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# Future energy use and $CO_2$ emissions of urban passenger transport in China: A travel behavior and urban form based approach

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## HIGHLIGHTS

- Developed an improved ASIF using empirically derived personal travel activity and built environment variables.
- Per capita urban passenger transport energy use increases as city size expands.
- Behavior targeting policies have national mitigation effects.
- National guideline on city transport policies should have spatial and temporal priority.

## ARTICLE INFO

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## ABSTRACT

Work on comparing cities in terms of their transport energy consumption and $CO_2$ emissions in the urban passenger transport sector has rarely been done using detailed travel activity data that takes into account city level differences in terms of economic development, population, and urban form. A personal activity based approach is necessary to better reflect travel behavior change results from different social, economic, urban form, technical, and transportation policy situations in the future. The present study extends the existing activity, modal share, energy intensity, fuel/carbon intensity (ASIF) modeling framework by disaggregating travel activity into key structural components and city-specific factors for 288 prefectural level cities in China. Testable econometric modeling systems were built to link mode split and mode specific travel distances with local economic and urban form characteristics in four different population sizes and two urban form types, based on 187 travel surveys in 108 Chinese cities in the past two decades. Scenarios of energy use and carbon emissions between 2010 (baseline) and 2050 were developed. Results showed that in 2010 urban passenger road transport in China generated 396 Mt $CO_2$ emissions and per capita urban passenger transport energy use increased as city size expanded. By 2030, under business as usual scenario assumptions, energy use in the urban passenger transport sector comprised 23.2 Mt of gasoline, 1.72 Mt of diesel, 3.36 billion $M^3$ of natural gas, and 0.62 billion kWh of electricity. While national policies targeting travel behavior change have been shown to mitigate emissions to some extent, urban transport policies targeted at specific spatial and temporal drivers of energy demand and emissions may be more effective in meeting policy goals. Short-term policies that promote car-pooling and ride sharing and medium-term policies that increase the cost of driving and promote public transport (such as transit oriented development, walkable neighborhood design, and parking pricing/restraint in city centers) help stabilize carbon emissions over the long term. However, the decision of building polycentric cities might have less significant impact on mitigating urban passenger transport in big cities. Moreover, large-scale promotion of electric vehicles should be designed from a long-term perspective rather than from a short-term one to achieve balanced carbon emissions in regard to the decarbonization process of electricity generation in China.

## 1. Introduction

Urban passenger transportation has received increasing concern for its impact on global warming, urban pollution, physical (in)activity, and human health [1–4]. The United Nations Framework Convention on Climate Change (UNFCCC) estimated that 7.0 Gt $CO_2$ eq of

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greenhouse gas (GHG) emissions were generated in 2010 from the transport sector globally, of which 72.06% was from the road sector [5]. Transport is perceived as the most challenging sector to mitigate emissions worldwide [6,7]. Efforts have been made to alleviate fast increasing energy use from passenger transport sectors, including technological improvements and transportation demand management (TDM). Over the past decades, TDM has increasingly been discussed as a way to contribute to a low-carbon society, as urban human mobility and energy use are largely interdependent [8,9]. For example, spatial planning that creates compact living and working environments helps reduce individuals' travel distances and encourages trip sharing and chaining [10–12]. City polices such as tax incentives for lower engine displacement gasoline vehicles or new energy vehicle purchases, priority for new energy vehicles, or improved frequency and service quality of public buses (PB) help urge travelers to use public transit or cleaner private vehicles (PV). These policies have been widely practiced in cities in different contexts across the globe. Although urban passenger transport policies have been enacted at the local level, a large number of them are promoted based on national standards or action plans as part of an international commitment to reduce global warming.

The impact of local behavior change policies on national scale energy consumption and $CO_2$ emissions of urban passenger transport is generally not well understood using existing evidence and approaches. On the one hand, aggregated national approaches, either top-down or bottom-up from provinces, use vehicle numbers or odometer data to estimate general vehicle activities. These methods have good responses to the change of the vehicle parameter itself (such as engine fuel efficiency); however, they overlook how the vehicles are utilized (such as the frequency and travel distance of passengers, how people are loaded, and shifting between other modes). Thus, they provide less information on how behavior targeting policies could result in energy and emission changes in urban passenger transport sectors. On the other hand, many recent studies have started to explore travel behavior, urban form and transport infrastructure, and demand management's effects at a more local level, including analytical approaches involving TRANUS [13], long-range energy alternative planning (LEAP) [14], logarithmic mean divisia index approach (LMDI) [15], Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) [16,17] and the Gompertz model [18]. These studies have higher accuracy in reflecting the effects on urban transport energy consumption from spatiotemporal change. However, the demanding detail of land use and traffic flow data make it difficult to estimate national effects, especially for less developed regions.

