Low-Cost Large-Scale Greenhouse Gas Emission Estimation Methodology: Better Urban Transport Investment through Carbon Finance and Evidence from Philippines

Holly Krambeck
Senior Transport Specialist
World Bank
1818 H St NW, Washington, DC 20433
Email: hkrambeck@worldbank.org

Yang (Carl) Lu, Ph.D. (Corresponding Author)
Transport Consultant
World Bank
1818 H St NW, Washington, DC 20433
Email: ylu2@worldbank.org

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ABSTRACT

The transport sector, particularly in developing countries, plays a critical role in global energy consumption and greenhouse gas emissions reduction strategies – not only because transport sector emissions comprise nearly a quarter of global emissions today, but also because without pre-emptive action in developing countries, transport sector emissions may increase particularly rapidly, and the costs of future retroactive mitigation activities may be prohibitive. In this paper, the authors review existing methodologies for estimating transport sector GHG emissions and introduce a new methodology that solves the challenge of attributing emissions from large-scale transport sector interventions using a low-cost and scalable methodology. The authors' methodology relies on emergent sources of big data — GPS data generated by multi-national transportation networked companies (TNCs), such as Uber and Grab, and high-resolution satellite imagery — to efficiently and effectively generate comparable traffic-induced GHG emissions estimates across multiple cities and countries.

INTRODUCTION

The transport sector, particularly in developing countries, plays a critical role in global energy consumption and greenhouse gas (GHG) emissions reduction strategies – not only because transport sector emissions comprise nearly a quarter of global emissions today, but also because without pre-emptive action in developing countries, transport sector emissions may increase particularly rapidly, and the costs of future retroactive mitigation activities may be prohibitive *(1)*.

In 2016, building upon the Paris Climate Accord, the World Bank announced the creation of a new carbon finance scheme, the Transformative Carbon Asses Facility (TCAF), which aims to mitigate transport emissions in developing countries in the order of 1 million tons CO_2e (carbon-equivalent) per year, over a program period of 3-5 years. To put this goal into perspective, a private car that travels 20,000 km per year will emit about 4 tons of CO_2e – this means that the program would be equivalent to removing about 250,000 cars from the roads. Given this magnitude, the TCAF program poses two challenges: 1) selecting a portfolio of projects that can, collectively, achieve these ambitious targets; and 2) creating a practical, auditable methodology to measure emissions reductions from this portfolio.

For the first challenge, while there is a multitude of technology interventions that can be undertaken to improve transport energy efficiency – better engines, a variety of fuel-efficiency retrofits – the impact of these interventions taken individually can be limited. For example, single-line bus rapid transit (BRT) projects supported by the Clean Development Mechanism (CDM) *(2)* carbon finance program mitigate GHG in the order of 40,000 to 50,000 tons CO_2e per year. At this rate, to reach the TCAF target, we would need to support 20 simultaneous BRT projects, which would pose untenable monitoring and evaluation costs (CDM annual monitoring costs for individual BRT projects range from $20,000 to $100,000 per year). On the other hand, policy, planning, and traffic operations interventions, congestion charging, improved public transit, upgraded non-motorized transport networks, better ITS systems – can have far more substantial, repercussive and long term impacts. However, until now, carbon finance methodologies could only support individual projects, whose emissions reductions are immediately attributable and quantifiable – i.e., technology-based improvements – and could not support projects with repercussive impacts, where the baseline cannot be accurately attributed to a specific intervention each year.

In this paper, we argue that under a performance-based carbon finance scheme such as TCAF, which rewards projects and programs that place developing countries on lower transport energy consumption trajectories, an approach that measures and rewards policy, operations, and planning interventions, in addition to technology shifts, is needed. We review existing methodologies for estimating GHG emissions from individual transport technology projects and then introduce a new methodology that solves the challenge of estimating emissions from large-scale transport sector interventions. The authors' methodology relies on emergent sources of big data — GPS data generated by multi-national transportation networked companies (TNCs), such as Uber and Grab, and high-resolution satellite imagery — to efficiently and effectively generate comparable traffic-induced GHG emissions estimates across multiple cities and countries.

LITERATURE REVIEW

Common Methodology Elements

The vast majority of models for estimating GHG emissions from transport operations rely on the same underpinning methodologies — the differences lay in the models' data inputs.

There are four components that may be found, in some form, in most GHG emissions models, whether the model is intended to estimate transport emissions from a project, for a city, or for a country:

- Carbon content of fuel – how many kg of CO_2e are emitted per unit of fuel combusted?
- Vehicle inventory – what types of fuels are being combusted?

- Fuel efficiency – how much fuel is combusted per kilometer traveled?
- Activity level – how many kilometers are vehicles traveling?

These components are not arbitrary. They reflect, in some combination, all activities that can be undertaken to reduce greenhouse gas emissions from transport operations. For example, replacement of a traditional Diesel bus system with a network of dedicated bus lanes and CNG hybrid buses would affect the carbon content of fuel (from Diesel to CNG), the fleet fuel efficiency (through new technology, as well as improved drive cycle through use of a dedicated lane), and reduction in activity level per passenger transported (through better transport management). The diagram, as shown in Figure 1 below, illustrates how these pieces come together.

