EXPLORATION ON QUANTIFYING CARBON DIOXIDE (CO_2) EMISSION FROM ROAD TRAFFIC IN MEGACITY

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ABSTRACT:

As the increasing concern for climate change, quantification on greenhouse gas (GHG) emissions in urban scale has been a key component for local climate actions. To explore an approach on estimating the GHG emissions closely to the real-world condition, in this paper, we make efforts on counting the carbon dioxide (CO_2) emissions from road traffic in Tokyo. The road traffic emissions mapping is achieved by linking spatial road line data with detailed activity data (traffic census). Through the data processing by Geographic Information System technique, the emissions of each road segment are estimated basing on the daily average traffic amount and speed of vehicles on each road segment. As our estimation, the CO_2 emissions from road traffic of Tokyo in 2015 are about 16,323 Gg. The highlight points mainly refer to linking the traffic census information for the observed road segments on map and allocation efforts for unserved ones. As the limited amount of observation points in traffic census, accurate estimation for unobserved road segments is a challenge. Our approach overcomes it by assumption of a familiar traffic condition for all road segments in the same sub-city area. This approach could simulate the traffic patterns closely to the real traffic condition so that it will more effectively support the emission mitigation policies on road traffic for local climate.

1. INTRODUCTION

The increasing atmospheric carbon dioxide (CO_2) concentration is lead due to the largest contributor of anthropogenic emissions as proposed by Le Quéré et al., 2016 in global carbon budget 2016. Among that city emissions are account for more than 70% (Oda et al., 2017). As reported by International Energy Agency (IEA), 2016, worldwide transport sector in 2014 as a whole was responsible for 23% of total CO_2 emissions from fuel combustion and road transport was responsible for 17%. Thus, transport is a major contributor to global climate change as a kind of anthropogenic activity. The mitigation potential of that is significantly large. Better understanding on the transport emission could support the mitigation policies more effectively. In recent years, two major measurements to understand the emissions are monitoring e.g. Frey et al., 2001; Zechmeister et al., 2006; Bishop et al., 2008; Liu et al., 2011 for road traffic emissions, and model-quantification (e.g. Namdeo et al., 2002; Smit et al., 2007 for road traffic; Corbett et al., 1997, 2003, 2010; Endresen et al., 2003; Du et al., 2011 for marine; Pison et al., 2004; Unal et al., 2005; Zhu et al., 2011 for aircraft). Corsmeier et al., 2005 have conducted a study on comparing the gaseous and particulate emissions from real-world road traffic by these two measurements. When talking about the air pollutants for road traffic emissions, carbon monoxide (CO), hydrocarbon, lead compound, nitrogen oxide (NO_x), and particulate matter ($PM_{2.5}$ & PM_{10}) are mainly mentioned. However, there is a growing emphasis on global greenhouse gas effect, especially for the major contributor CO_2.

In some cases, continuous observations of emissions from a source are available, but usually direct measurements are unavailable, and emissions must be estimated. Vehicles are the source of CO_2 emissions from road transport. As the mobility of vehicles, it is impossible to monitor the emissions from all of them. A common way to quantify that is downscaling the total emissions that estimated by the statistics data on total fuel used by vehicles and emission factors. For instance, Nejadkoorki et al., 2008 have developed an approach to estimate road traffic CO_2 emissions for an urban area in UK. Kannari et al., 2007 downscaled the total road emissions into 1×1 km mesh for Japan. Bun et al., 2018 downscaling the total into all road lines for Poland. Janssens-Maenhout et al., 2017 have made efforts on doing that for global scale. However, there are some limitations by this kind of downscaling efforts e.g. uncertainty on location of emission sources and fuel consumption data relevant with road traffic increases when implementing downscaling, and there is assumption that each type of road with the same traffic flow so that it could not well reflect the real-world traffic patterns.

“Bottom-up” approach, where local source activities are described in detail could better estimate urban emissions with higher spatial resolution. To overcome these challenges, in this paper, we make efforts on quantifying the CO_2 emissions from road traffic in urban scale by bottom-up approach. With this approach the real-world traffic census information is applied for

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relevant road lines. Tokyo metropolis is the capital of Japan with a large number of vehicles in use (4,419,478 automobiles by Automobile Inspection & Registration Information Association, 2018). In hence, the emissions from that are very large and there could be high mitigation potential. Thus, accurately quantifying the road traffic emission is essential to support the local climate actions. To conduct a pilot study, Tokyo is chosen as the study area.

