Simulating Transport CO_2 Emission in Urban Beijing from 2000 to 2010

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1. Introduction

In the transport field, much attention is given to estimation and mitigation of CO_2 emission. Much prior research has estimated CO_2 emission using aggregate data on total energy consumed or average vehicles kilometres travelled (VKT), while not considering the influence on emission of factors that operate at a more resolved functional level, such as the neighbourhood-scale built environment (e.g. Dhakal, 2009; Cai et al., 2012). Very few studies have so far used disaggregate data to accurately estimate transport CO_2 emission based on individuals' daily urban travel, particularly for developing countries, possibly due to a lack of detailed travel data.

Using individuals or households as the basic analytical unit, spatial microsimulation potentially represents a useful tool for generating disaggregate forecasts over a long period (e.g. Ballas et al., 2005). On the basis of an activity diary survey and two data sets of population census (for 2000 and 2010), we employ spatial microsimulation to simulate a realistic synthetic populations' daily travel behaviour and estimate their CO_2 emission at a fine geographical resolution between 2000 and 2010 for urban Beijing. We also compare and analyse the changes in travel behaviour and transport CO_2 emissions during this decade, and examine the role of other factors contributing to the modelled trend.

2. Research Area and Data

2.1 Research area

We adopt urban Beijing as our case study, which comprises the urban districts of Dongcheng, Xicheng, Chongwen and Xuanwu in the central urban area, and the districts of Chaoyang, Fengtai, Shijingshan and Haidian in the inner suburban area (Figure1). We use the finer geographical (i.e. sub-district) level to provide better spatial resolution and more details in the CO_2 emission forecasts. In total, there are 146 sub-districts in 2000 and 136 sub-districts in 2010 in urban Beijing, many located in the Chaoyang and Haidian districts.

Figure 1. Research area

2.2 Data sources

This study uses multiple data sources. First, an activity diary survey, conducted in 2007 in ten representative neighbourhoods in urban Beijing, is used to derive continuous activity-travel records of many individuals on a typical workday. Further details on this survey can be found in Wang et al (2011). Second, two data sets of population census in urban Beijing are used; one is the fifth population census conducted in 2000 and the other the six population census conducted in 2010 by the national government. Several tabulations and cross-tabulations on household and individual socio-demographic attributes such as gender, age, education, employment, occupation, housing tenure, housing area, are derived as constraining tables. Moreover, land use data and statistical yearbook are employed to explore the potential factors of changing travel behaviour and CO_2 emission over 2000 – 2010 at different levels. Figure 2 presents a conceptual diagram of the multiple data sources and how they are linked through our spatial microsimulation framework.