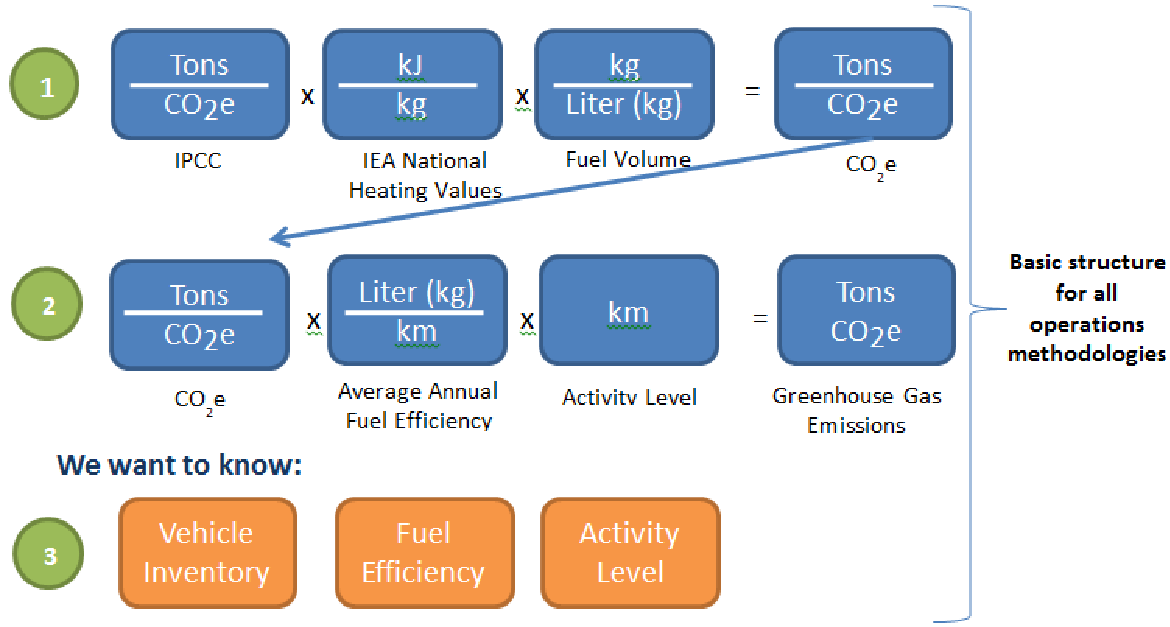

Figure 1. Components that Contribute to Transport GHG Emissions

Methodology Examples

While the basic underlying principles across different GHG emissions calculation methodologies are similar, they differ in terms of data requirements and therefore level of reliability and accuracy of the calculated results.

Taking the activity level for example, most models take the vehicle miles traveled (VMT) as a direct input, such as: Computer Programme to calculate Emissions from Road Traffic (COPERT) *(3)*, developed by European Commission, the World Bank model *(4)*, developed by their Carbon Finance team, the International Vehicle Emission (IVE) model *(5)*, and the model developed by City of San Francisco *(6)*. That is, these models assume that there is a reliable source of VMT data that can be input into a model, which may hold true for advanced economies, but in developing countries, is rarely the case. In the model proposed by GIZ team for a GEF project *(7)*, the vehicle miles traveled are estimated based on the average travel distance obtained through a household survey.

With respect to the fuel efficiency, both COPERT and MOtor Vehicle Emission Simulator (MOVES) *(8)*, developed by US Environmental Protection Agency, provide the emission rate based on different travel speeds. In the GIZ model, travel conditions are classified as high, medium, and low speeds, and different emission rates are assigned. Again, these models assume such speed survey data is readily available and provide default parameters where data is scarce.

Interested readers could refer to *(9)* for more detailed review of existing GHG emission inventory models. To summarize, the general deficiency of existing models are the inaccurate calculation of the activity level and failure to include the speed effect, due to the data unavailability. To overcome the above limitation, Gois et al. *(10)* proposed a detailed estimation method based on satellite imagery and GPS data, which is able to compute the VMT and determine the fuel efficiency directly, and applied it in the city of Lisbon, Portugal. Compared with other models, the Portuguese model has greater accuracy, but its extensive data requirements have hindered its wider adoption, especially in the less developed countries, where there is limited or even no traffic data.

Today, with the recent rise in transportation networked companies (TNCs), such as Uber and Grab, through big data partnerships, such detailed speed data can be made available in developing countries. Similarly, with the rapidly declining costs and increasing availability of high-resolution satellite imagery, accurate and low cost volumetric data can be obtainable. Taking advantage of these new data sources, we developed a GHG estimation methodology with similar logic to the Portuguese model, but at a much lower cost for developing countries.

LEVERAGING BIG DATA

Speed Data

As noted in the literature review, the challenge in developing a methodology that can be scaled for use in estimating the impact of GHG mitigation measures for carbon finance congestion alleviation programs is not necessarily the methodology's computational complexity -- rather, it is accessing the necessary attributable data, namely traffic speeds and volumes, in a standardized manner.

To this end, for collection of speed data, the team has formed a partnership with Grab — a taxi hailing app company that supports more than 800,000 drivers in Malaysia, Singapore, Indonesia, Vietnam, the Philippines, Thailand, and Myanmar — as well as Easy Taxi and other companies whose data, collectively, covers more than 30 countries and millions of drivers. Under this Open Transport Partnership (OTP), anonymized traffic statistics, such as speeds linked to road segments, are made available to the public under an open data license. Interested readers could refer to the Open Traffic Completion Report *(11)* for more information.