2. METHODOLOGY

2.1 Workflow on estimating emissions from road traffic

Complying with Intergovernmental Panel on Climate Change guidelines (IPCC, 2006), the emissions from road traffic are counted by combing information on the extent to which a human activity take place (called activity data) with coefficients which quantify the emissions per unit activity. The activity data used in this estimation is extracted from traffic census by Ministry of Land, Infrastructure, Transport and Tourism, 2017. And the emission factors are extracted from a technical note by Dohi et al., (2012).

Even though each vehicle is an emission source from road traffic, it is not realistic to monitor the emissions from each vehicle. Therefore, road central lines are considered as the proxy data for the sources of emissions from fuel consumed by vehicles when passing through the road. As the flow chart shown in figure 1, the whole process on CO_2 emissions estimation from road traffic mainly contains 3 steps: mapping the observation points used in the traffic census to link them with the relevant road segments, allocating the parameters (daily traffic amount and 12 hours average speed) for the non-observed segments, and calculating the emissions for each road segment. In this study, CO_2 emissions are estimated by ArcGIS v. 10.4 and the coordination system of WGS 1984 is used on each map.

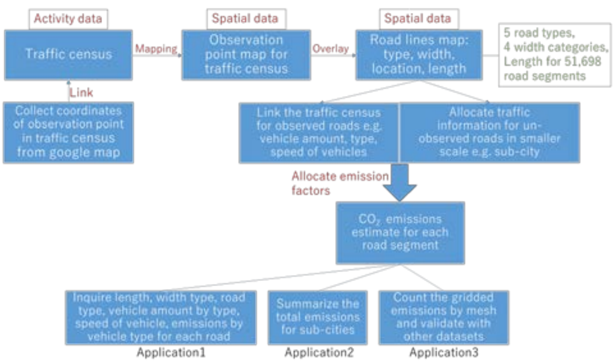

Figure 1. Flow chart on road traffic emissions mapping

2.2 Data processing on maps

As the flow chart described in figure 1, the resolution process starts from collecting the coordinates for observation points in traffic census from google map. The observation points with road traffic census information are then mapped by the coordinates and linked with the relevant road segments on map. The road lines map used for linking with activity data and emission factors is a digital road map containing detailed attributes e.g. 5 types of major roads, 4 categories of width of roads, and lengths of 51,698 road segments provided by Japan Digital Road Map Association, 2017. As the limited observation points by traffic census, the estimation for unobserved road segments is difficult. To solve this problem, we make an assumption that all road segments in one small scale area own the same traffic patterns by road type and width categories. For that, all road segments are first identified by the administrative map of sub-city and the average traffic amount and speed are summarized from the observed roads in each sub-city. And then neighbourhood allocation approach is used to allocate un-observed road segments with the same traffic information e.g. traffic amount and average speed from observed ones in the same sub-city area by width category and road type.

2.3 CO_2 emissions estimated for each road segment

The equation used for estimation from road traffic is shown in equation 1. The emissions are estimated with detailed activity data and carbon intensity by different speeds of vehicles. The activity data on the daily vehicle amount and average speed is extracted from the traffic census. Traffic census is conducted by government for all provinces every 5 years in Japan and it contains investigations on road conditions, traffic amount, and travel speed of vehicles (average). 5 types of road segments are chosen as investigate target e.g. high-speed national highway, urban highway, general national highway, major regional roads (prefectural roads and designated city roads), and general regional roads. In traffic census, all vehicles are classified into 2 types e.g. small vehicle (light passenger car, regular passenger car, light truck, and small freight car), and large vehicle (bus, regular truck, and special use vehicles). The emission factors by speed and vehicle type are listed in table 1. Through calculation in attribute table of the road layer, carbon intensity by speed is allocated for each road segment as the values of speed from traffic census.

$$E_{ro} = \sum(A_{vt,rt} \times EF_s) \tag{1}$$

where E_{ro} is the annual emissions from road traffics, A is the annual vehicle amount passing through a road segment, vt is the type of vehicles, rt is the type of roads, EF is the carbon intensity data, s is the speed of vehicles.