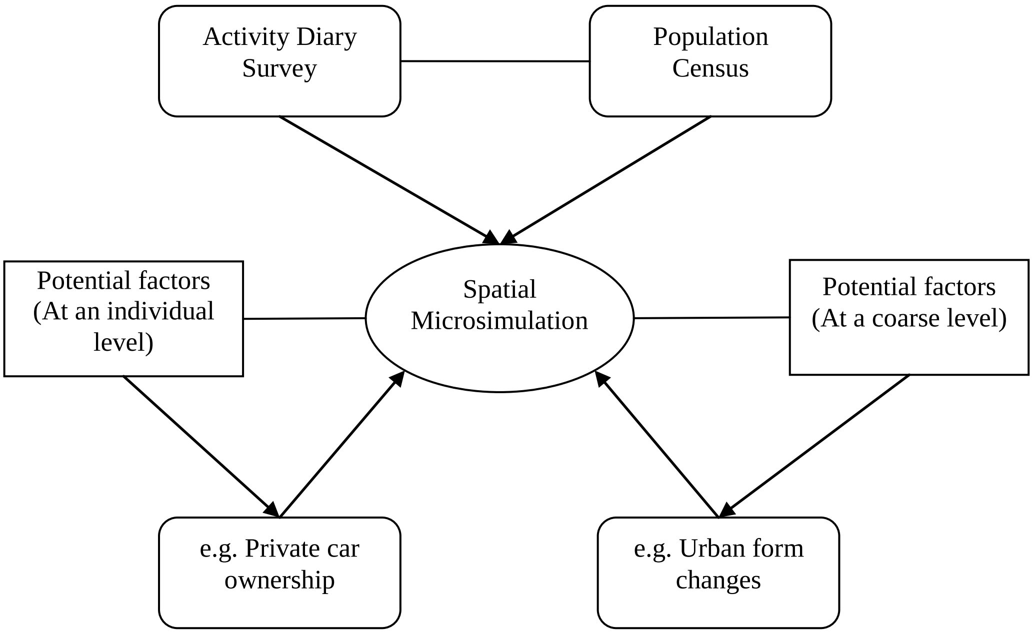

Figure 2. Data sets linking in the spatial microsimulation framework

3. Methodology

The Flexible Modelling Framework (FMF), developed at the University of Leeds, is adopted to run the microsimulation model. The FMF is a software modelling tool incorporating a static spatial microsimulation algorithm based on Simulated Annealing (Harland, 2013). Several synthesising algorithms are available; for an appraisal of the strengths and weaknesses of the three most commonly applied techniques see Harland et al (2012). The FMF also includes model evaluation options that provide a variety of fitness statistic calculations at individual cell, category and overall attribute levels.

The Simulated Annealing method is a refinement over the basic combinatorial optimisation approach of hill climbing, and is used to generate the synthetic population. It incorporates the Metropolis Algorithm allowing both backward and forward steps in the search for the optimised combination of sampled population (Harland et al., 2012). The Simulated Annealing algorithm randomly selects the synthetic population from the sample population optimising to reduce the Total Absolute Error and provide the best possible match to the real life population in each geographic zone. The weight for each individual in the sample population can be 0 representing exclusion or any number up to the total population count representing the number of times a particular individual has been selected in a specific geographical zone. The replacement criteria can be explained by an equation, as in Williamson et al (1998):

$$p(\delta E) = exp(- \delta E / T)$$

where δE represents the potential change in combination performance, and T refers to the maximum level of performance degradation acceptable for the change of one element in a combination. Regarding the replacement elements randomly selected and evaluated, those improving combination performance are automatically accepted, while those degrading performance are only accepted if $p(\delta E)$ is greater than a randomly generated number between 0 and 1.

4. Results

4.1 Estimating CO_2 emission in 2000

Using several important socio-demographic attributes (i.e. gender, age, education, employment, occupation, housing tenure, and housing area) as constraints, a realistic synthetic population is generated at the sub-district level in 2000 for urban Beijing. Further details on the synthesising process can be found in Ma et al (2014). The goodness-of-fit statistics (e.g. Total Absolute Error, Percentage Error) indicate a very good overall fit to the observed population. Then, we link the travel attributes from the survey data to the simulated synthetic population, and spatially simulate the population's travel distance and mode choice at fine geographic resolution. Transport CO_2 emissions from each individual's daily travel are also estimated based on a complete account of travel activities during the workday, derived from the survey (Ma et al., 2011). Figure 3 illustrates the average travel CO_2 emissions estimated using the synthetic population of each geographical zone in the year 2000.