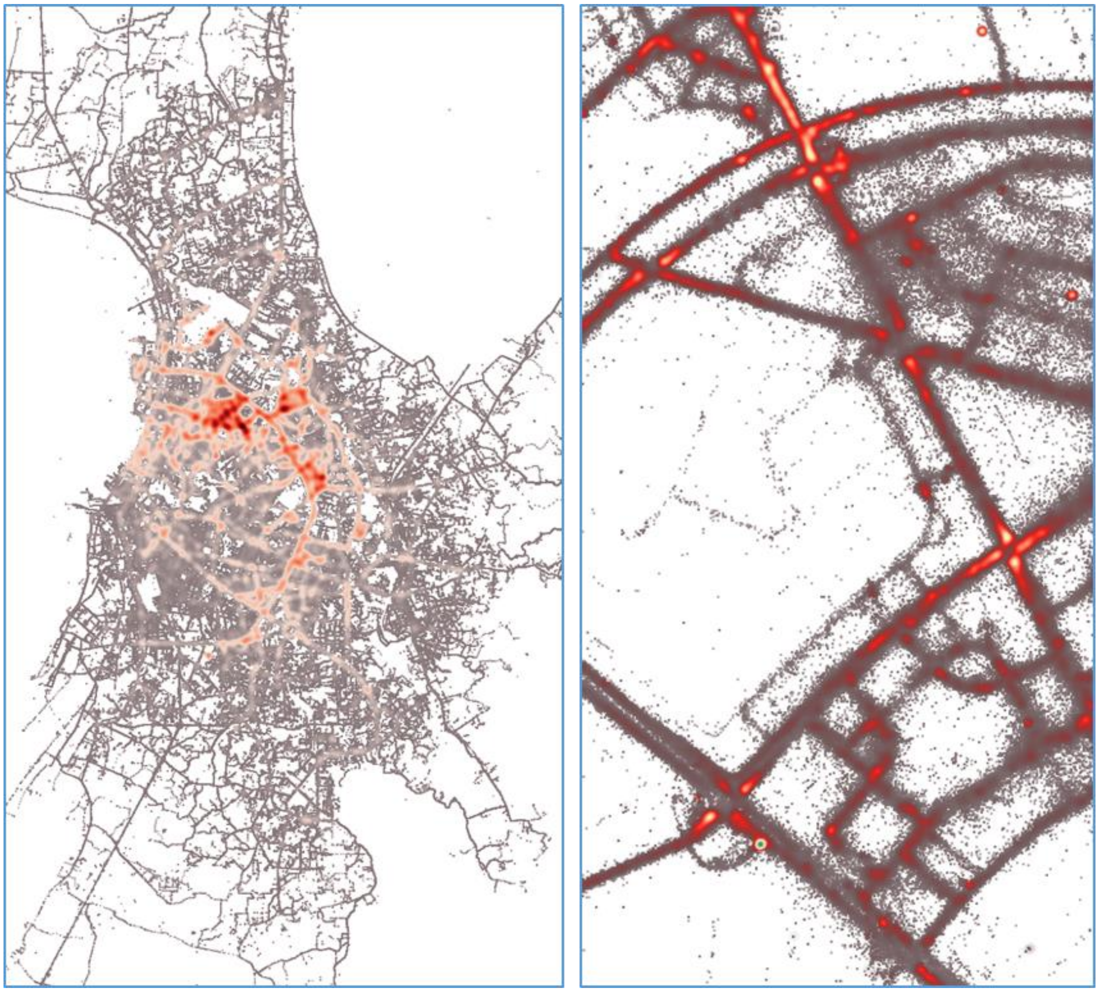

Figure 2. Density of Grab GPS data in Manila over a 24-Hour Period (February 24, 2016)

To help low-capacity government agencies make effective use of the OTP data, the team has supported the development of Open Traffic: an open source visual web-based interface for querying the data. For selected time periods, the Open Traffic platform may be used to query the database of stored travel times by road segment to generate a map of average travel speeds.

Volume Data

For traffic volume count data, the team experimented with the use of time-stamped, high-resolution satellite imagery provided by DigitalGlobe for generating accurate counts that can be correlated with the speed data. This method has the advantage of being implementable from a desktop without the need for field data collection, with relatively accurate count results that can be compared across cities and countries. The time stamps associated with these images are matched to the speed data recorded at that time, and with a sample of imagery over time, we can build a rudimentary predictive model of volumes correlated with speeds for a given corridor.

METHODOLOGY

As summarized in Figure 1, GHG emissions can potentially be reduced from three different types of interventions: reducing CO_2e emissions per kg fuel combusted, reducing fuel combusted per km travelled, and/or reducing the total vehicle-km travelled. Urban congestion alleviation interventions primarily belong to the second and third categories, through such activities as: optimization of area traffic control systems or implementation of travel demand management programs.

CO_2e emissions caused by congestion are computed with Eq. (1). The hourly additional emission per road segment is the difference between the emission rate when the segment is congested and not congested, multiplied by the vehicle-miles traveled. The total of additional emissions is the summation of the segmental additional emissions for all types of vehicles (denoted by *v*) at all segments (denoted by *n*) over 24 hours (denoted by *m*).

$$\text{Total Daily Additional Emission} = \sum_{m=1}^{24}\sum_{n=1}^{N}\sum_{v}^{V} \text{Hourly Vehicle Miles of Travel}_{v,n,m} \times \begin{pmatrix} \text{Emission Rate at Congested Condition}_{v,n,m} \\ \text{-Emission Rate No Congestion}_{v,n,m} \end{pmatrix} \tag{1}$$

Hourly Vehicle Miles of Travel is the hourly traffic volume (# of vehicles) multiplied by the segment length. The segment length can be directly extracted from a .shp file generated by the routing function of Open Traffic or from any reliable GIS road network base map.

To capture volume, with the high-resolution time-stamped satellite imagery, we can manually count the number of vehicles within each segment and further obtain the traffic density (# of vehicles per mile/km). If the proof of concept is successfully established from this study, the counting process could become automated, since the technology to do so is already available in the market. By definition, the flow rate (# of vehicles per hour) equals the traffic density times the space mean speed at that segment. The travel speed by segment and time could be exported from the Open Traffic platform. Interested readers can find the detailed method to compute the segment speed at *(11)*. Hourly volume has the same value as the flow rate but with different units (# of vehicles).

Ideally, for one specific city, the CO_2e emission rates (in grams per mile/km) should be obtained from field surveys as suggested by International Vehicle Emissions (IVE) Model to take into account the mode split and fleet compositions. Currently, the IVE Model authors maintain a database including emission factors for US, China, India, and Thailand. Due to the budget limitation, the methodology adopted in this study leverages emission rates for pilot cities (i.e., Manila and Cebu).

Emission rates for passenger cars at different speeds are obtained from the data generated from MOVES. The MOVES model can generate emission rates for speeds from 2.5 to 75 mph with a 5 mph incremental interval, as shown in *(13)*.

Mode split is obtained from other transport studies (e.g., BRT demand survey) and/or contact in local transport authorities. Emission rates for other vehicle types (e.g., jeepneys, bus, motorcycle, trucks, etc.) can be obtained from relevant local studies *(14)*. The relative magnitude will be multiplied to the emission rates of passenger cars at different speeds obtained in *(13)*.

