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China's transportation energy consumption and CO_2 emissions from a global perspective

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HIGHLIGHTS

- Transport sector in China are analyzed from a global perspective.
- Passenger transport turnover reduction and modal shifts is less sensitive to carbon price.
- Bio-fuel, electricity and H_2 will play an important role for carbon mitigation in transport sector.
- The transport sector is more difficult to decarbonize than other sectors.

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ABSTRACT

Rapidly growing energy demand from China's transportation sector in the last two decades have raised concerns over national energy security, local air pollution, and carbon dioxide (CO_2) emissions, and there is broad consensus that China's transportation sector will continue to grow in the coming decades. This paper explores the future development of China's transportation sector in terms of service demands, final energy consumption, and CO_2 emissions, and their interactions with global climate policy. This study develops a detailed China transportation energy model that is nested in an integrated assessment model —Global Change Assessment Model (GCAM)—to evaluate the long-term energy consumption and CO_2 emissions of China's transportation sector from a global perspective. The analysis suggests that, without major policy intervention, future transportation energy consumption and CO_2 emissions will continue to rapidly increase and the transportation sector will remain heavily reliant on fossil fuels. Although carbon price policies may significantly reduce the sector's energy consumption and CO_2 emissions, the associated changes in service demands and modal split will be modest, particularly in the passenger transport sector. The analysis also suggests that it is more difficult to decarbonize the transportation sector than other sectors of the economy, primarily owing to its heavy reliance on petroleum products.

1. Introduction

The International Energy Agency (IEA) estimates that the transportation sector accounts for approximately 19% of global energy consumption and 23% of energy-related carbon dioxide (CO_2) emissions (IEA, 2012). The sector's energy consumption and CO_2 emissions, and their contributions relative to other sectors, are all projected to grow substantially over the course of the current century (Kyle and Kim, 2011). The IEA projects that global transportation energy use and CO_2 emissions will increase by approximately 50% by 2030 and by over 80% by 2050 (IEA, 2009). China's transportation sector has grown rapidly in recent years, and it is probable that this will continue in the coming decades given the country's current low vehicle ownership level. As of 2010, the transportation sector accounts for approximately 15.6% of total final energy use in China with gasoline and diesel consumed in the secondary and tertiary for transport included (National Bureau of Statistics (NBS, 2011; Wang, 2010), considerably below the average figure of 32% for Organization for Economic Cooperation and Development (OECD) countries (IEA, 2012).

A number of studies have provided scenarios for energy consumption and CO_2 emissions in China's transportation sector. There are energy consumption and CO_2 emissions scenarios for

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transportation and other sectors from 2005 to 2050 with MARKAL (MARKet ALlocation) models, including MARKAL-MACRO (Chen, 2005), MARKAL-ED (Chen et al., 2007), Western China MARKAL (Chen et al., 2010), and China TIMES (Chen et al., 2013). These studies disaggregate the transportation sector into 10 modes (air, railway, bus, car and waterway for passenger transport, and air, railway, truck, waterway and pipeline for freight transport). Zhou et al. (2013) provided projections through to 2050 using the Long range Energy Alternative Planning (LEAP) system model. This study calculated freight transportation service demand as a function of economic activity, and passenger transport on assumed average kilometer traveled by individual modes (e.g., bus, train, and car). Fu (2011) analyzed medium- and long-term energy saving potentials in different energy efficiency improvement scenarios. Other studies analyzed the sector's energy consumption and CO_2 emissions from a global perspective (Koljonen and Lehtila, 2012; Luderer et al., 2012; Pietzcker et al., 2014).

Based on the historical trend during 2000–2005, Yan and Crookes (2009) projected road energy consumption and CO_2 emissions from 2005 to 2050 in both business-as-usual and best-case scenarios. In the best case scenario, a series of policy measures such as private vehicle controls and fuel tax are assumed. Huo et al. (2012a) developed the Fuel Economy and Environmental Impacts (FEEI) model for road transportation, and projected the well-to-wheels and tank-to-wheels energy use and greenhouse gas emissions up to 2050. Specifically, the model presented various vehicle types, such as private light-duty passenger vehicles (LDVs), taxis, business LDVs (owned by the government and companies), public buses (for urban and rural transport), intercity buses, and light-and heavy-duty trucks. Hao et al. (2011, 2012) also separated passenger and freight vehicles for their analysis. Several studies analyzed energy consumption and CO_2 emissions of rural vehicles (Sperling et al., 2005; Yao et al., 2011), and railways (He et al., 2010). These bottom-up studies analyzed passenger and freight sectors in detail, providing scenario analyses at various scales informed by disaggregated technological and socioeconomic representations.

