Chapter 4

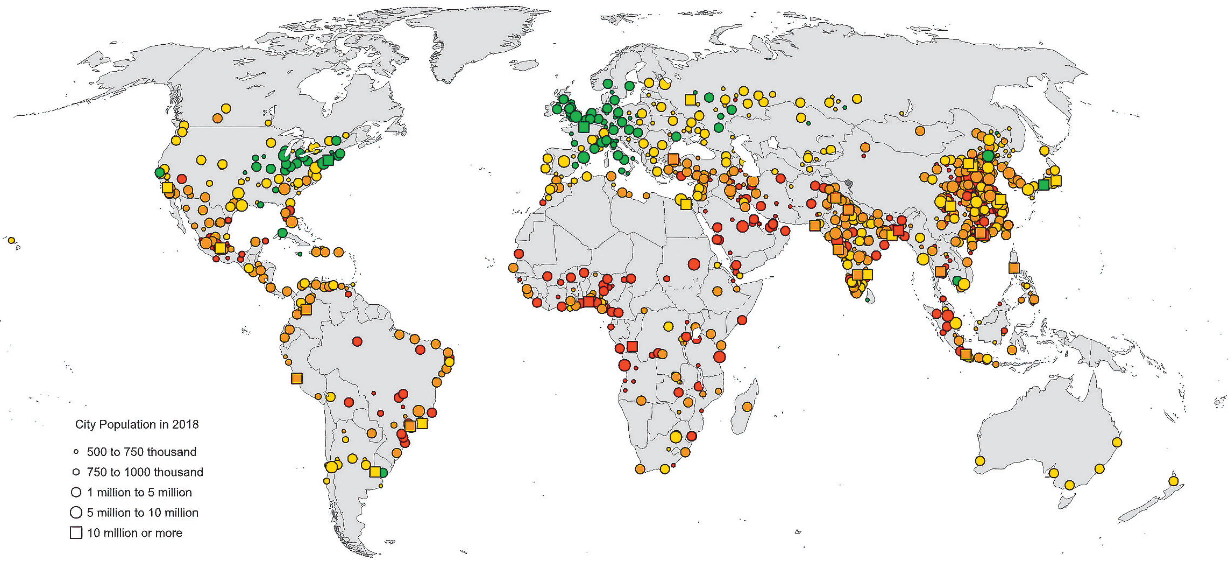
Measurement of Impacts on GHG Emission Reductions by Smart City

More than 90 % out of 16 GHG gas that cause global warming is carbon dioxide. Therefore, reducing carbon dioxide emissions from our activities is the central policy for low carbonization and the most important effort to curb global warming.
This carbon dioxide is also emitted by our fundamental activities such as breathing, etc., but the main cause is that it burns fossil fuels consisting of hydrocarbons, an oxidative action that combines carbon with oxygen through the process of obtaining energy. Therefore, Carbon dioxide is emitted from all activities that use fossil fuels as energy. Next to the industrial sector, which requires a lot of energy, and the household sector, which is involved in our daily activities, carbon dioxide emissions from the internal combustion engine-powered transportation sector are high. In particular, transportation such as automobiles is powered by an internal combustion engine that uses gasoline and diesel as its main energy sources, so it is one of a major source of carbon dioxide emissions in cities that require a lot of travel. Even in the case of trains and electric vehicles, which have become increasingly popular in recent years, carbon dioxide is emitted if thermal power is used to generate electricity from view point of life cycle. Therefore, in promoting smart cities, the realization of a transportation system that is efficient, that is, reduces unnecessary movement as much as possible, is the key to reducing greenhouse gas emissions.

Currently, cities consume over two-thirds of the world's energy and account for more than 70% of global carbon dioxide emissions. Thus, achieving smart cities and reducing greenhouse gas emissions in cities is the most important step in combating global warming. Naturally, carbon dioxide is emitted from various activities in industry and homes even in cities, but the proportion of the amount emitted from transportation is very large. In particular, as cities grow in size, they become more active, have a wider range of travel, become more crowded, consume more energy, or emit more carbon dioxide.

It is expected two-thirds of the global population will settle in towns and cities by 2050. As shown in Figure 4-1 [1], 90% of this urban growth will take place in less developed regions such as East Asia, Sub-Saharan Africa, and South Asia including India. In such areas, urbanization is largely unplanned, fueling the continuous growth of mostly poor informal settlements. Currently home to some 1 billion people, informal settlements are where the impact of climate change is most acute. This situation will be more serious.

Figure 4-1 World Urbanization Prospects [1]



Thus, urban development, especially smart city development will play significant role in climate action. Urban density can also create the possibility for a better quality of life and a lower carbon footprint, for example through improved standards in house building and more efficient infrastructure and planning. This is one of the goals of smart cities. But the most important measure is how to achieve an efficient transportation system. This will significantly reduce emissions from transportation, which is the main source of carbon dioxide emissions, and reduce carbon emissions throughout the city.

How to estimate carbon dioxide emissions in a city?

