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Low-carbon futures for Shenzhen's urban passenger transport: A human-based approach

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ABSTRACT

Shenzhen, one of China's leading cities, has the potential to be a model for achieving China's ambitious CO_2 emission reduction targets. Using data from a travel diary survey in Shenzhen in 2014, we develop a human-based agent model to conduct a scenario study of future urban passenger transport energy consumption and CO_2 emissions from 2014 to 2050. Responses to different policy interventions at the individual level are taken into account. We find that with current policies, the carbon emissions of the urban passenger transport sector in Shenzhen will continuously increase without a peak before 2050. Strengthening 21 transport policies will help Shenzhen to peak the carbon emissions by 2030 for passenger transport. Among these policies, the car quota policy and the fuel economy standard are essential for achieving a carbon peak by 2030. In addition, a package of seven policies, including fewer car quotas, a stricter fuel economy standard, raising parking fees, limiting parking supply, increasing EV charging facilities and subway lines, and improving public transport services, is sufficient to peak carbon emissions by 2030, although at an emissions level higher than for the 21 policies.

1. Introduction

Cities are the center of energy consumption and emissions, as they account for 75 percent of global energy consumption and nearly 80 percent of greenhouse gas emissions (World Bank, 2010). Achieving sustainable transport is one of the most fundamental challenges in realizing greater carbon efficiency at the city level (Hickman and Banister, 2007). Transport accounts for 15–40% of total city CO_2 emissions and, in emerging economies, often accounts for the greatest share of the *increase* in carbon emissions as many individuals aspire to own vehicles to pursue modern lifestyle (IEA, 2014). Cities in emerging economies, therefore, have an urgent need to tackle sustainable transport on a grand scale in order to create pathways towards sustainability. In addition, the relatively low motorization rate and underdeveloped transport infrastructure mean that cities in emerging economies like China have more scope to be flexible in adapting to environmental and climate challenges. It is of pressing importance to understand what the future urban low-carbon transport will look like and the role transport can play in realizing low-carbon urban futures, especially in emerging economies.

Shenzhen is an ideal study site for carrying out research on this topic. Shenzhen is one of China's leading cities in terms of responding to new development opportunities and challenges as one of China's most successful Special Economic Zones. Its policies are watched closely by leaders in other parts of the country. China promised to peak its total carbon emissions by 2030 at the 21st Conference of Parties held in Paris in December 2015. To realize this ambitious commitment, achieving a sustainable transport system is one of the most fundamental challenges facing cities in China. Given its relatively low motorization rate and

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Nomenclature

Symbol	Definition
ABM	agent-based model
BAU	business-as-usual scenario
BEV	battery electric vehicle
BuyC	probability of buying a car
BuyF	probability of buying a car of subscript fuel type
C	carbon emissions, $kgCO_2/(person \cdot day)$
CAR	probability of owning a car
CHT	number change of previous year's subscript trips
DCRS	decreased number of trips for subscript individual
DIST	the travel distance, km/trip
DUM	dummy, =1 if policy launched
e	count number of five fuel types
EI	energy intensity, $MJ/(100\,km \cdot person \cdot trip)$
EIV	energy intensity of subscript trip, $MJ/(100\,km\,km \cdot vehicle)$
EV	electric vehicle
f	fuel type of vehicles
FUEL	emission coefficient of subscript fuel type
GW h	10^9 watt hours
HEV	hybrid electric vehicle
i	agent
IBM	individual-based model
ICRS	increased number of trips for subscript individual
LG	the lower growth scenario
LE	the least emissions scenario
life	the lifespan of cars
m	transport mode
MNL	multi-nomial logit estimator
MtCO2	million tons of carbon dioxide
Mtoe	million tons of standard oil equivalent
NMT	non-motorized transport
NP	new policies scenario
OLS	ordinal least square estimator
PF	the probability of using subscript fuel type
PM	the probability of selecting subscript mode
PSGR	number of passengers for the subscript trip
PT	public transport
t	trip
TC	city carbon emission, MtCO2/year
TRIP	the number of the subscript type of trips
W	weight for the subscript individual, 10^4 person
x	a vector of dependent variables
z	a vector of dependent variables
α	a vector of regression coefficients
β	a vector of regression coefficients
ε	a vector of coefficients for corresponding regression
η	a vector of coefficients for corresponding regression
ν	travel speed of the subscript trip
σ	the magnitude of policy in the subscript year
τ	year
ω	the SP/RP correlation coefficient

underdeveloped transportation infrastructure, Shenzhen has the potential to serve as a model for leapfrogging to a low carbon transport system in China or other emerging economies.

In this paper, we address the following three questions: (1) What are the current level and trends of energy consumption and carbon emissions in Shenzhen's urban passenger transport sector? (2) Can Shenzhen peak carbon emissions from urban passenger transport by 2030? And (3), if yes, how can it be achieved? What specific policies are needed? What is the carbon reduction contribution of each policy?

To answer these questions, based on a detailed travel diary survey in Shenzhen in 2014 (Zhao et al., 2016), we develop a human-based agent model, in which changes in individual travel behavior due to various policy interventions and the resultant energy consumption and carbon emissions are estimated. The agent model in this study is a simplified version of the agent-based models (ABMs) or individual-based models (IBMs) that simulate the actions and interactions of autonomous agents (either individual or collective entities such as human beings, or organizations) and thus assesses their overall impacts on the system given rules from game theory or other behavioral models (Grimm and Railsback, 2005). ABMs have been used in various disciplines such as biology, economics, business, and technology after its invention in the early 1970s to understand the collective actions of the population (Niazi and Hussain, 2011). In the domain of transport, ABMs are mostly used to simulate traffic conditions and thus optimize the management of the urban transport systems/infrastructures and have rarely been employed to study real-world situations in the transport sector (Chen and Cheng, 2010). We are among the first to use the method to understand human travel behaviors and their impact on energy consumption and carbon emissions. In contrast to classical ABMs that simulate interactions of agents based on rules like the game theory, the agents in our model are not competing with each other and the travel decision of a given agent is thus not influenced by decisions of other agents.[1] However, we model the transport decisions of agents in detail and calibrate their responses to micro-data.

Our approach overcomes the following major limitations of existing literature that models human behavior and its determinants at disaggregated levels. First, human behavior is influenced by multiple factors, some of which are not sufficiently studied in quantitative studies. A rich literature employs utility-maximization models to simulate changes in human behaviors influenced by factors such as socio-economic and price changes (e.g., Small et al., 2007; van Wee et al., 2013; Rösler, 2011; Cartenì et al., 2016, etc.), urban forms (e.g., Yang et al., 2000; Frank et al., 2008, etc.), gain-loss asymmetry (Rose and Masiero, 2010) and so on. The role of many other factors, such as the physical and social environment (Mattauch et al., 2016), beliefs and attitudes (Bamberg et al., 2010), habits (e.g., Heinen and Ogilvie, 2016; De Bruijn and Gardner, 2011, etc.), and preferences (e.g., Zegras, 2009; Gadenne, 2011; Van Acker et al., 2016, etc.) are also explored in earlier studies but usually in very stylized ways due to lack of data. Of note,

[1] In general, people make travel decisions based on known situations such as the policies and prices, and previous experience.