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Terrestrial transport modalities in China concerning monetary, energy and environmental costs

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ABSTRACT

We investigate the terrestrial transport by pointing out the amount, the quality and the distribution of resources use among nine transport modalities at the national scale in China, under monetary, energy and emergy perspectives. The private car mode accounts for the largest share of the total monetary, energy and environmental resource investment of the terrestrial transportation, which means the lowest input-output and environmental efficiency. Consequently, improvement of energy and environmental efficiency in individual transport modes and the inevitable need to encourage the population to shift to public transport modes whit better performances remain crucial priorities. The most efficient transport modality depends on the evaluation method applied that assigns different priorities to specific aspects. From a monetary perspective, the most efficient passenger transport modality is the regular train followed by the high-speed train. In terms of cumulative energy demand, regular train and subway have the lowest unit cost among all passenger transport modes. Concerning the emergy accounting considering the environmental support, the urban bus for passengers and the regular train for commodity transport show the best performance per unit service. Even with needs for improved technical efficiency, the promotion of above less resource-intensive modalities in accordance with the different purposes would improve the global efficiency of the transportation system and offer better and larger transport options with the same resource investment.

1. Introduction

The transport sector in China is rapidly growing with the economic development. Specifically, the volume of the freight transport increased from 4445.2 billion ton-km (t-km) in 2000 to about 17,835.6 billion t-km in 2015 and that of the passenger transport rose from 1226.11 to 3055.89 billion passenger-km (p-km) over the same period.[1] The average annual growth rate was 9.71% and 6.28% for freight and passenger transport, respectively. In 2012, 84.71% and 52.89% of the total transport volume of the passenger and freight transport were delivered by the terrestrial transport because of the vast inner land area of China and relatively limited possibilities for sea transport implementation. Hence, a comprehensive and proper understanding of the terrestrial transport could be a prerequisite for the policy making and sustainable development of the transport sector.

Concerning the literature focusing on the transport sector in China, most existing studies only offered a partial picture. More specifically, Liu et al. (2015) explored the energy consumption and CO_2 emissions by the passenger transport in Beijing. Xu and Lin (2015a) examined the carbon dioxide emission reduction of China's freight transport via vector autoregression model. Hao et al. (2015) estimated and predicted the energy consumption and greenhouse emissions by the Chinese freight transport through the year 2050. Li et al. (2016) assessed the impact of the integrated transport system in China as a function of monetary investment. Xu and Lin (2015b) identified the nonlinear relationship between the influential factors (per capita GDP, energy intensity, urbanization level, cargo turnover and private vehicle inventory) of the carbon dioxide emissions of Chinese transport. Duan

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[1] ton-km and p-km means that transferring one passenger or one ton of goods for 1 km.

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et al. (2015) quantified the carbon emissions of the transport sector in China by means of a streamlined life cycle assessment. Gambhir et al. (2015) evaluated the technologies and the cost of the potential reduction of carbon dioxide in the Chinese road transport sector. Ling-Yun and Qiu (2016) estimated the relationship between the transport harmful emissions, the environment and human health in China. Guo et al. (2014) identified the transport carbon dioxide emission patterns at regional level in China. Peng et al. (2015) uncovered the energy saving and emission reduction potential of the passenger transport in Tianjin. It is evident that most of the research results about Chinese transport sector paid large attention to emissions and energy consumption, while other indirect aspects such as quality and environmental cost of resource use as well as labor intensiveness and monetary costs are not sufficiently addressed. Of course, focusing on energy is of paramount importance for the transport sector. However, infrastructures, vehicles and drivers are also important factors to operate the transport sector and all these factors should be involved into the evaluation of the resource demand and sustainability of the transport sector. Federici et al. (2004) investigated the local scale transport in a small province of central Italy, focusing on passenger and freight short-distance transport in order to highlight the thermodynamic efficiency and environmental benefits of urban and peri-urban mass transport (train, trucks and buses) compared to private car use. They introduced for the first time an integrated multi-method assessment of transportation patterns and discussed the benefits and added value of such methodological integration, capable to contribute to a better understanding of transport dynamics and suggest environmental friendly policies. Later on, the same authors performed a multi-method multi-scale comparison of selected long-distance terrestrial transport modalities and highlighted that fuel and electricity consumption were not the only important factors affecting the transport sector, but also material consumption for vehicles and infrastructures played a crucial role (Federici et al., 2008). This was confirmed by Federici et al. (2009) that compared air transport and terrestrial highway and high-speed train transport, showing that infrastructures may in some cases play a dominant role and that there were break-even distances and use modalities (low passengers occupancy) beyond which patterns characterized by heavy material infrastructure (highways and high-speed train) may unexpectedly become more impacting and resource demanding than air transportation mode.

