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Transportation carbon dioxide emissions by built environment and family lifecycle: Case study of the Osaka metropolitan area

E.O.D. Waygood [a,*], Yilin Sun [b], Yusak O. Susilo [c]

[a] Université Laval, École supérieure d'aménagement du territoire et de développement régional, Pavillon Félix-Antoine-Savard, 2325, rue des Bibliothèques Local 1622, Québec, QC G1V 0A6, Canada
[b] Department of Civil Engineering and Architecture, Zhejiang University, China
[c] Centre for Transport Studies, Department of Transport Science, KTH Royal Institute of Technology, Sweden

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ABSTRACT

How a city grows and changes, along with where people choose to live likely affects travel behavior, and thus the amount of transportation CO_2 emissions that they produce. People generally go through different stages in their life, and different travel needs are associated with each. The impact of the built environment may vary depending on the lifecycle stage, and the years spent at each stage will differ. A family with children may last for twenty to thirty years, while the time spent without dependents might be short in comparison. Over a family's lifecycle, how big of a difference might the built environment, through household location choice, have on the amount of transportation CO_2 emissions produced? From a climate change perspective, how significant is residential location on the CO_2 produced by transportation use? This paper uses data from the Osaka metropolitan area to compare the direct transportation CO_2 emissions produced over a family's lifecycle across five different built environments to determine whether any are sustainable and which lifecycle stage has the greatest overall emissions. This understanding would enable the design of a targeted policy based on household lifecycle to reduce overall transportation CO_2 of individuals throughout one's lifecycle. The yearly average per-capita family lifetime transportation CO_2 emissions were 0.25, 0.35, 0.58, 0.78, and 0.79 metric tonnes for the commercial, mixed-commercial, mixed-residential, autonomous, and rural areas respectively. The results show that only the commercial and mixed-commercial areas were considered to be sustainable from a climate change and transportation perspective.

Introduction

Carbon dioxide (CO_2) is an externality of the transportation sector that continues to increase despite improvements in other sectors (EEA, 2011; Susilo and Stead, 2012). Although vehicles have improved their fuel-efficiency, increases in distances traveled have eliminated potential reductions (Millard-Ball and Schipper, 2011). One side of that increase can be a spreading-out of the built environment (Kitamura et al., 2008; Kitamura and Susilo, 2005; Millard-Ball and Schipper, 2011; Susilo and Kitamura, 2008), while another could be changes in household structures and where they choose to settle. Finally, VandeWeghe and Kennedy (2007) argue that transportation is a key sector to affect the overall greenhouse gas (GHG) profile of a city.

* Corresponding author. Tel.: +1 4186562131x3740; fax: +1 4186562018.
E-mail address: owen.waygood@esad.ulaval.ca (E.O.D. Waygood).

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In national estimates of transportation CO_2 emissions, traffic in and through a zone are frequently used (Minx et al., 2013; Waygood et al., 2013). That method is adequate when one is concerned with estimating the total CO_2 emissions and where it is occurring, but without consideration to the source. However, as that method does not look at the origin of the trip, a potential exists that an area where the locals walk and use public transportation will be assigned high per capita transportation CO_2 because of trips that originate (and perhaps finish) outside of their zone. As opposed to that approach, the research carried out here examines the propensity of a household to produce CO_2 emissions through transportation choices based on the built environment of their household location.

As people's travel varies across different lifecycle stages, and the built environment affects travel, the primary research question is: *to what extent does household location choice affect the direct CO_2 emissions produced over a household's lifetime through transportation*? Further, unlike previous studies, this research examines the travel patterns of a region with a strong rail-based mass transportation network. This understanding will improve understanding of lifetime household transportation CO_2 emissions for transit-oriented development.

The remaining sections of the paper are: the background, the methods, the results, discussion, and finally the conclusion.

Background

Transportation greenhouse gases

Transportation is only one of many sectors that contribute to greenhouse gas (GHG) emissions. However, in studies that include transportation with other contributing sectors such as buildings, more urbanized areas typically have lower emissions. In an aggregate study of global cities, Kennedy et al. (2009) found that GHG emissions from transportation were inversely related to the cities' densities. In Toronto, Canada (VandeWeghe and Kennedy, 2007) it was found that once outside of the transit-intensive cores, that private auto emissions surpassed those from buildings and that all of the highest emitting areas were located in the lower-density suburbs. Minx et al. (2013) in a study of all human settlements in the UK found that the three urban settlement types used in their studies had lower extended territorial emissions than the two rural settlement types. In a study of 57 US cities, Clark (2013) found that increases in core densities increased energy efficiency, but with only a small impact on GHG emissions. These studies typically used aggregate measures of density to examine the impact of the built environment and used socio-demographic information such as household size.

As described above, the built environment has been found to impact transportation greenhouse gas (GHG) emissions such as CO_2e (CO_2 equivalents) emissions. In North America, studies have shown differences such as 70% greater emissions for the periphery of a city versus city center in Quebec, Canada (Barla et al., 2011) or 3.65 times greater in low density versus high density areas in Toronto (Norman et al., 2006). Others have examined what aspects of the built environment correlate to reductions in transportation CO_2 emissions. In Montreal, Canada Zahabi et al. (2012) found that land use mix, population density and public transit accessibility are associated with reduced emissions. In Seattle, USA Frank et al. (2000) found that population density and work track employment density were associated with reductions in transportation emissions. In China, different neighborhood development styles were compared and those that were either traditional (ancient) or aimed to have a job-social-residential balance (enclaves) had the lowest transportation emissions (Guo et al., 2013). Along with household location, vehicles tend to be larger in periphery regions which thus contribute further to increased emissions (Lindsey et al., 2011; Liu and Shen, 2011). Thus, we anticipate that more urbanized areas will have lower transportation CO_2 emissions, but how that differs by household type is not always clear and no studies outside of generally car-oriented North American cities were found with respect to such measures.

Influences on travel behavior

Research that examines travel behavior in general can help explain differences in transportation CO_2 emissions. Empirical evidence in North America suggests that car travel is lower in traditional-style neighborhoods characterized by higher densities and a mixture of land uses where accessibility is often better with more pedestrian-orientated design features that encourage greater use of non-motorized modes (e.g. Cervero, 1996; Ewing and Cervero, 2010; Frank and Pivo, 1994; Gordon, 1997; Handy, 1996). Similar results have been found in Europe (Naess, 2006; Snellen et al., 2002; Susilo and Maat, 2007) and Japan (Sun et al., 2009; Susilo and Kitamura, 2008). Such differences likely help explain the differences found for CO_2 emissions from transportation across a city's built environment.

The travel desires and needs of people will vary over their lifetime. Beige and Axhausen (2008) concluded that changes in residence, education and employment decrease the probability of variations in the ownership of mobility resources (e.g. a car, bicycle, transit pass, etc.). Further, in a separate analysis, Beige and Axhausen (2012) indicated that the changes in mobility resource ownership are significantly related to changes in employment, education and residential location as well as to household demography. In both cases residential location and significant changes in one's life affected the mobility options available. In line with this, Chatterjee et al. (2012) also found that life-change events could lead to changes in bicycle use throughout individual's life course.

Amongst life-change events, a change in the household make-up from childless to having dependent children will impact travel needs and desires. A young, childless couple will behave differently from a family with children, who will in turn