In order to measure the low-carbon effect of the realization of smart cities, it is first necessary to consider how to estimate the amount of carbon dioxide emitted from current cities. Generally, there are two possible methods for estimating carbon dioxide emissions: a bottom-up approach and a top-down approach (Figure 4-2). Due to the variety of activities taking place in cities, it is quite complicated to estimate overall emissions with a bottom-up approach. Basically, the amount of activity for each activity is grasped, and this is multiplied by the emission factors to obtain it. If it can be organized as an inventory for each activity, it can be accumulated and the total emission amount can be estimated, but finding all of them is a huge task. In addition, there is a boundary problem. Since there are various exchanges between cities and other regions, it becomes a difficult problem to define how much emissions are limited to cities.

On the other hand, the top-down approach is a method of estimating carbon dioxide emissions based on energy consumption of the city as a whole. For example, if you know the energy consumption of the country as a whole, there is a way to estimate the contribution of the city from the ratio of the inhabitants living in the city and the industry in which it is located. Alternatively, if the carbon dioxide emissions of the country as a whole are estimated, it is possible to estimate the contribution in the same way mentioned above. If the energy consumption of each city is directly known, it is not so difficult to estimate the carbon dioxide emissions from it. If the above statistics are not

Figure 4-2 Top-down and Bottom-up Approach

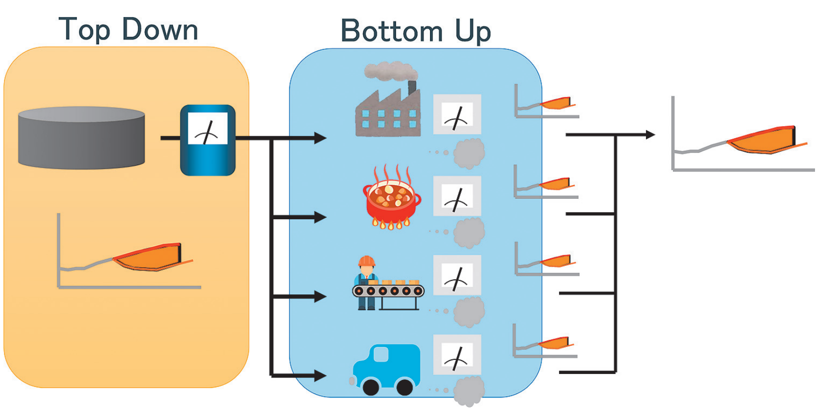


Figure 4-3 Bottom-up Approach

available, carbon dioxide can be estimate the amount of emissions by analyzing the relationship between some activity and carbon dioxide emissions in other cities and extrapolating the activity of the target city to this relationship. However, when adopting a top-down approach, it is difficult to estimate the effectiveness of individual reduction measures. Therefore, this method can be used when the emission whole is calculated as a frame.

1: Bottom-up approach

The amount of carbon dioxide emitted from each activity can be calculated by multiplying the basic amount of activity by the emission factor, as shown in Figure 4-3. When estimating carbon dioxide emissions in the transportation field, the emission factor is shown as emissions per unit distance, per vehicle, or per person, based on an inventory of emissions. In the case of automobiles, the amount of fossil fuel consumed varies greatly depending on the driving conditions, so the amount of carbon dioxide emissions also changes. In such cases, the emission factor is expressed as a function such as velocity. For such emission factor, after creating a driving mode in each city, carry out chassis dynamometer test according to this mode to measure carbon dioxide emissions, and create a curve showing emission factor by speed.

On the other hand, the amount of activity is calculated by the product of traffic volume and mileage. Therefore, it is generally expressed as a kilometer or a person kilometer for each road section. In addition, if the emission source is a function of velocity, the average velocity for each road section is also required. These traffic volumes and average speeds can be calculated by calculating the traffic volume distribution.

If you want to consider changes in carbon dioxide emissions due to vehicle driving conditions, apply an emission model to the driving conditions of each vehicle in a micro traffic simulation to estimate changes in carbon dioxide emissions in considerable detail. It is also possible to do.

2: Top-down approach

When estimating carbon dioxide emissions at the national or regional level, a top-down approach is employed. Among estimation formulas based on a top-down approach as shown in Figure 4-4, the Kaya formula is the most widely known.

In this formula, total CO_2 emissions can be expressed by multiplying (1) CO_2 emissions per energy consumption, (2) energy efficiency of economic activities, (3) economic level per capita, and (4) population.

By using this formula, it is possible to explicitly incorporate the population size and economic level of each country into the estimation of carbon dioxide emissions, and it is possible to analyze the impact of economic development on the increase in carbon dioxide emissions. In this formula, except for (2) Energy efficiency of economic activity, each value can be obtained relatively easily by basic statistics such as economic statistics and demographic statistics. It should be noted that (2) Energy efficiency of economic activities is affected by the technological level of each country.

When estimating emissions as a city, it is conceivable to apply the Kaya equation and input data for the city bell to estimate, as in the case of estimation at the national level. Alternatively, it is conceivable to divide the estimation results at the national level into the ratio of the economic activity level of each city to obtain the emissions at the city level. The former method cannot be estimated without statistics showing economic activity at the city level.