Additional fuel cost caused by congestion is computed by using the CO_2e emissions rate from a gallon of gasoline provided by IPCC and IEA *(12)*. Based on the local fuel price, the fuel emission can be further converted to the dollar unit, as shown in Eq. (2). Different conversion value should be used for the diesel vehicle.

$$Total\ Daily\ Fuel\ Cost = Fuel\ Cost(\$/gallon) \times Total\ Daily\ Additional\ Emission \,/\, Emission\ Rates\ for\ a\ gallon\ of\ gas \tag{2}$$

CASE STUDY

The methodology has been tested in Metro Manila and Cebu City, Philippines, where the World Bank is investigating new traffic congestion alleviation strategies that could be financed by the TCAF. The extent and severity of congestion levels in the Philippines has become untenable in recent years. For example, according to a study *(15)* undertaken by the Japan International Cooperation Agency (JICA), congestion in Metro Manila costs the economy PHP 2.4 billion (USD 48 million) per day.

Using acutely congested areas as a study basis, the following steps were taken to test the methodology:

1) Select the study area / corridors;
2) Gather data from standardized, global open data sources, including:
    a) Road network from the Open Street Map
    b) Traffic speeds from the World Bank's Open Transport Partnership
    c) Traffic counts from time-stamped high-resolution satellite imagery
    d) Country-specific fuel heating value from the International Energy Administration
    e) Default emissions rate per km values from IVE and MOVES, two internationally-recognized databases of fuel efficiency parameters for a range of vehicle types by region and by age, accompanied by models for changes in fuel efficiency with varying average travel speed
3) Gather data from country-specific sources, namely modal split from previous studies (typically available where there is a World Bank urban transport investment program); and
4) Calculate GHG emissions under free-flow and congested conditions and compute the difference.

Step 1: Select Study Area / Corridors

When conducting a congestion-based GHG emissions analysis, it is important to recognize that measurements on every corridor in an urban area are not necessary to analyze urban congestion. In fact, in most cases, only key urban arterials, where the difference between free-flow and peak-hour travel conditions varies substantially throughout a 24-hour period, are needed. On non-arterials, the difference between congested and non-congested travel behavior will generally be negligible in comparison.

For developing and testing the methodology, the team examined two primary urban arterials, shown in Figure 3A and 3B. In Manila, the team analyzed congestion on Epifanio de los Santos Avenue (EDSA), a 23.8-km 12-lane (6 in each direction) road that experiences severe congestion and has been identified by both previous and current government administrations as a national priority for congestion alleviation. Weekday congestion on EDSA, which carries about 179,822 vehicles per day, begins as early as 6:30 a.m. and persists until past 10:00 p.m.

In Cebu City, National Bacalso Avenue is the city's primary east-west arterial, which carries approximately 50,000 vehicles per day across its 4.7-km length. The western portion of the road is median-divided urban arterial, with three lanes in each direction, while the eastern portion is an undivided urban road, with two lanes in each direction.

