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Exploring transport carbon futures using population microsimulation and travel diaries: Beijing to 2030

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ABSTRACT

Evaluating transport policy for cities in developing countries is often constrained by data availability that limits the use of conventional appraisal models. Here, we present a new 'bottom-up' methodology to estimate transport CO_2 emission from daily urban passenger travel for Beijing, a megacity with relatively sparse data on travel behaviour. A spatial microsimulation, based on an activity diary survey and two sample population censuses, is used to simulate, for Beijing's urban districts, a realistic synthetic population, and their daily travel and CO_2 emission over 2000–2010. This approach provides greater insight into the spatial variability of transport CO_2 emission than has previously been possible for Beijing, and further, enables an examination of the role of socio-demographics, urban form and transport developments in contributing to emissions over the modelled period.

Using the 2000–2010 CO_2 emission estimates as a baseline, CO_2 emissions from passenger travel are then modelled to 2030 under scenarios exploring politically plausible strategies on transport (public transport infrastructure investment, and vehicle constraint), urban development (compaction) and vehicle technology (faster adoption of clean vehicle technology). The results showed that, compared to the trend scenario, employing both transport and urban development policies could reduce total passenger CO_2 emission to 2030 by 24%, and by 43% if all strategies were applied together. The study reveals the potential of microsimulation in emission estimation for large cities in developing countries where data availability may constrain more traditional approaches.

Introduction

China has experienced rapid urbanisation and spatial restructuring since the 1980s, accompanied by major growth in travel, and the associated issues of energy consumption and greenhouse gas emission, traffic congestion and local air pollution (Feng et al., 2013). The IFEU (2008: 10) estimate that between 1990 and 2006, the stock of vehicles in China increased tenfold, total vehicle kilometres (vkms) travelled increased fivefold, and energy and carbon dioxide emissions have increased fourfold. Even after such growth, the transport sector in China still accounts for a considerably lower share of final energy use than observed in Europe (Ibid: 6). However, as the Chinese economy develops, there is an anticipated further growth in transport carbon emissions in the future. The IFEU (2008: 6) highlights the uncertainty associated with such transport carbon emission estimates for China. Unofficial estimates of transport energy use are about a third higher than official

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estimates, with the discrepancies attributed to the way that official statistics report energy use (e.g. freight transport energy use is classified as industry, and passenger transport excludes private transport).

Accurately estimating transport CO_2 emission at the national level is evidently challenging. Estimating at the urban level presents more difficulties, yet is an important task, as cities account for a disproportionately large share of energy use and emissions. Chinese cities are also growing rapidly; evaluation of the impact of planning policy on travel CO_2 emissions is therefore particularly important. Dhakal (2009) estimates that Chinese urban areas account for 84% of energy use, and whilst this demand is from all sources, the share attributed to transport is growing rapidly. Estimates of transport carbon emission in China have to date employed aggregate data on total energy consumed or vehicle population registered, and tend to neglect the influence on emission of factors that operate at a more resolved functional level, such as socio-demographic attributes or land use characteristics (e.g. Cai et al., 2012). Using less aggregate travel attributes (such as trip frequency, mode choice, and vehicle kilometres travelled) in CO_2 emission estimation has major advantages over the former aggregate approach (He et al., 2013), but few studies of transport CO_2 emission in transitional economies use such an approach, largely due to a lack of the data needed to support such disaggregate models; this is certainly the case for China.

However, microsimulation offers the potential to develop such models using the more limited data availability that is often a feature of developing economies. The key advantages offered by this approach are that emission estimates can be developed for more constrained geographies (such as cities), and that a more functionally resolved model results which enables exploration of development scenarios and policy or plan interventions. Thus microsimulation offers the potential, for example, to go beyond policy scenarios that estimate emission response to aggregate changes in vehicle characteristics (e.g. total number, average vkms) and to additionally consider how travel characteristics (e.g. trip frequency, travel distance, mode choice) of individuals influence carbon emission.

Spatial population microsimulation uses individuals or households as the basic analytical unit, and represents a useful tool for generating disaggregate forecasts over a long period (Ballas et al., 2005). On the basis of deterministic reweighting, synthetic reconstruction or combinatorial optimisation techniques, microsimulation models can synthesise much individual-level data for large populations by combining surveys and census data. It can also perform static what-if simulations to explore the impacts of alternative policy scenarios on the synthetic population for a base year, and perform future-oriented 'what-if' simulations by updating the basic microdata set over a long period (Ballas and Clarke, 2001). The spatial microsimulation approach has been widely used in the fields of geography, transport and social sciences in advanced economies (e.g. Birkin and Clarke, 1988; Beckman et al., 1996; Kitamura et al., 2000; Miller et al., 2004; Lovelace et al., 2014), but there is little research on its application to urban transport CO_2 emission, particularly for developing countries.

Here, we present a new bottom-up methodology to provide an improved transport CO_2 emission estimate from individual's daily urban travel in Beijing from 2000 to 2030. On the basis of an activity diary survey and demographic data from the 2000 and 2010 population censuses (a 10% sample of Beijing's population), we employ spatial microsimulation to simulate for the city a realistic synthetic population, their daily travel behaviour and CO_2 emission at a fine geographical resolution (urban sub-district) between 2000 and 2010. We compare and analyse the changes in travel behaviour and transport CO_2 emissions over this decade, and examine the role of socio-demographics and change in urban form in contributing to this modelled trend. Next, the transport CO_2 emission from passenger travel behaviour is projected to 2030 under four scenarios, to illustrate the utility of the approach. The four scenarios are (i) transport policy trend, (ii) land use and transport policy, (iii) urban compaction and vehicle technology, and (iv) combined policy, and are developed to explore travel behaviour and transport CO_2 emission under current and politically plausible strategies on transport, urban development and vehicle technology.

Methodology

Case study city

We developed our microsimulation for Beijing, China's capital city that is a major source of transport related CO_2. Beijing is undergoing rapid change, yet lacks the resolved data to support more conventional emission estimation approaches. Beijing has experienced an increase in its urban area of 168% in the decade since 1998 (National Bureau of Statistics of China, 2009), an expansion that has been accompanied by suburban sprawl characterised by low density and mono-functional land use, while the traditional inner city urban space retains a high density, mixed land use (Zhao et al., 2010; Wang et al., 2011). Beijing can be divided into three broad zones: the central urban, inner suburban and outer suburban. The central urban zone (Fig. 1) comprises the urban districts of Dongcheng, Xicheng, Chongwen and Xuanwu, located in the inner city and representing the traditional business districts. The inner suburban zone includes the districts of Chaoyang in the northeast, Haidian in the northwest, Fengtai in the southwest and Shijingshan in the far west. These two central urban and inner-suburban zones accounted for approximately 63% of all households in 2000, with the inner suburban zone experiencing most of the post 1980s urban expansion. Most of the northern sub-districts are characterised by a high population density, in contrast to the lower density towards the periphery (Fig. 1). The outer suburban area refers to the remote counties and villages in the Beijing municipality.

Beijing lacks any publicly available travel survey data, hence to develop a representation of the travel behaviour of the Beijing population, a microsimulation model was developed that draws on both a travel diary survey designed and