It should also be noted that the energy efficiency of economic activity can vary between cities and other regions, or from city to city.

CO_2 Emission in Indian cities

There are many estimates of GHG emissions for cities in the world. For example, Moran, et al. [2] estimated carbon footprint of 13,000 cities including Indian cities based on carbon footprint per capita. Carbon footprints in top 25 India cities are in Table 4-1. Since this is estimation of top-down approach,

Figure 4-4 Top-down Approach

it is hard to identify the contribution by sectors.

On the other hand, Ramachandra, et al. [3] estimate uses a bottom-up approach to estimate GHG emissions in major cities. In Table 4-2, it can be seen that the ratio of emissions from road traffic is 13% to 56%, which varies greatly depending on the city, but the ratio of road traffic to the total emissions is large.

Table 4-1 Carbon Footprint of Top 25 India Cities [2]

Urban cluster	Footprint/cap ($t\ CO_2$)	Population	Footprint ($Mt\ CO_2$)	Global ranking	Domestic ranking
New Delhi	2.6 ± 0.6	27,230,000	69.6 ± 16.0	30	1
Kolkata	1.7 ± 0.3	24,792,000	42.9 ± 8.2	49	2
Mumbai	1.5 ± 0.3	21,450,000	32.1 ± 6.5	70	3
Hyderabad	3.2 ± 0.7	8,396,000	26.5 ± 6.2	90	4
Chennai	2.3 ± 0.6	9,483,000	21.8 ± 5.6	108	5
Bangalore	2.0 ± 0.6	10,591,000	21.6 ± 6.0	110	6
Pune	2.8 ± 0.9	6,697,000	18.9 ± 6.1	130	7
Ahmadabad	1.8 ± 0.7	6,635,000	12.2 ± 4.5	185	8
Malapuram	2.0 ± 0.5	4,812,000	9.5 ± 2.5	234	9
Jaipur	2.5 ± 0.9	3,819,000	9.4 ± 3.3	238	10
Chandigarh	3.9 ± 1.3	2,247,000	8.8 ± 2.9	257	11
Lucknow	1.8 ± 0.7	4,590,000	8.5 ± 3.2	269	12
Nagpur	2.8 ± 1.0	2,982,000	8.3 ± 2.9	273	13
Indore	2.6 ± 1.0	2,844,000	7.5 ± 2.9	291	14
Coimbatore	3.2 ± 1.4	2,213,000	7.2 ± 3.2	303	15
Vadodara	3.5 ± 1.3	1,987,000	6.9 ± 2.7	321	16
Kanpur	1.7 ± 0.7	3,776,000	6.5 ± 2.5	342	17
Asansol	1.9 ± 0.7	3,245,000	6.1 ± 2.2	356	18
Ludhiana	2.9 ± 1.3	2,081,000	6.0 ± 2.7	365	19
Raipur	2.1 ± 0.7	2,684,000	5.7 ± 1.9	390	20
Bhopal	2.4 ± 0.9	2,277,000	5.5 ± 2.0	404	21
Kavaratti	1.7 ± 0.5	3,106,000	5.1 ± 1.6	436	22
Varanasi	1.1 ± 0.5	4,165,000	4.6 ± 1.9	485	23
Surat	1.2 ± 0.5	3,698,000	4.6 ± 2.0	487	24
Cochin	2.2 ± 0.6	2,013,000	4.5 ± 1.3	491	25

Table 4-2 GHG emission in Major India Cities [3]

	Emission ratio by field (%)							
City	Total emissions (Mton)	Road Transport	Domestic Sector	Industry	Agriculture & Livestock	Waste & Waste water	Electricity consumption	Auxiliray consumption & Transmission lose
Delhi	38.648	32.08	30.26	7.89	2.49	5.78	19.28	2.22
Greater Mumbai	22.797	17.41	37.20	7.89	0.12	8.46	23.44	5.48
Kolkata	14.812	13.30	42.78	17.66	0.22	7.18	17.04	1.82
Chennai in 2009-10	22.086	19.50	39.01	20.25	0.05	3.72	15.77	1.70
Greater Bangalore	19.799	43.48	21.59	12.31	1.31	5.73	15.46	0.13
Hyderabad	13.734	56.86	17.05	11.38	0.46	6.70	7.54	0.00
Ahmedabad	9.123	24.92	27.88	22.41	1.52	7.17	11.80	4.31

References

[1] National Institute of Corrections: 2018 Revision of World Urbanization Prospects. https://info.nicic.gov/ces/2018/global/population-demographics/2018-revision-world-urbanization-prospects-0, 2018.

[2] Moran D., K. Kanemoto, M. Jiborn, R. Wood, J. Többen, and K. C. Seto: Carbon Footprints of 13 000 Cities. Environmental Research Letters, Vo.13, No.6, 064041, 2018.

[3] Ramachandra T.V., B.H. Aithal and K. Sreejith: GHG Footprint of Major Cities in India. Renewable and Sustainable Energy Reviews, Vol.44, pp.473–495, 2015.