Speed: km/h	Intensity for small vehicles: g CO_2/vehicle/km	Intensity for large vehicles g CO_2/vehicle/km
5	437.1	1645.8
10	328.8	1371.7
15	237.1	1099
20	209.8	1013.8
25	187.5	928.7
30	171.3	855.7
35	158.9	793.7
40	149.5	741.9
45	142.2	700.1
50	136.9	667.9
55	133.2	645.4
60	131.1	632.3
65	130.3	628.6
70	130.9	634.3
75	132.8	649.3
80	135.9	673.6
85	140.2	707.2
90	145.6	750.1

Table 1. Carbon intensity data by 2 types of vehicles used for estimating the road traffic emission

From table 1, we could find that the carbon intensity value increases when the speed enlarges until 65 km/h and then that

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decreases as the speed increased. The intensity data of large vehicles are significant larger than small vehicles at the same speed. The vehicles emit the least CO_2 emissions when the speed reaches about 65 km/h. And that are the largest when the speed is close to 0 km/h e.g. the traffic congestion and idling condition. Thus, beside reducing the vehicle number, decreasing the idling time and traffic congestion are also effective to mitigate the road traffic emissions. Using public traffic is also useful to decrease the emissions per capita rather than the use of car.

3. RESULTS AND DISCUSSIONS

3.1 Primary result

After emissions from all road segments are estimated, the visualization tool of symbol function is used to show that on map. The result map on road traffic CO_2 emissions in Tokyo 2015 is shown in figure 2 (island areas are included in calculation but excluded on the result maps), and the length, width category, road type, vehicle amount by type, speed of vehicle, and annual CO_2 emissions by vehicle type for each road could be inquired on map. Blue lines show lower emissions from road segments and the highest emission road segment emits about 11 Gg CO_2 per year (red line). The total emissions from road traffic of Tokyo in 2015 is about 16,323 Gg CO_2.

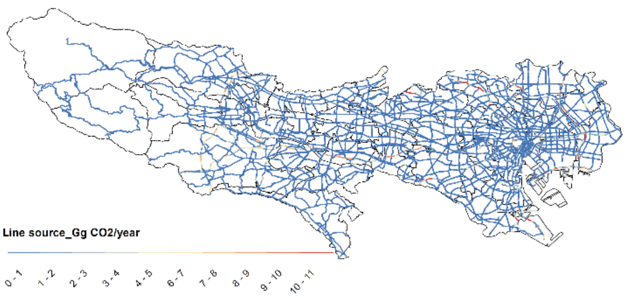

Figure 2. The CO_2 emissions map on road traffic of Tokyo in 2015, unit: Gg CO_2 yr^{-1}

3.2 Sub-city total emission map

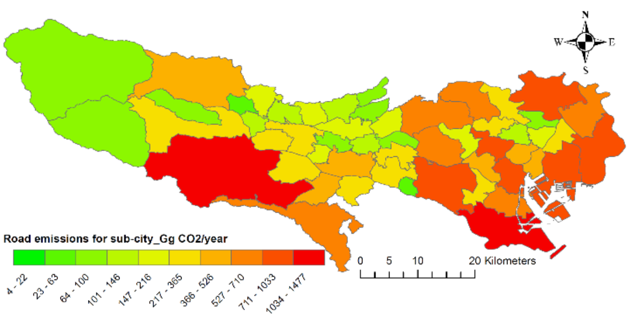

Figure 3. Total CO_2 emissions from road traffic in each sub-city of Tokyo in 2015, unit: Gg CO_2 yr^{-1}

As an application, we also summarized emission total for each sub-city by using the administrative map provided by Ministry of Land, Infrastructure, Transport and Tourism, 2017. As the result map shown in figure 3, the total annual CO_2 emissions from road traffic of sub-city are about 4 Gg (small island area) to 1,477 Gg (Hachioji). From this map, traffic amount, vehicle speed, and annual emissions by vehicle type for each sub-city could be confirmed. To that end, the result map containing the detailed information in sub-city scale make it possible to implement the mitigation actions from urban scale down to sub-city scale. It will also be helpful for evaluating the effect of mitigation policies.