In China, fast-paced economic growth, auto industry development, infrastructure investment, and higher spatially dispersed cities have simultaneously spurred the need and capability of owning and using cars for ordinary urban households. As the Chinese government commits to reducing its carbon emissions before 2030, transportation, especially passenger transport is important when referring to emissions reduction [6,11,19,20]. Existing literature provides a wide spectrum of approaches and angles to evaluate energy consumption and $CO_2$ emissions from the transport sector. This has enhanced the missing official released data on energy consumption of transportation. According to the yearbook of energy use in China, transportation energy use data was combined with 'storage, post, and communication' information [20–22]. As further discussed in the next section, these studies collectively suggested that data resolution and collection methods need to be further improved in a national scale energy study. Disparity of city populations, economies, and spatial layouts need to be considered as these influence motorized travel intensity and structure, and they might have substantial effects on national energy consumption and emissions, which need to be evaluated.

The present study attempts to develop a city level national energy consumption and $CO_2$ emissions framework based on personal travel activity. It contributes to the existing literature in the following aspects: (1) It creates a nationwide energy and $CO_2$ emissions modeling framework that allows urban travel demand policies to be evaluated in terms of travel reductions and mode shift. This is realized by a detailed decomposition of vehicle kilometre traveled (VKT) into passenger trip generation, passenger mode choice, and passenger distance traveled based on an adjusted activity, modal share, energy intensity, fuel/carbon intensity (ASIF) approach. (2) It provides statistical estimation rather than approximation in two main motorized travel elements: mode split and travel distance. Based on 187 travel surveys in Chinese cities conducted in and after 2000, these two elements were associated with local economic or land use characteristics. They are examined in five modes (PV, PB, taxis (TX), motorcycles (MT), and E-bike (EB)), four city sizes (mega, big, medium, and small), and two urban forms (monocentric and polycentric). (3) An outlook towards 2050 is provided. Nine scenarios with different economic and policy backgrounds such as different economic growth, transit-oriented-development, TDM, E-haul, new energy, and low displacement vehicle promotion were compared. None of this can be accomplished by an aggregate vehicle-based approach using a single VKT value.

The remainder of the paper consists of four parts. First, it provides a review of various studies using a decomposition approach to study energy use and $CO_2$ emissions, focusing on China's road transport sector. Second, it presents the adopted research framework, methodology, and data. Third, it provides baseline and scenario results on the energy consumption and $CO_2$ emissions of urban passenger transport with different economies and policy backgrounds. Finally, it presents the results of a comparative analysis using different scenarios of future development in China before concluding with implications for policy and urban planning.

## 2. Previous work on China

Different approaches have been applied to provide estimations or projections of passenger transport's energy consumption or $CO_2$ emissions in China, based on various data structures and characteristics. According to Loo and Li [23], approaches could generally be categorized into distance-based (includes aggregate and disaggregate approaches) and fuel-based (includes bottom-up and top-down approaches). Fig. 1 presents results of national energy consumption (gasoline, diesel, and oil equilibrium) and $CO_2$ emissions in the road transport sectors using these methods.

For distance-based methods, the disaggregate approach distinguishes different passenger transport modes such as PV, PB, TX, and MT. Therefore, it enables mode specific effects such as average speed, distance, loading factor, energy, or emission intensity to be taken into consideration; however, consequently becomes data demanding. Studies using the disaggregate distance-based approach generally multiply passenger turnover volume, regularly measured by passenger kilometer, with energy or emission factors for different modes. These components are then summed as total energy consumption or $CO_2$ emissions for passenger transport sector. Based on this method, He et al. [86] estimated from national level data that road vehicles consumed 72.51 Mt oil (gasoline and diesel combined) and generated 229.04 Mt $CO_2$ emissions in 2002. Loo and Li [23] estimated from provincial level data that average $CO_2$ emissions for road transport was approximately 250 Mt on average in 2009. Taking into account the full lifecycle of energy production and use (Well-To-Wheel, WTW) it has been estimated that road transport accounted for around 1000 Mt (WTW) $CO_2$ emissions, compared to around 750 Mt (Tank-To-Wheel [TTW]) in 2015 [6]. In comparison, using the aggregate distance-based approach $CO_2$ emissions from passenger cars were estimated at about 91.4 $MtCO_2$ in China in 2005 [24]. Although this does not provide mode split results, it was able to consider locally specified VKT for passenger turnover volume, which provides valuable evidence on regional disparity.

Compared to the distance-based method, the fuel-based method has the advantage of yielding higher accurate fuel specific results, and avoids uncertainty in differences in the 'real world' operation of