Therefore, it is necessary to evaluate terrestrial transport sector in China from a more comprehensive perspective involving all elements of infrastructures, vehicles, fuels and labors by clarifying the amount, quality and distribution of resources from monetary, energy and environmental aspects for various policy targets. In order to do so, we have categorized the terrestrial transport sector into 9 modalities, namely private car, taxi, urban bus, long distance bus, subway, regular train and high-speed trains for passengers, trucks and regular trains for freight transport. Monetary assessment involves total cost investment for infrastructure, vehicles, energy and labor, while energy evaluation considers the direct and indirect commercial energy consumption associated with the construction of the infrastructure and vehicles as well as the energy used to drive vehicles. Furthermore, we also implement the emergy accounting approach, which considers the direct and indirect environment support to the production and operation processes related with the transport sector at the larger scale of the biosphere. These three evaluations focus on different characteristics of the transport sector (e.g., expensive technology, energy and labor intensity, need for infrastructures, resource replacement time) and could be used for different purpose oriented policy making. Expected results are both to ascertain the monetary, energy and environmental costs per unit of transport service provided and the total costs of each modality at the level of the entire country. Moreover, the most demanding and expensive input flows are investigated, in order to suggest targeted improvements.

2. Methods

This paper compares the terrestrial transport modalities in China in terms of monetary cost and energy depletion as well as of demand for environmental support in 2012, per unit of passengers and freight transported.

2.1. The terrestrial transport system in China

The terrestrial transport system is mainly composed by the road system, subway and railway systems. For the road system, we categorized it into different sub-modalities according to the transport purposes, namely private cars, taxi, urban buses and long distance buses, for passengers, and trucks for freight. Subway is a special sub-category, in that it only serves urban passengers as an alternative to road transport. Regular trains (electric and diesel) serve both passenger and freight transport, while high-speed trains are mainly used for passengers. Each transportation modality includes three main steps:

a) Construction and maintenance of infrastructures (road, railway, bridge and tunnels);
b) Construction of vehicles (cars, urban buses, long distance buses, subway trains, regular and high speed trains, trucks);
c) Operation phase (annual flows of energy, labor and services).

A system diagram of terrestrial transport in China (nine different road and rail modalities) is shown in Fig. 1. The nine transport modalities are categorized into passenger and freight transport, and then into road and rail modes. The operation of the transport sector occurs over three phases: construction of vehicles, construction of infrastructure (rail and road), and the actual processes of transport of passengers and freight. All these three phases are supported by direct flows of free environmental inputs as well as by materials, fuels, labor and services (indirect labor over the supply chain), which are also indirectly supported by the environment. The environment not only provides supporting resources to the process, but also provides environmental services for uptake of emissions and disposal of solid waste from all the anthropic processes involved. Fig. 1 shows that untreated emissions may affect and degrade the surrounding environment by means of feedback loops interacting with upstream natural processes.

The basic data set of all modalities (Table 1) were collected from the statistic yearbooks (China Statistical Yearbook, 2013), from published official government reports and from studies carried out by international Institutions, such as the World Bank. It is quite obvious that the road system takes the dominant role in the terrestrial transportation sector in terms of the length of the infrastructure and the service supported. The total length of the road system in China is 4.24E + 06 km; in the railway system, the regular railway is 9.67E + 05 km and the high-speed railway is 1.01E + 04 km. The road system transported 5.76E + 12 p-km in 2012 that accounts for 84% of total transport service by all terrestrial transport modalities, while the railway and subway systems transport 14% and 2% of the total transport service, respectively. Among the road transport modalities, private cars and long distance buses are the two most important ones and respectively provide a transport service around 3.01E + 12 p-km (44% of the total) and 1.85E + 12 p-km (27% to the total).

2.2. Accounting methods

We treated each transport modality as an independent system (disregarding, as comparatively negligible, the specific infrastructures that connect each modality to the others) and firstly carried out a thorough inventory of all the input flows on the local scale (foreground data). It is important to underline that this inventory forms the common basis for all subsequent assessments, namely monetary cost accounting,