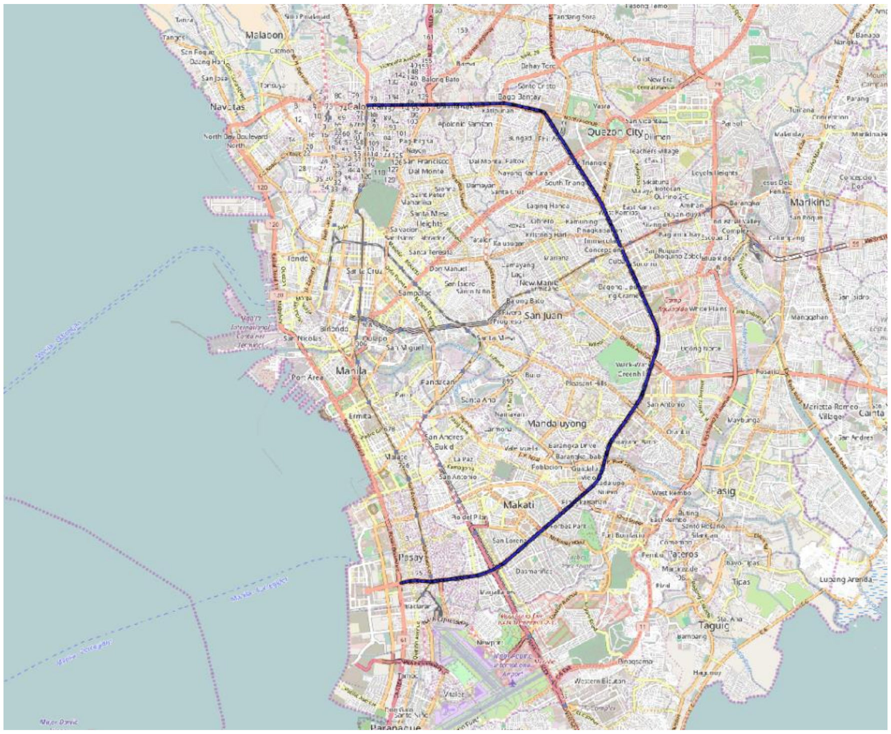

Figure 3A. EDSA in Manila

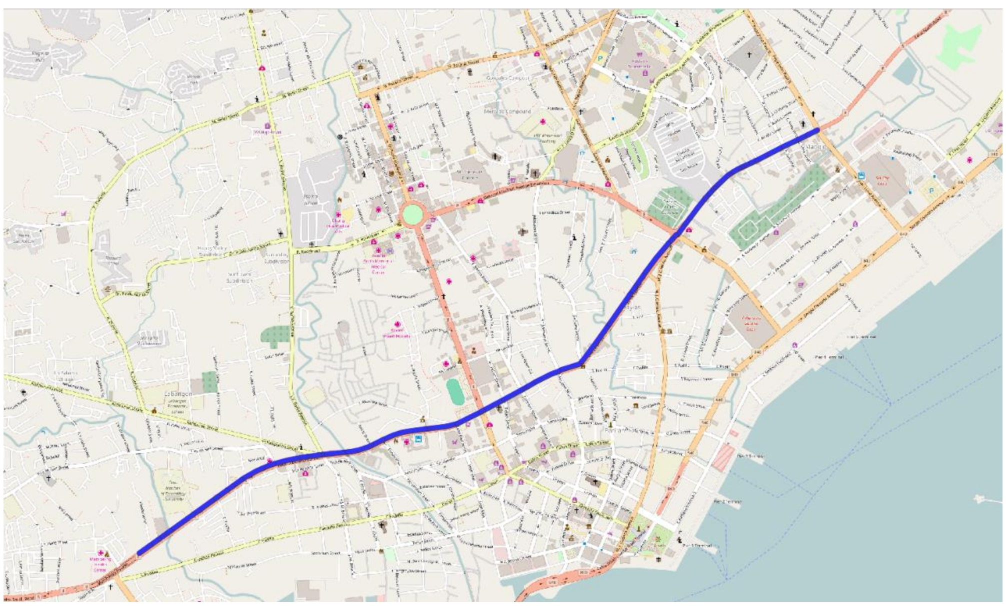

Figure 3B. National Bacalso Avenue in Cebu

Step 2A: Collect Data (Standard Global Datasets)

Road Network Map

The road network map provides the length of each roadway segment that is used to compute vehicle-km traveled (# of vehicles * km-traveled), underpins the traffic speed calculations, and also serves as the base map to match the vehicle counts to each roadway segment.

The Open Street Map (OSM) is a crowd-sourced, global, and open data repository of geospatial data. The OSM is increasingly being used to support World Bank-financed projects, and there are on-going initiatives throughout World Bank partner countries to continue to expand the map. OSM data may be downloaded directly from the Open Street Map server, or through multiple web-based user interfaces for querying the dataset (e.g., www.osm.org). In this study, OSM data was used to support traffic speed estimations and route length estimation.

Traffic Speeds

Traffic speeds are required to compute the number of vehicles per hour (flow rate), which equals traffic density * speed, by definition. They are also used to derive emission rates, since vehicles have significantly different emission values at different speed ranges.

As noted previously, reliable traffic speed data were directly obtained through World Bank's Open Transport Partnership, and we used the routing function of the open source Open Traffic platform to quickly generate and export speed data for all covered segments in the study date and time period.

The speeds along EDSA in Manila for the selected date and time were queried using the Open Traffic visual querying platform and exported to a .csv file, for further analysis, as shown in Figure 4A and 4B.

Figure 4A. Exporting Speed Data from Open Traffic

Edge Id	Date Start	Date End	Monday	Tuesday	Wednesd	Thursday	Friday	Saturday	Sunday	Time Start	Time End	Average Speed KPH
1000159040	5/2/2016	5/8/2016	0	0	1	0	0	0	0	10:00	10:59	56.5
1000159041	5/2/2016	5/8/2016	0	0	1	0	0	0	0	10:00	10:59	21.5
1000159042	5/2/2016	5/8/2016	0	0	1	0	0	0	0	10:00	10:59	21.5
1000159043	5/2/2016	5/8/2016	0	0	1	0	0	0	0	10:00	10:59	30.5
1000159044	5/2/2016	5/8/2016	0	0	1	0	0	0	0	10:00	10:59	37.5
1000159045	5/2/2016	5/8/2016	0	0	1	0	0	0	0	10:00	10:59	26.5
1000159046	5/2/2016	5/8/2016	0	0	1	0	0	0	0	10:00	10:59	26.5
1000159047	5/2/2016	5/8/2016	0	0	1	0	0	0	0	10:00	10:59	34.5
1000159048	5/2/2016	5/8/2016	0	0	1	0	0	0	0	10:00	10:59	24.5
1000159049	5/2/2016	5/8/2016	0	0	1	0	0	0	0	10:00	10:59	24.5
1000159050	5/2/2016	5/8/2016	0	0	1	0	0	0	0	10:00	10:59	30.5

Figure 4B. Exported Speed Data in .csv Format

Traffic Counts

Traffic counts are required as inputs to compute the traffic density (# of vehicles per km) for each segment. The number of vehicles per hour can be derived from both speed and density.

The number of vehicles is obtained through counts of vehicles in high-resolution (<1-meter), time-stamped satellite imagery. For the purposes of methodology development, the counting process was conducted manually, with some acceleration through a digitalization procedure based on the QGIS platform (vehicles identified in the imagery were pinned as a point layers in QGIS - QGIS is an open-source geospatial analysis platform (http://www.qgis.org/en/site/). The point layer was then matched to the nearest segment through the QGIS plugin "NNJoin", and the number of points matched to the segment equals the number of vehicles on that specific segment). If this study proof of concept is successful, a vendor that specializes in automated vehicle counts from satellite imagery can be hired to support this data processing step.

Satellite imagery of Manila was added to QGIS as a raster layer, and the vehicles on the outer loop of EDSA were pinned as green points, as shown in Figure 5.