3.3 Compare the differences with EAGrid-Japan inventory

To compare our result with other dataset, a 1×1 km mesh from a national inventory of East Asian Air Pollutant Emission Grid Database for Japan (EAGrid-Japan) made by Kannari et al, 2007 is used to summarize the gridded total emissions for our result. As the result shown in figure 4, the higher emission area (in red) locates in the east central area of Tokyo where the traffic amounts are large. The largest gridded total emission is about 157 Gg per year. The west area (in green) shows extreme low emissions where belongs to mountain and forest area. The grey grids reflect the zero emission areas.

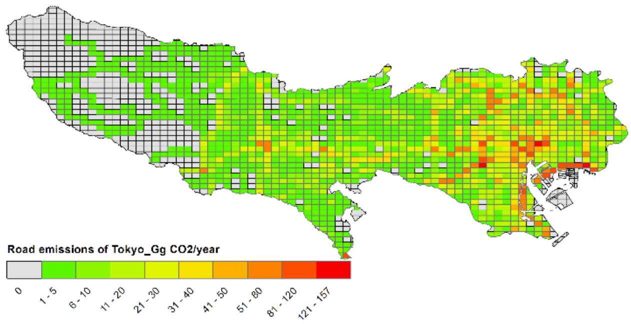

Figure 4. CO_2 emissions map with a resolution of 1×1 km on road traffic of Tokyo in 2015, unit: Gg CO_2 yr^{-1}

Then we also extracted the gridded emission map on road traffic in Tokyo domain from the latest version of EAGrid-Japan, EAGrid-Japan 2010 updated by Fukui et al., 2014. The result is shown in figure 5 and the largest gridded total is about 52 Gg per year. The total emissions are about 14,659 Gg per year. Our total result is larger than that of EAGrid-Japan 2010. The reason for that is EAGrid-Japan made the emission map by downscale the national total emissions in 2010 into each grid with the gridded total of road length by road width categories. From figure 4 and figure 5, we could see familiar distribution of gridded emission values for the high and low emission areas.

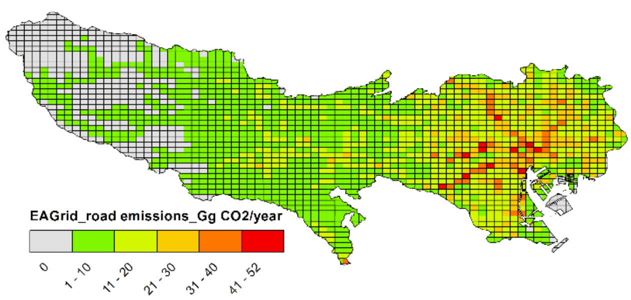

Figure 5. CO_2 emissions map on road traffic of Tokyo from EAGrid-Japan 2010, unit: Gg CO_2 yr^{-1}

Another reason is that the downscaling efforts used by EAGrid-Japan are made under the assumption that the same type of roads in the mesh are with the same traffic patterns so that the result could not accurately reflect the real traffic conditions. To make the update version, the emissions in 2010 are estimated by using emissions value in 2000 multiplied by the variation ratio of national total fuel consumption data in 2010 referring to 2000.

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However, location of emission sources for 2010 reused the same distribution with 2000. Therefore, the spatial variation of roads from new construction and end of use since 2000 could lead the errors on the distribution of emissions in EAGrid-Japan 2010. We also recognized limitations of this approach e.g. the uncertainty that contained in the allocation process for un-observed road segments and the exclusion of the narrow roads.

4. CONCLUSIONS

In this study, we developed approach to quantify the CO_2 emissions from road traffic in Tokyo basing on detailed information from traffic census. Due to the availability of traffic census data, this kind of bottom-up approach we used could be applied in other cities of Japan. As a result, the CO_2 emissions from road traffic of Tokyo in 2015 are about 16,323 Gg.

Through the comparisons with a national CO_2 emission inventory of EAGrid-Japan 2010, our result shows familiar distribution with it. And the advantage of this approach is that from the result map we could detect detailed information on e.g. road type, width category, length, vehicles amount, speed, and annual emissions from each road segment rather than only the gridded total emissions provided by EAGrid-Japan. Limitations of this approach mainly refer to the uncertainty from allocation efforts for un-observed road segments and the exclusion of the narrow roads.

As the success on mapping for the CO_2 emissions from road traffic in urban domain, it will support the local climate actions in future. To effectively mitigate the emissions from road traffic, our suggestions are that reducing the vehicle number, decreasing the idling time & traffic congestion, and keeping the travel speed at about 65 km/h.

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