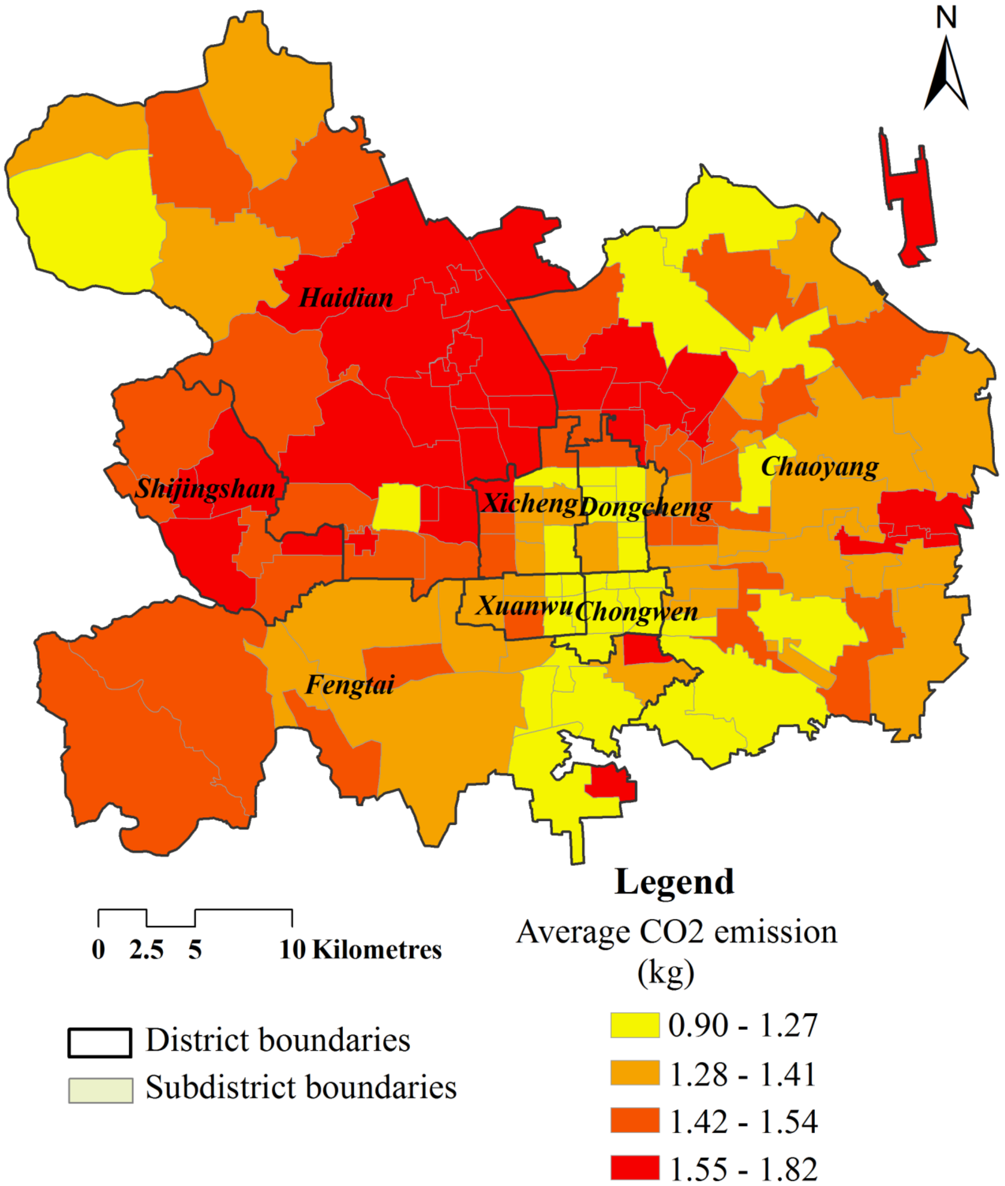

Figure 3. Average CO_2 emission from the synthetic population by sub-district in 2000

Multiplying total population by average travel CO_2 emission for each geographic zone, we can calculate the total CO_2 emission across districts in urban Beijing (Figure 4). The CO_2 emission in Haidian district is the highest, about 310 tonnes on a typical workday, followed by Chaoyang district with approximately 280 tonnes. In contrast, the districts in the urban central area, i.e. Dongcheng, Xicheng, Chongwen, and Xuanwu, have lower CO_2 emission from people's daily urban travel. In total, transport CO_2 emission estimates from the synthetic population (aged 15 and above, about 10% sample of the total urban population) peek at 1,038 tonnes on a typical workday in urban Beijing for the year 2000.