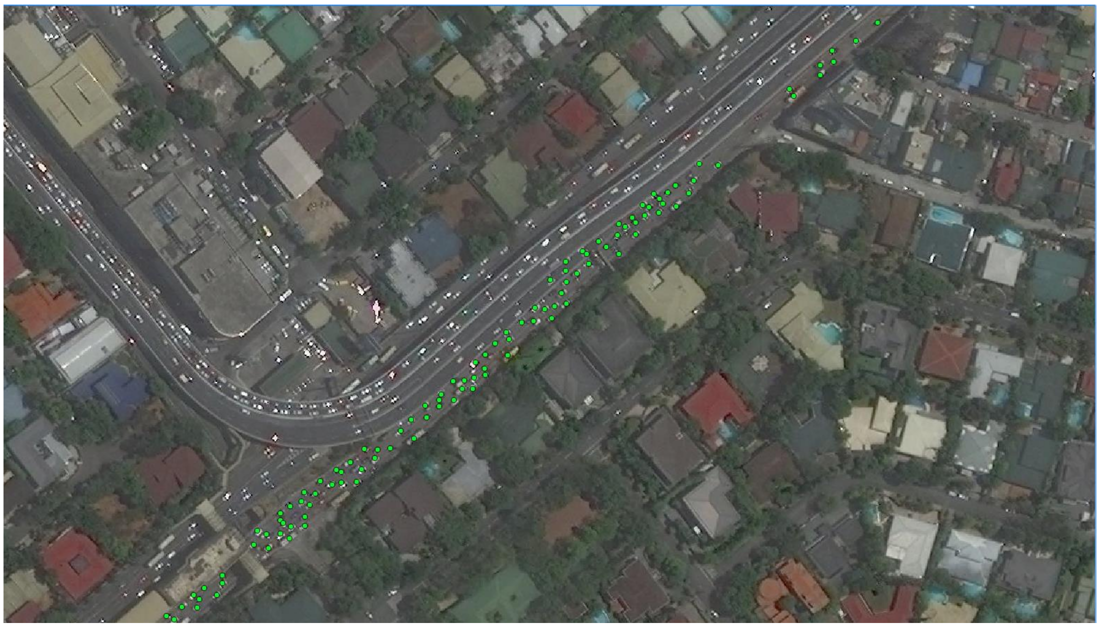

Figure 5. Pinning Vehicles as Point Layer in QGIS

Country-specific Fuel Heating Values

The country-specific heating value is needed to compute the carbon content of fuel per liter combusted. This value is directly collected from IEA National Heating Values (www.iea.org). Taking Philippines as an example: the national heating value of gasoline is 45,427 KJ per kg combusted, the carbon-equivalent content of gasoline is 75,391 kg/TJ (IPCC value); and 1 kg gasoline equals 1.18 liters. Thus, 2911 grams of CO_2e is produced per liter of gasoline combusted.

Default Emissions Rate per km

A vehicle's fuel efficiency (and therefore emissions rate) is impacted by average travel speed, as well as the degree to which the vehicle frequently starts and stops in high traffic conditions. Thus, there are two dimensions of congestion that affect emissions – traffic speed during congested periods, and the duration of the congestion period itself.

To estimate congestion-induced emissions, we use the emissions rate per km-traveled under free-flow traffic conditions as a baseline, and compare this rate to the congestion period rate.

For this study, the emission rates of different vehicle types under a range of travel speeds are obtained from the US Environmental Protection Agency's MOVES model, which generates emission rates for speeds from 4 to 121 kph with an 8 kph incremental interval. These values were further adjusted to accommodate the unique local vehicle composition, such as jeepnies (microbuses). However, there are multiple global models that could be used for this purpose, and pending expanded use of this methodology, these models will be compared to determine which would most suitable for a given region.

The emission rates from a local study *(14)* were obtained under the "best possible local conditions". Here, it was assumed that this value corresponds to the condition with daily average traffic speed under smooth driving. The average travel speeds in Manila are 30-35 km/h (18.75-21.88 mph); thus, 275 gram/km (440 gram/mi) for passenger car in Philippines is about 40 gram/mi higher than the MOVES value. The emission rates at other speeds and types of vehicles should be increased proportionally.

Step 2B: Collect Data (Country-specific Datasets)

Modal Split

All of the data sources listed so far can be sourced from global, standard databases and models, without the need for field data collection. However, there still remains one key data input that can only be obtained locally – modal split and/or fleet composition.

Since different types of vehicles generate distinct carbon emissions per km travelled, the modal split data (i.e., the percent of passenger car, bus, truck, etc. along the study corridor) is needed to produce more accurate GHG emissions estimation.

It is noted that the difference in emissions between a truck and a car is far greater than the difference between a 10 year-old car and a 5 year-old car. Thus, for the purpose of monitoring changes in emissions over time, so long as the modal split information is updated through the implementation period, the methodology is viable.[1]

For the study, modal splits were obtained directly from World Bank project data and local transport authorities. This information is comparatively easy to obtain, as many existing urban transport projects have already conducted surveys to collect such information.

The 2015 modal split for EDSA in Manila, obtained from the Department of Transportation, is shown in Table 1.

Table 1. Modal Split of EDSA in Manila

Mode	Percent
Car	75%
PUJ	3%
Bus	5%
Truck	2%
Motorcycle	15%

Step 3: Calculate the Emission Difference

Following the Eq. (1), the line chart in Figure 6 illustrates this emission increase under congestion:

[1] In most cases, even if more detailed information about the fleet were available, such as through vehicle registration data (which generally is only available in advanced economies), these information cannot reflect the specific fleet characteristics of vehicles operating in project areas.

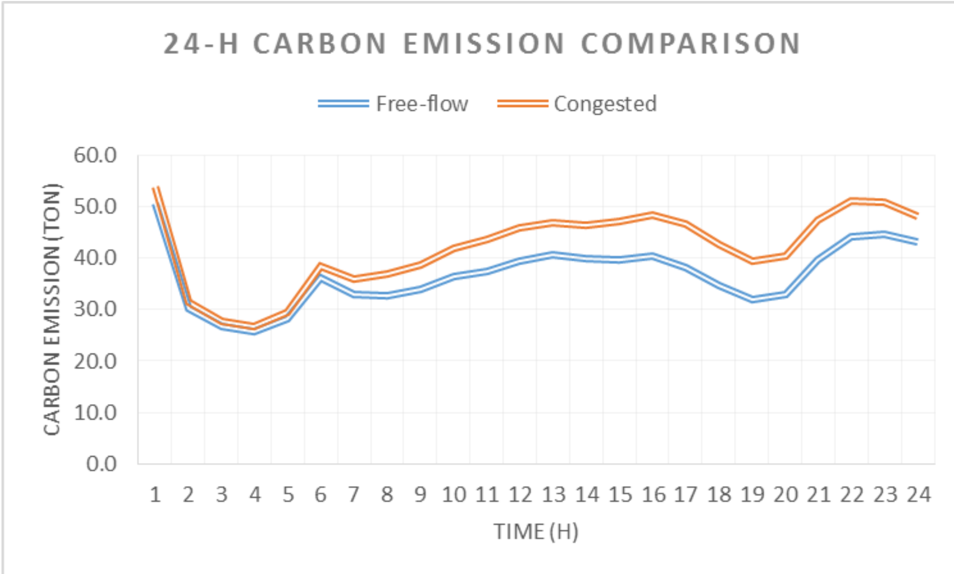

Figure 6. Comparison of Carbon Emission Generation under Free-flow and Congested Conditions

If looking at the percentage change shown in Table 2, the difference on the generated total emissions between the congested and free-flow conditions is 14.30%. And the largest difference (over 20%) appears during the PM peak when the congestion is most severe.

