2.15% as an estimate of ride-hailing trips' share of total VMT in Harris County.

Share (S):

Mode for ride-hailing is assumed to be exclusively on-road passenger vehicles. Occupancy may be aligned with U.S. Census data or assumed to be equal to single occupancy vehicles.

- Tier 1: Use factor of 1.5 to scale ride-hailing trip share to associated VMT share. This proposed methodology suggests this factor of 1.5 until local data becomes available.

This factor (of 1.5) may strike readers as excessive or even punitive, but it emerges from existing work. Pinto de Moura et al. (2020) suggest that total VMT from ride-hailing trips (i.e., the "load factor" in practitioner parlance, in this case to include "deadheading" miles) is on average 1.5 times that of private vehicles performing the same trips. In other words, ride-hailing has 50% greater greenhouse gas emissions impact per mile than using a privately owned vehicle.

Current rule-making by California's Public Utilities Commission (PUC) and Air Resources Board (ARB) for Senate Bill 1014 (the Clean Miles Standard) (CARB 2019a, 2019b) address precisely this issue, and the work has recently described a taxonomy of different ride-hail work "periods" for the purpose of calculating the GHG emissions intensity of ride-hail trips:

- Period 0 - Work session not yet started (not covered by rule-making)
- Period 1 - Driver looking for riders
- Period 2 - Driver en route to riders
- Period 3 - Rider(s) in vehicle

This taxonomy demonstrates the categories of VMT that ride-hailing vehicles must perform in order to execute trips, and we agree with California's decision to allocate periods 1, 2, and 3 to the calculation of ride-hailing's carbon intensity.

Intensity (I):

Intensity factors should align with the factors used in the community inventory to calculate community emissions from on-road passenger transportation. These factors can include:

- Tier 1: On-road factor – This factor calculated using EPA’s MOVES model takes into account vehicle fuel economy; speeds; and local congestion to calculate an average GHGs / VMT for the community for the specific time period.
- Tier 2: Average fuel economy – An average fuel economy may be used instead of an on-road factor but does not appropriately account for speed and congestion when estimating fuel use from VMT. Average fuel economy values may be taken from Bureau of Transportation Statistics Data; Energy Information Administration’s Annual Energy Outlook; or (in the case of Oregon) census tract-level average fuel economy’s based on state vehicle registration data.

Fuel (F):

Fuel factors should align with those used elsewhere in the community inventory to calculate community emissions from on-road passenger transportation.

Method 3 Example

Fehr & Peers (2019) found that 13% of San Francisco core community on-road vehicle miles traveled (VMT) from use of ride-hailing services.

The following ASIF formula illustrates how to use Method 3, and best available data, to estimate the share of ride-hailing VMT and emissions.

$$\text{Emissions} = \text{Activity (A)} \times \text{Mode Share (S)} \times \text{Intensity (I)} \times \text{Fuel (F)}$$

$$\text{Ride-Hailing Emissions} = \text{Ride-Hailing VMT (A)} \times \text{Occupancy Factor (S)} \times \text{Miles per Gallon} \times \text{Passenger Vehicle Fuel Emissions Factor}$$

$$319,940 \text{ MT CO}_2\text{e} = 532,206,622 \text{ VMT (A)} \times 1.5 \text{ (S)} \times 0.407 \text{ kg CO}_2 / \text{VMT}$$

Step 1: Estimating Ride-Hailing VMT

$$\text{Ride-Hailing VMT} = \text{Total Community On-Road VMT} \times \text{Ride-Hailing \% (from Figure 5)}$$

$$532,206,622 \text{ VMT} = 4,093,897,091 \text{ VMT} \times 12.8 \%$$

Total On-Road VMT: Publicly available in San Francisco’s 2017 greenhouse gas inventory and reported as 4,093,897,091 VMT. Data available online at <https://data.sfgov.org/Energy-and-Environment/San-Francisco-Communitywide-Greenhouse-Gas-Invento/btm4-e4ak>.

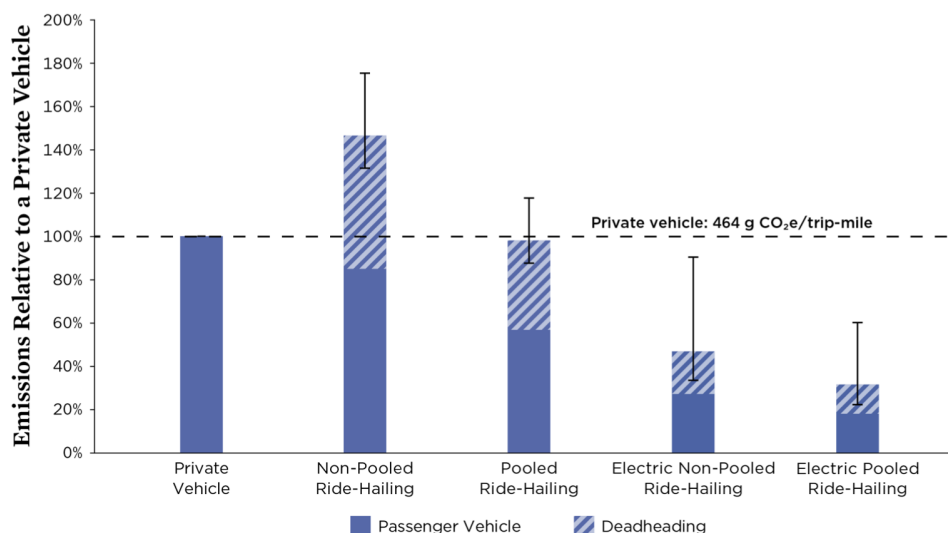
Step 2 Estimating Occupancy / Load Factor

