A system dynamics approach to scenario analysis for urban passenger transport energy consumption and CO2 emissions: A case study of Beijing

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HIGHLIGHTS

• The creation of a Beijing urban transport carbon model using system dynamics.
• The effect of different policies on energy conservation and emission reductions.
• The cumulative effect of different individual policies.
• The optimal sequence of individual policy implementation in comprehensive policy.

ABSTRACT

With the accelerating process of urbanization, developing countries are facing growing pressure to pursue energy savings and emission reductions, especially in urban passenger transport. In this paper, we built a Beijing urban passenger transport carbon model, including an economy subsystem, population subsystem, transport subsystem, and energy consumption and CO2 emissions subsystem using System Dynamics. Furthermore, we constructed a variety of policy scenarios based on management experience in Beijing. The analysis showed that priority to the development of public transport (PDPT) could significantly increase the proportion of public transport locally and would be helpful in pursuing energy savings and emission reductions as well. Travel demand management (TDM) had a distinctive effect on energy savings and emission reductions in the short term, while technical progress (TP) was more conducive to realizing emission reduction targets. Administrative rules and regulations management (ARM) had the best overall effect of the individual policies on both energy savings and emission reductions. However, the effect of comprehensive policy (CP) was better than any of the individual policies pursued separately. Furthermore, the optimal implementation sequence of each individual policy in CP was TP → PDPT → TDM → ARM.

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1. Introduction

In response to oil shortages, air pollution and climate change, an increasing number of governments have begun to set goals for energy savings and emission reductions (Zhang et al., 2014, 2011a, 2011b; USEPA, 2012). More than half of the world's population currently lives in cities. What is more, their Greenhouse Gas (GHG) emissions accounted for more than 80% of the world's total GHG emissions (Feng et al., 2013). In China, approximately 18% of the population lives in the 35 largest cities, but they brought in vast energy consumption and CO2 emissions, which accounted for more than 40% (Dhakal, 2009). Therefore, energy savings and emission reductions at the city level played a vital role in the process of fulfilling existing overall energy conservation and emission reduction targets (Chen and Chen, 2012; Zhang et al., 2012; Chun et al., 2011; Li et al., 2010). In addition, energy consumption and CO2 emissions from urban passenger transport played an important role at the city level; therefore, energy conservation and emission reductions in urban passenger transport became important measures by which to achieve low-carbon development goals (Litman, 2013a, 2013b; Geng et al., 2013; Chiou et al., 2013).

Currently, there are many researchers interested in urban transport energy conservation and emissions reduction measures (AASHTO, 2009; Ross Morrow et al., 2010; Gross et al., 2009;
energy vehicles’ market share in road traffic using the MARKAL model. Cortés et al. (2008) developed an object-oriented simulation platform using a Java program to analyze urban traffic network energy consumption and emissions. On the whole, bottom-up methods perform economic analyses poorly, providing useful detailed descriptions of technology. These analyses generally overestimate the potential for economic progress (Nakata, 2004).

(3) Hybrid methods mainly include NEMS, POLES, PRIMES, POLES model, and so on. For example, Messner and Schrattenholzer (2000) analyzed an energy supply situation according to demand changes for different passenger and cargo transport units using an IIASA-CEC E3 model. Hickman et al. (2010) built the transport and carbon simulation model and investigated a series of potential policy packages that could reduce the emission’s effect in London. Yang et al. (2009) built Long-term Evaluation of Vehicle Emissions Reduction Strategies and researched how to reach the target of reducing CO₂ emissions by 80% by 2050 in California. On the whole, hybrid methods combine the advantages of top-down and bottom-up methods. Not only are their functions more complete, but they also have a more complex structure. Therefore, they are more suitable to the simulation of complex giant systems.

Past research using hybrid methods normally assumed that the evolution structures of urban transport energy consumption and emissions were known; therefore, they reflected the dynamic process of energy consumption and emissions poorly and had difficulty conveying the uncertain behaviors of the primary issues associated with urban transport systems. Conversely, SD combines qualitative analysis with quantitative analysis and uses system synthesis reasoning to describe these undefined behavioral characteristics, making SD a better choice in dealing with nonlinear, high order complex time-varying systems. For these reasons, we chose the SD model to evaluate urban passenger transport energy consumption and CO₂ emissions in Beijing.

SD was first proposed for the analysis of a complex dynamic feedback system by J. W. Forrester in 1956 (Zhao et al., 2011). Based on computer simulation technology, this visual tool can analyze relationships among various factors, simulate quantitative data and obtain information on the feedback structure, function and behavior of the system. This makes it easier for us to understand the system overall and formulate various relevant policy scenarios to control the system’s dynamic evolution mechanism (Yuan et al., 2008).

Currently, SD has been widely applied in various research fields, including societal and economic systems research (Forrester, 1969, 1971), ecosystem research (Saysel and Barlas, 2001), transportation research (Suryani et al., 2010) and so on. For instance, in the field of energy management, SD was widely applied to national energy policy-making and evolution (Ford, 1983; Nail, 1992; Quadrat-Ullah, 2005; Barisa et al., 2015). In addition, SD was also used extensively in energy efficiency assessments (Dyner et al., 1995) and the development of the energy industry (Bunn and Larsen, 1992; Chyong Chi et al., 2009). In the field of transportation, SD was applied to research into the operational management of the public transport enterprise (Bivona and Montemaggiore, 2010), the operational management of roads and infrastructure networks (Fallah-Fini et al., 2010), the usage of low emission cars such as electric vehicles and hydrogen vehicles (Walther et al., 2010), and the relationship between land usage and urban transport (Paffenbichler et al., 2010). Recently, Vafa-Arani et al. (2014) built an SD model that included urban transportation and air pollution industries subsystems to research urban air pollution in Tehran, Iran. However, in spite of these findings, there is still little literature in the field of the urban passenger transport energy and...
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