Table 2. Percentage Difference of the Generated Total Emissions by Hour

Hour	Diff	Hour	Diff	Hour	Diff	Hour	Diff
0	6.53%	6	9.61%	12	15.62%	18	23.75%
1	4.05%	7	12.25%	13	16.58%	19	22.72%
2	3.69%	8	13.69%	14	18.88%	20	19.37%
3	3.68%	9	14.94%	15	19.87%	21	15.67%
4	4.67%	10	16.25%	16	21.69%	22	14.48%
5	6.29%	11	16.37%	17	23.67%	23	11.57%

The emission breakdown based on vehicle type in Figure 7 shows that the majority of emission comes from passenger cars. And although the bus and truck only take a small portion in the modal split, due to their high emission rates, the contribution on the total GHG emissions is significant.

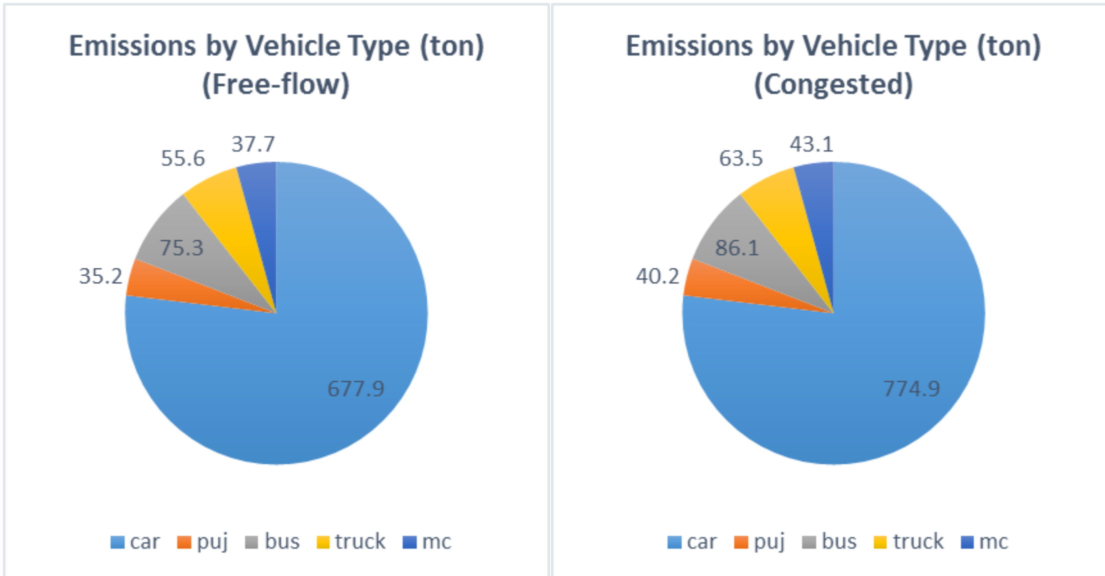

Figure 7. Emission Breakdown by Vehicle Type

The number of vehicles in EDSA for one day is estimated to be 179,822. In terms of aggregate emissions, under free-flow emissions rates, a total of 882 tons CO_2e are generated per day along the selected corridor. Under current congestion conditions, about 126 tons CO_2e may be directly attributable to congestion per day (total emissions per day = 1,008 tons).

Similarly, taking the mode split along Cebu's Bacalso Avenue from the survey data provided by local transport authority, the hourly emission under current condition for different types of vehicle were computed. Then, applying the emission rate at no congestion, the total emission under perfect condition was computed, and its comparison with the one under current condition was presented in Figure 8A and 8B. As expected, in the early morning, there is no significant difference since the traffic is not congested, while the gap is significant for congested periods.