Using the ASIF method, occupancy or load factor is calculated by dividing vehicle miles traveled (VMT) by passenger-miles traveled (PMT). This information is not readily available for San Francisco. Therefore, we suggest using a factor based on Pinto de Moura et al. (2020), as it is the most recent estimate supported by a detailed review of the technical literature.

This work found that per vehicle mile traveled by ride-hailing services for a single passenger in average internal combustion engine vehicle powered by E10 is on average 1.5 times greater than the same trip made by a private vehicle. The finding that ride-hailing trips involve 50% more VMT than equivalent trips by private vehicles is the result of additional “deadhead” VMT by ride-hailing services required to travel to the passenger and back to the home base after the passenger is dropped off. The report also illustrates the effect of use of electric vehicles and pooled trips on ride-hailing’s impact. Figure 6 provides the summary results for the various configurations considered by Pinto de Moura et al.

For the purpose of a Method 3 estimate it is suggested a factor of 1.5 is used until more accurate information becomes available. It is possible that California’s current deliberations (CARB 2019a, 2019b, 2019c) could provide data and rationale to support a significantly different value at some point in the future.

Figure 6: Summary of Modeled Greenhouse Gas Intensity of Car-based Modes



Source: Pinto de Moura et al. (2020), Union of Concerned Scientists

Step 3 – Use Existing Community On-Road Emissions Factor

San Francisco’s on-road emissions factor is available as part of on-road transportation emissions in the 2017 community inventory. Using inventory data, it is calculated at 0.407 kg CO₂e per VMT. This calculation divides on-road MT CO₂e (1,666,353 MT CO₂e) by on-road VMT (4,093,897,091 VMT).

Final Thoughts and Future Extensions

The foregoing work provides a set of feasible paths, for a variety of current circumstances, for quantifying the greenhouse gas emissions impact of ride-hailing at the city or metropolitan scale. Yet the guidance here, while usable off the shelf today, leaves several questions we hope future research, practitioner effort, and policy will tackle.

First, we need policies mandating disclosure of basic data from ride-hailing companies. Other than California's Clean Miles Standard, which will not be fully implemented until January 2023, there are no requirements by states or local jurisdictions that ride-hailing firms disclose emissions data, or even the building blocks of complete emissions calculations.

This idea is not new; indeed, D'Agostino et al. (2019) state that demanding "clear data-sharing requirements designed for transportation network companies and other mobility providers" is essential for achieving a variety of desired policy outcomes. The authors note, however, that there are no general policy norms for disclosure, much less a set of widely accepted standards, by which municipal and state governments receive data from ride-hailing firms. Still, the rationale for regulation is strong (National Academies of Sciences, Engineering, and Medicine, 2016).

Second, the indirect emissions effect of ride-hailing through congestion deserves attention. As noted at the outset, Erhardt et al. (2019) demonstrate convincingly that a substantial share of the additional congestion that emerged in San Francisco in the 2010-2016 period is due to ride-hailing. Several other metropolitan regions studied in Fehr & Peers (2019) suffer similar preexisting congestion and significant ride-hailing activity that an observer might suspect congestion effects of a similar magnitude to San Francisco.

Yet no easy method exists, as the circumstances of Erhardt et al. (2019) demonstrate: the authors rely on painstaking custom data assembly and the use of a regional travel demand model, techniques that pose insurmountable barriers for most community carbon footprinting efforts.

We believe that, with considerable additional research in the same vein, rules of thumb could emerge based on taxonomy of different circumstances. The table below shows a conceptual guidance table that one could articulate with data similar to the San Francisco case, but for a large number of communities. Consider two simple axes: a measure of a given congestion, and a quantification of ride-hailing's penetration of the local marketplace. We envision a simple lookup table with the following form:

Figure 7: Hypothetical Framework for Allocating Congestion Impacts to Ride-Hailing

On-road emissions share resulting from congestion impacts attributable to ride-hailing	Low ride-hailing mode share <5%	Medium ride-hailing mode share 5-10%	High ride-hailing mode share >10%
Low congestion	None	None	None
Medium congestion	None	5%	8%
High congestion	None	8%	20%

The specific mode share magnitudes here are intended to be evocative but not conclusive; we have selected bins that capture regions in Fehr & Peers (2019), from high (San Francisco) to medium (Boston and Washington, D.C.) to low (Seattle, Los Angeles, and Chicago). Again, these values are for “core counties” that are not entirely equivalent comparisons, but the heterogeneity provides a starting point. Similarly, the congestion levels are not specified, but one could assemble such categories based on existing modeling tools. Indeed, there are regular assessments of congestion levels that could inform this categorization, such as the Federal Highways Administration’s quarterly Urban Congestion Reports (Federal Highways Administration (2019)). In short, while no simple method exists, the building blocks may be out there.