The major limitation of these models is the inability of representing how various transportation service demands and their modal split may evolve over time and interact with long-term climate mitigation target to limit warming to about 2 degrees. Moreover, some previous studies do not separately represent urban, rural and intercity passenger transport despite significant differences in travel patterns, vehicle speed, and fuel economy, because of different road infrastructure and traffic conditions (Brand et al., 2012; Girod et al., 2012; Zhang et al., 2007). Transportation service is considered to increase with income (Kim et al., 2006; Zhou et al., 2013), hence urban/rural income inequalities may contribute to different development paths for per capita travel and transportation energy use in these areas.

This study attempts to address the literature gap by nesting a highly disaggregated Chinese transportation sector in the Global Change Assessment Model (GCAM) and the improved model is named as GCAM-China. This paper explores the development of different transportation services and fuel consumption using reference and various carbon price scenarios in China with application of the improved GCAM-China model. Section 2 of this paper describes the disaggregated China transportation model and the basic assumptions for the reference scenario. Section 3 presents the reference scenario results, focusing on the service demands by mode, final energy use and CO_2 emissions. Section 4 explores the effect of carbon policy on the sector's development. The final section summarizes the results and concluds with policy implications.

2. Methods

2.1. Current transportation energy use in China

Characterizing the current patterns of transportation energy consumption in China is important because it reveals consumer preferences for competing modes and technologies and thereby shapes the extent that fuel substitution and modal shifts can occur in response to external drivers. There are official energy consumption statistics (NBS, 2011) for the Chinese transportation sector. However, the definition and coverage of the statistics differ from other countries (Mao et al., 2009; Wang, 2010). For example, road transportation energy consumption statistics only covers business vehicle fuel consumption, while other transportation energy consumption is assigned to residential and commercial sectors (Jia et al., 2010). Thus, an engineering approach estimates approximately a 75% higher energy demand in the Chinese transportation sector than the statistics indicate (Mao et al., 2009). However, such an approach requires assumptions relating to current fuel consumption (measured in liters or MJ of fuel per 100 km) and vehicle use intensity (measured in kilometers of travel per vehicle per year), neither of which are currently fully known in China (Huo et al., 2012b).

To estimate final transportation energy by fuel, Wang (2010) applied an oil allocation method. His study suggests that, in addition to oil consumed by business vehicles, 95% of the gasoline and 35% of the diesel used in the industry and commercial sectors, and all the gasoline and 95% of the diesel used in residential and agriculture sectors are attributable to the transportation sector. Since this simple method can estimate transportation energy use by fuel, it is used in various studies (Qi, 2012).

Our study uses an engineering approach to calculate transportation energy consumption by fuel and mode, all calibrated to fuel-level transportation energy consumption estimated by the oil allocation method. This method reveals that total transportation energy consumption has increased from 4.165 EJ in 2000 to 9.428 EJ in 2010, with an annual average growth rate of 8.5% (Fig. 1). Oil products were the main energy sources in the transportation sector, accounting for over 92% of total transportation energy consumption. Coal consumption decreased in conjunction with the phase-out of steam locomotives during this period, being substituted by oil and electricity. The share of natural gas and electricity remained relatively low.

2.2. Transport policies in China

In the transportation sector, there are four key policy mechanisms: fuel economy standards and labeling, vehicle and fuel taxation, public transportation, and subsides for energy-efficient vehicles, electric and H_2 vehicles (Lo, 2014).

2.2.1. Fuel economy standards and labelling

Fuel economy standards (FES) are regarded to be the most important measure to improve automobile energy efficiency. FES regulate fuel consumption or carbon emissions per distance traveled of vehicle, and require automakers to design and produce more efficient vehicles. The phase 1 standards were introduced in July 2005. They set up maximum allowance fuel consumption limits by weight category rather than fleet average. After the implementation of the phase 1 standards, average fuel economy of new vehicles had decreased from 9.11 L/100 km to 8.06 L/100 km during 2002 and 2006. The phase 2 standards were introduced in January 2008, and put forward even higher requirements.

Unlike the phase 1 and phase 2 standards, the fleet average system was introduced in the phase 3 standards. Compared to the phase 2 standards, the phase 3 standards require average energy