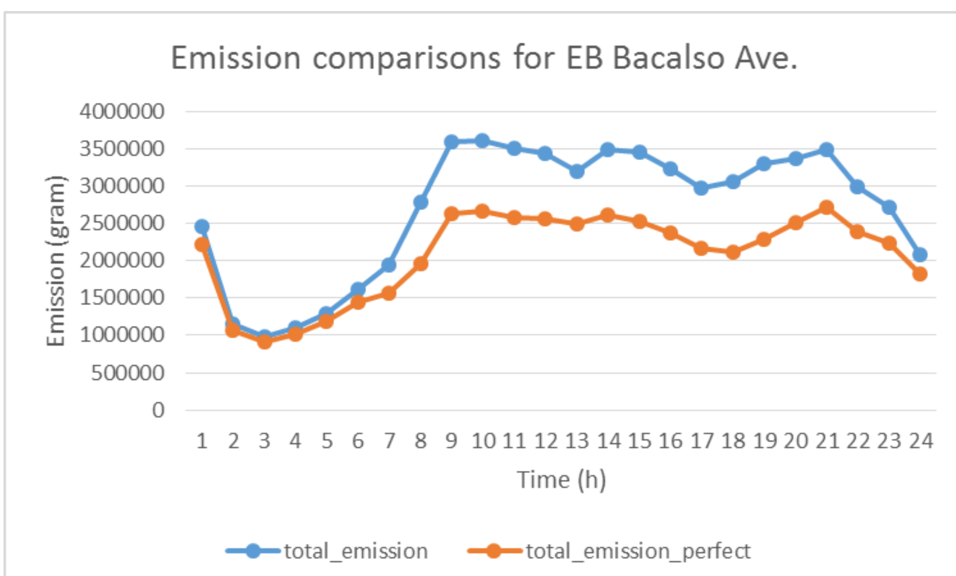

Figure 8A. Comparison of Total Emission along Bacalso Ave. EB

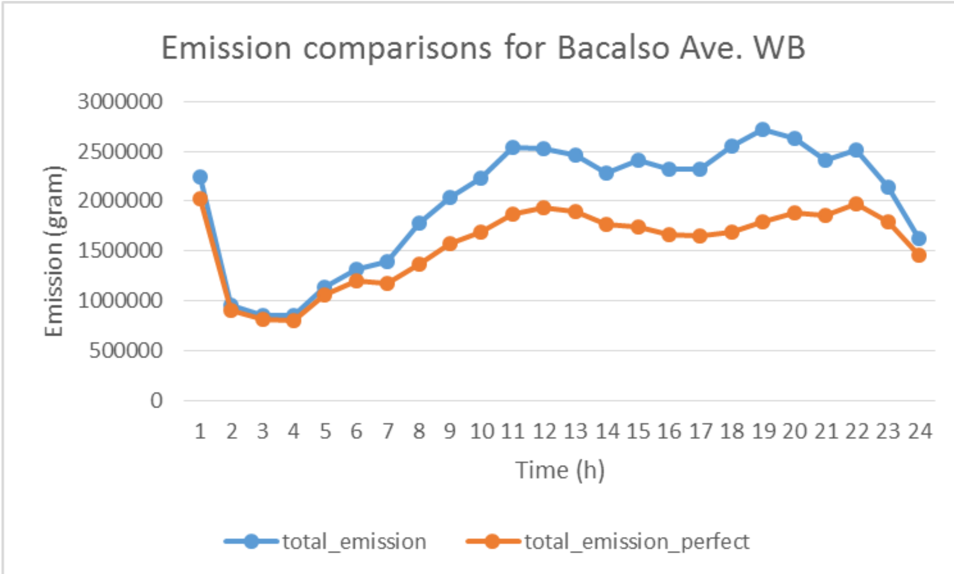

Figure 8B. Comparison of Total Emission along Bacalso Ave. WB

The gas price in Philippines on September 19th 2016 is \$0.83/liter. Thus, based on Eq. (2), the additional emission is 25.56 ton which costs \$7283.24 for Bacalso Avenue in Cebu.

City-wide Envelope Estimation

Using our methodology and Manila case study data, we have estimated potential city-wide GHG emissions reductions under several congestion mitigation strategies.

Scenario 1: Improvement in Traffic Operations and Management (i.e., Connected and Adaptive Traffic Signal System)

An existing study has shown that the implementation of adaptive traffic signal systems together with the optimization of signal timing could result in travel time savings at the level of 10% *(16)*. For our analysis, three levels of improvements, 5%, 10%, and 15%, were used, respectively. In Metro Manila, traffic signals are managed separately by 17 different governmental jurisdictions, most of which do not operate adaptive systems. These systems are not coordinated, resulting in a citywide sub-optimal system.

Under the existing condition at EDSA (pilot corridor), the emissions are estimated to be 641.98 ton/day and 594.92 ton/day for the inner and outer loop, respectively. Under the low (5%) improvement level, the speed was increased by 5%, the emission is estimated to be 629.73 ton/day and 582.90 ton/day for the inner and outer loop. Assuming the number of ordinary working days in Philippines is 247 *(17)*, the savings per year is (641.98 – 629.73 + 594.92 – 582.90) * 247, which is 5994.69 ton/yr. The length of EDSA and the major arterials in Metro Manila is 28.1 km and 1199.2 km *(18)*, respectively. Thus, the network ratio is 1199.2 / 28.1, that is 42.68, and the potential emission saving for Metro Manila per year is 5994.69 * 42.68, which is 255,853 ton/yr.

Similarly, under the mid-level improvement (10%) and high-level improvement (15%), the total emission savings for Metro Manila would be 485,036 ton/yr and 692,818 ton/yr, respectively.

Scenario 2: Improvement in Transportation Demand Management (i.e., Congestion/Road Pricing)

An existing study estimated that the implementation of congestion/road pricing can lead to 2% - 10% vehicle miles travelled (VMT) reduction *(19)*. The potential emissions saving under three different levels of VMT reductions (i.e., 2%, 6%, and 10%), is estimated to be 187,436 ton/yr, 562,308 ton/yr, and 936,969 ton/yr, respectively.

Scenario 3: Improvements in both Traffic Operations and Management and Transportation Demand Management (i.e., Adaptive Traffic Signal System + Congestion/Road Pricing)

If both traffic operation and demand management strategies were implemented, and the same performance improvement levels were assumed (i.e., low-level improvement: 5% + 2%, mid-level improvement: 10% + 6%, and high-level improvement: 15% + 10%), the resulted emission saving is 438,124 ton/yr, 1,018,142 ton/yr, and 1,560,526 ton/yr, respectively, which clearly satisfies the requirement of TCAF or similarly ambitious large-scale transport emissions mitigation program.

CONCLUSION

In conclusion, this study leveraged emergent sources of big data to develop a low-cost methodology to measure the GHG mitigation effect from activities undertaken to mitigate traffic congestion across difference cities and countries. The methodology will support carbon finance initiatives that seek to incentivize emissions mitigation in the transport sector through large-scale congestion interventions, which previously could not be included in carbon finance programs for lack of a practical, affordable means to evaluate program impact. The interventions measurable through this method include: reducing the congestion period duration, while improving traffic speeds and reducing stop-and-go travel – such as traffic signal timing improvements or other traffic operational management measures; reducing overall vehicle miles travelled, such as changes to the modal split (e.g., replacement of jeepnies with buses); and/or affecting the fuel mix, such as changes to electric or hybrid buses.

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