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Estimation of passenger car CO_2 emissions with urban population density scenarios for low carbon transportation in Japan☆

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ABSTRACT

The aim of this study is to quantify the potential reduction of CO_2 emissions by passenger vehicles over the long term through the introduction of compact cities. We determined the correlation between population distribution and passenger car CO_2 emissions from 1980 to 2005 and simulated passenger car CO_2 emissions in 2030 under both compact and dispersed scenarios. We conducted correlation analysis and scenario analysis with the data sets of municipal CO_2 emissions of passenger cars, national population census figures, and future population distribution scenarios. Then, we estimated the annual CO_2 emissions of passenger cars per capita by mesh cell density category. The results show that the difference in emissions per capita between the compact and dispersed scenarios is roughly 5% in Japanese municipalities as a whole.

1. Introduction

Cars account for roughly 20% of all CO_2 emissions in Japan. The Japan's Intended Nationally Determined Contribution (INDC) for greenhouse gas emissions is taken as a 26% reduction in GHG emissions by 2030 from 2013 levels. The Japanese cabinet has announced its long-term emissions reduction target of 80% by 2050 compared to 1990 levels. Given these conditions, avoiding climate change will require not only improvements in the fuel efficiency of cars but also reductions in the distances that cars travel.

However, meaningful reductions in the distances that passenger cars travel involve more than just individual effort. Take a person who decides to ride the bus to work instead of driving his or her own car, for instance. If riding the bus means having to catch one of only a few available buses every day or needing to make a much longer commute, the transition from driving to riding would be an unrealistic shift to make for that individual. From the medium- to long-term perspective, people would need to choose new places to live or travel to.

In the society-wide context, these selections coalesce to propel one of the most effective ways of cutting passenger car CO_2 emissions: modifying urban structures to create urban land use that eliminate excessive dependence on cars. The practice of controlling urban structures, called “transit-oriented development” (TOD [1]), has gained recognition as a useful method for limiting the amounts of CO_2 emissions from passenger cars. That said, observers can only speculate about how making medium- to long-term changes to the urban structures of cities across Japan will impact CO_2 emission levels.

Through empirical research, Newman et al. [2] showed that higher land use density correlates to lower gasoline consumption. Critics of the study, however, have argued that the researchers oversimplified the idea of city density into a single value and ignored the various conditions that create differences among countries and cities; due to these and other problems, scholars have cast doubt on the idea that increased density leads to reduced energy consumption [3].

This study, which focuses on cities in Japan, thus formulates correlations between passenger car CO_2 emissions by city over a 25-year period (1980–2005) and the population density of each mesh cell for each city to produce estimates of CO_2 emission volume by mesh cell size. We also use this input and past demographic data to create two population distribution scenarios for the year 2030. Through scenario analyses that assess the potential of differences emerging under each set of scenario conditions, we aim to identify the ideal population distribution patterns for cutting CO_2 emissions and outline the effects of said patterns.

2. Materials and methods: an overview of the data used and the analyses performed

The Japanese government conducts sampling studies of car usage and complete censuses of national demographics every five years. Using the following three sets of data, we performed analyses as shown in Fig. 1.

a) Annual passenger car CO_2 emissions by municipality at six points in time (1980–2005)

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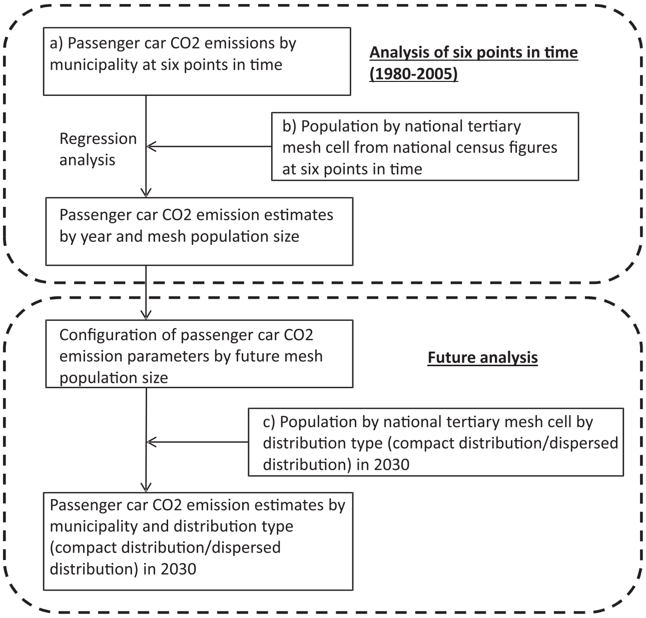

Fig. 1. Analysis process.