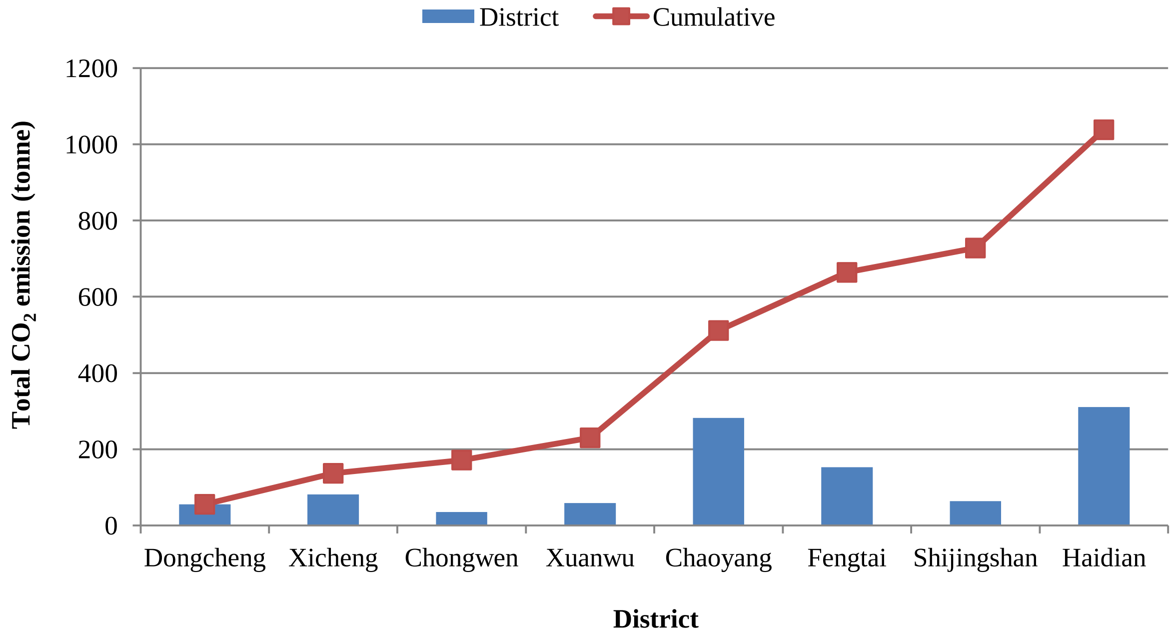

Figure 4. District CO_2 emission and the cumulative total in 2000

4.2 Estimating CO_2 emission in 2010

To explore time trends in travel CO_2 emissions, the activity diary survey and population census for 2010 are used. Again a synthetic population is generated using our spatial microsimulation approach and the population's daily travel behaviour and CO_2 emission estimates are examined across urban Beijing. For instance, Figure 5 presents the average CO_2 emission from the synthetic population in each district in 2010.

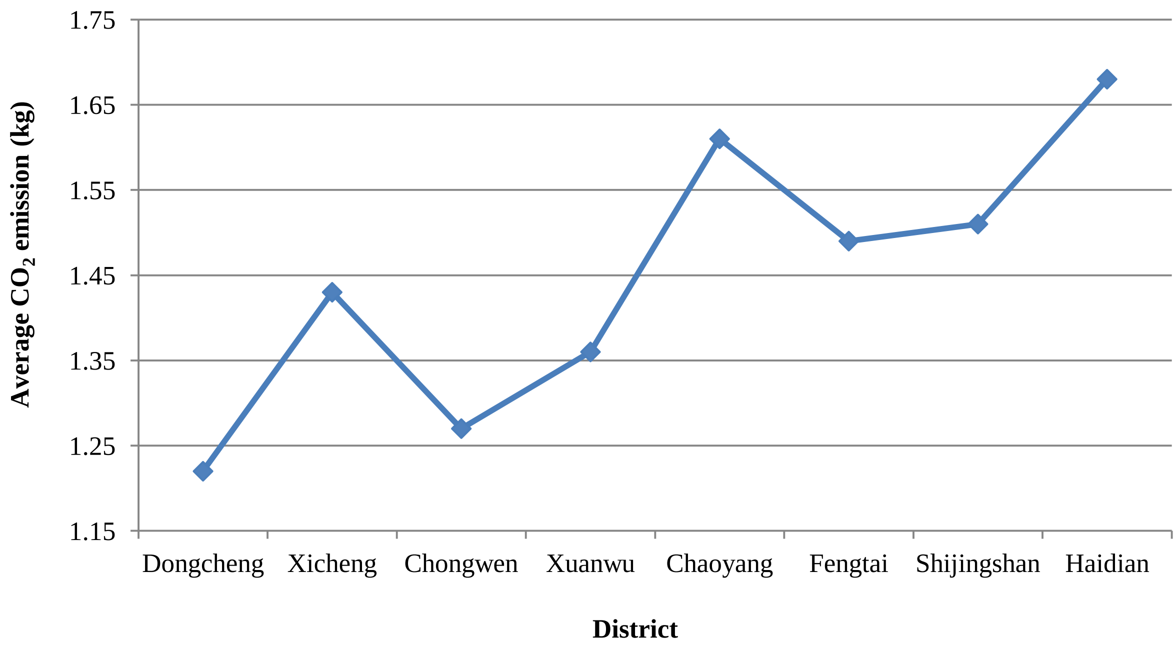

Figure 5. Average CO_2 emission from the synthetic population by district in 2010

However, this result is only a proportion of the final estimates of CO_2 emissions in 2010, as the microsimulation is mainly constrained by socio-demographic changes since the decade from 2000. Prior research has demonstrated that people's daily travel behaviour is not only influenced by socio-demographic attributes, but also by urban form characteristics and public transit/private vehicle usage. As Beijing experienced rapid urbanization/suburbanization and deep spatial restructuring process from 2000 to 2010, its urban form features – using population density as a proxy – obviously changed, as illustrated in Figure 6.