There is important policy overlap at the intersection of data disclosure and congestion, and Chicago is already assessing a graduated tax on ride-hailing aimed at disincentivizing trips during congested times and in the most congested places (D’Onofrio and Schulte 2020), as a result of well-documented congestion (City of Chicago 2019, Lopez 2019).

There remain also several methodological issues related to greenhouse gas inventories that relate to ride-hailing but are not specific to that mode. In general, community-scale greenhouse gas accounting focuses on direct emissions from narrowly defined activities, but current methods struggle to attribute those activities to systems of behavior. For example, the carbon footprint of building and maintaining transportation *infrastructure*, separate from private or transit vehicle emissions, is a substantial emissions source when one accounts for complete life-cycle emissions (Chester and Horvath, 2009). Yet current methods largely segment tailpipe and on-road emissions so they are not understood as stemming from the same activities.

Thus, one might ideally hope to attribute not just tailpipe emissions to ride-hailing, but also to allocate an appropriate pro-rated share of infrastructure emissions to it and thereby quantify the extent to which it perpetuates resource-intensive, car-centric development. Even where cities quantify emissions from infrastructure, a rare category in community carbon footprints, this connection between infrastructure and on-going transportation activity is extremely rare. In addition to such allocation being far beyond the norm of current GHG accounting, it is simply not available off the shelf methodologically.

Relatedly, the discussion in the literature review of modal shift looms again here at the close. The introduction of a new mode necessarily creates changes that are difficult to model in the moment, and the previous citations are only survey snapshots. We simply do not yet have a complete picture of how ride-hailing shifts trips away from other modes, provides a complement to particular modes, or even fosters entirely new trips. Even when we quantify its direct effects, these important indirect effects

A common feature of the foregoing points – missing data, quantifying congestion impacts, allocating infrastructure impacts, the nature of modal shift – is uncertainty. Carbon footprinting exercises already struggle to bring new sense of scale to popular, policy, and technical audiences; the additional burden of assigning levels of uncertainty to newly juxtaposed emissions sources makes the overall task truly challenging.

Yet we know that ride-hailing introduces potentially far-reaching challenges, not just in quantifying its current impacts, but further in assessing its impacts on patterns of behavior that in turn impact longer-lasting patterns of investment. Is the net effect of ride-hailing to foster greater dependence on the automobile, or does its flexibility lead to a net decrease in car ownership? Does it lead to greater automobile VMT or does its presence as a safety net allow people to choose transit and

active transportation modes more consistently? And in the long run, what is the impact of ride-hailing on urban form? Does it force the accommodation of more car-centric development, or does it allow the conservation of urban space that in turn fosters other non-car modes? And can our existing planning and modeling tools chip away at these bigger questions, or do we need entirely new tools and frameworks?

We hope that the current work provides the thin end of the wedge in the practitioner space by allowing cities and regions that currently quantify their community GHG emissions to confront ride-hailing directly. Perhaps from that start, we will move toward answering these broader questions about the net carbon impact of ride-hailing as a mode.

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Appendix A: Model request for data

This appendix provides ready-to-use language for practitioners seeking data from ride-hailing firms in order to include ride-hailing emissions in municipal greenhouse gas inventories.

This example is drawn from request language used by the City of Beaverton in a request that Lyft disclose data on local ridership. We sought information for Beaverton because the jurisdiction already has a community greenhouse gas inventory. While the request was ultimately unsuccessful, we believe this is an appropriate way to approach ride-hailing firms, at least until comprehensive disclosures such as those required by California's Clean Miles Standard are commonplace.

Good afternoon [ride-hailing contact],

The City of Beaverton is currently conducting a community greenhouse gas inventory as part of our commitment to climate action and as a priority for the Mayor Denny Doyle. These inventories have become commonplace in Oregon and follow existing protocols, such as the Global Protocol for Community Greenhouse Gas Inventories. As part of this work, the City is interested in measuring the climate impact of ride hailing services to help us better understand the current impact and to plan accordingly towards Beaverton's community climate goals.

In order to gauge current conditions and set a baseline to measure future process we are asking for the following data:

- *Time period: Jan - Dec, 2017*
- *Geographic area: City of Beaverton, Oregon*
- *Trips, Distance, and Fuel Economy*
 - *Total vehicle-miles traveled (VMT) for trips with an origin OR destination within City of Beaverton geographic boundaries (city limits)*
 - *Total VMT for trips with an origin AND destination within City of Beaverton geographic boundaries*
 - *Total number of trips with an origin OR destination within City of Beaverton geographic boundaries*
 - *Total number of trips with an origin AND destination within City of Beaverton geographic boundaries*
 - *Average fuel economy of the Lyft vehicles that serve Beaverton*
 - *Percentage of VMT served by a fully battery electric or hybrid electric vehicle*

If you have any questions please let me know. I appreciate your assistance with this.