We created this set of CO_2 emission estimates for each municipality with passenger car registration data from Road Traffic Censuses and Vehicle Origin–Destination Surveys, which the Japanese government generally conducts at five-year intervals to investigate the movement of cars throughout Japan. The 1994 and 1999 surveys deviated from this five-year schedule, each occurring one year early. The sampling study data, which covers approximately 2% of all passenger car owners in Japan, describes the travel distance per trip unit on a single weekday and a single non-weekday in the fall. We multiplied this travel distance by the primary unit of emission volume per unit of travel distance by vehicle type, which we determined based on the national figures for travel distance by vehicle type, fuel consumption, and emission factor by fuel type (see Formula 1). Annual emissions by municipality are calculated by aggregation of the emissions by day type, area and vehicle type. The emissions in towns and villages should be paid attention on the uncertainty because the number of samples might be not enough. The process for a) adheres to the approach of Matsuhashi et al. [4].

$$C_{art} = e_t \sum_i d_{arti} \qquad (1)$$

C_{art}: CO_2 emissions by day type (weekday/non-weekday), municipality, and vehicle type.

e_t: emission factor by vehicle type (mini cars, small cars, buses, mini freight vehicles, light duty vehicles, passenger-freight vehicles, heavy duty vehicles, specific purpose vehicles).

d_{arti}: travel distance per trip unit by day type (weekday/non-weekday), area, and vehicle type.

a: day type (weekday/non-weekday).
r: municipality of vehicle registration.
t: vehicle type.
i: trip number.

b) Population by national tertiary mesh cell from national census figures at six points in time (1980–2005).
This data aggregates national census population figures into a tertiary mesh (a grid that divides the land area of Japan into mesh cells measuring 1 km by 1 km). The Japanese government conducts national censuses every five years.

c) Population by national tertiary mesh cell by distribution type (compact distribution/dispersed distribution) in 2030.

We created two municipal population distribution scenarios for use with identical municipal populations. By applying opposite patterns of population distribution changes that municipalities have experienced in recent years (compact distribution/dispersed distribution) to future conditions via the cohort change ratio method, we constructed two highly probable scenarios. The process for c) adheres to the approach of Ariga et al. [5].

We created our population distribution scenarios based on past demographic data of 2000 and 2005. For classification purposes, we created 36 categories: we first sorted municipalities into twelve “municipality type” categories according to several variables (whether the municipality was inside or outside a metropolitan area, whether the municipality was a “city” or a “town or village,” and whether the population of the municipality was growing, shrinking, or stable) and then created three “population distribution” tiers for the twelve categories based on whether the changes in the corresponding population distributions were compact, dispersed, or static. This gave us a total of 36 categories. Next, we determined the population change parameter set for each category, sorting the data by mesh cell population size, gender, and age (at five-year intervals). We used the scope of the Three Major Metropolitan Person Trip Surveys (Tokyo, Keihanshin and Chukyo) to define “metropolitan area” for our study and set the population boundary separating cities from towns and villages at 30,000. To ensure a proper balance among the municipalities, we also set the population change threshold to $+/-3\%$ over five years. For population distribution, we set the threshold for the five-year change in the Gini coefficient of population distribution (calculated based on the cumulative residential area share and cumulative population share for the lowest-density area and moving upward; see Formula 2) to 0.01. We then derived future population distribution patterns by multiplying the data for the corresponding municipality category by the parameters for the appropriate scenario (compact distribution or dispersed distribution).

$$G = 1 - \Sigma_i b_i (p_i + p_{i-1})/10000 \qquad (2)$$

G: Gini coefficient of population distribution.

b_i: the percentage of the inhabitable land area occupied by the mesh cell with the ith-lowest population density.

p_i: the percentage of the total population represented by the cumulative population of the mesh cells with the lowest population densities (from the mesh cell with the lowest population density to the mesh cell with the ith-lowest population density).

The data sets for a) and c) are available on the “Kankyō Tenbōdai” section of the National Institute for Environmental Studies website (http://tenbou.nies.go.jp/).

We analyzed the correlation between past municipal population distribution and passenger car CO_2 emissions, operating under the assumption that mesh cell population size (population density) would affect annual per capita passenger car CO_2 emissions. As Fig. 1 shows, we first analyzed the correlation between past population distribution and passenger car CO_2 emissions based on sets a) and b). We then evaluated the results of that analysis and the possible future population distribution scenarios created by c) in terms of passenger car CO_2 emissions. We employed the regression analysis approach for the first step, using population distribution variable to explain the passenger car CO_2 emissions variable, and used the results of the first step for the subsequent scenario analysis. Although the Road Traffic Censuses for 1994 and 1999 occurred one year ahead of the conventional schedule, we appropriated the data from the 1994 and 1999 studies as the data for 1995 and 2000, respectively, in order to ensure that our estimates were consistent with the national census data.