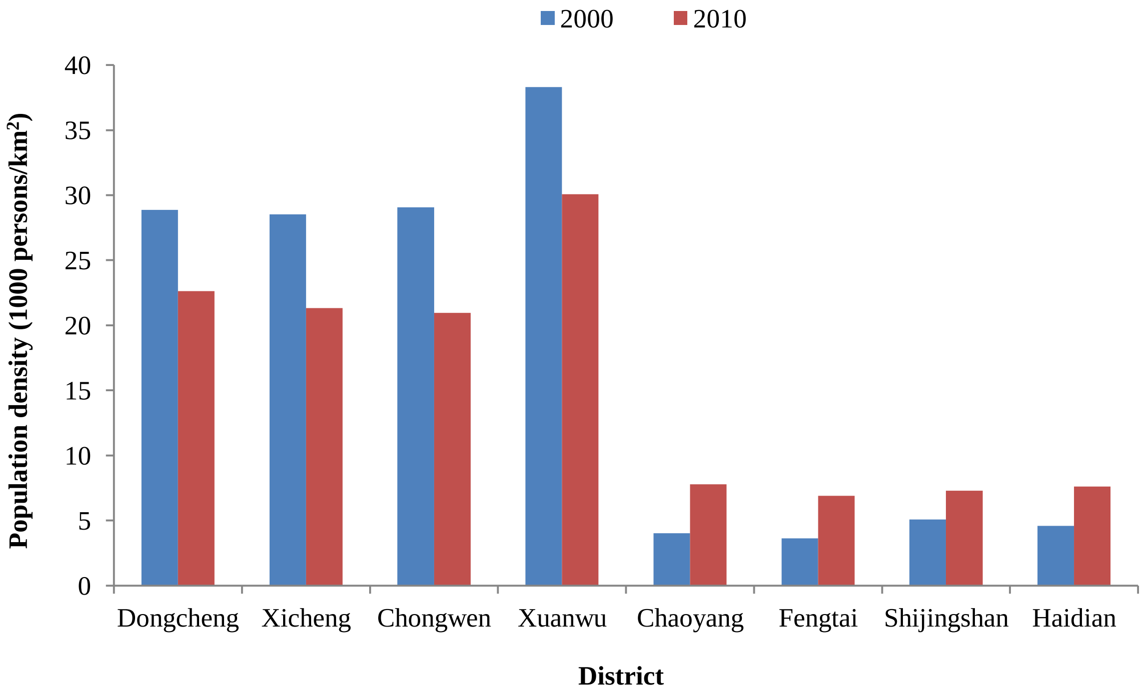

Figure 6. Population density in eight urban districts between 2000 and 2010

Moreover, the amount of private cars shows significant increase during the period 2000 – 2010 in urban Beijing, which would have an effect on the population's travel distance, mode choice and subsequent CO_2 emissions as well. Given these urban form variables are not constrained in the microsimulaiton model, we will estimate the proportion of CO_2 emissions by urban form changes and adjust the simulation results for 2010 by adding their effects. This portion of the research project is currently at an early stage and subsequently only initial results are reported here.

5. Conclusion

This study presents a spatial microsimulation approach to estimate improved transport CO_2 emission from individuals' daily travel behaviour in urban Beijing. It simulates and spatially analyses a geographically detailed realistic synthetic population's travel behaviour and the subsequent CO_2 emission at disaggregate level over the period 2000 – 2010. This spatio-temporal analysis seeks to combine microsimulation approaches from geography and transport activity studies from the transport field and apply this in a developing country, where detailed data to undertake fine scale analysis of phenomena such as CO_2 emissions generated by travel behaviour is very scarce.

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Biography

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