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Life cycle assessment of High Speed Rail in China

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ABSTRACT

China has built the world's largest High Speed Rail (HSR) network. Its environmental impacts have been examined by the means of life cycle assessment (LCA) which describes the whole picture of the HSR system instead of single stages, with a case study for the high-speed railway that links Beijing and Shanghai. The research employs the China-specific life cycle inventory database Chinese Core Life Cycle Database (CLCD). Vehicle operation dominates most impact categories, while vehicle manufacturing/maintenance/disposal and infrastructure construction contribute mostly to mineral consumption (43% and 38%) and organic compounds in water (54% for infrastructure construction). Several scenarios are developed to explore effects of changes in HSR development, utilization, electricity mix, and infrastructure planning and construction. Suggestions are provided for improving the life cycle environmental performance of China's HSR systems.

Introduction

China has built the world's largest High Speed Rail (HSR) network in less than five years (Lu, 2012). In addition to prompting economic integration and providing safer and faster transportation service, HSR powered by electricity also brings potential environmental benefits compared to conventional trains that are mostly powered by coal or diesel oil. In particular, HSR avoids consuming oil during the operation, leading to reduced air emissions from vehicle and air travels. However, the operation is only one piece of the whole life cycle of an HSR system which includes also infrastructure development, vehicle manufacturing, and electricity generation. All these pieces from the HSR life cycle have different environmental implications. To date, there is no study specifically examining the life cycle environmental impacts of China's HSR system. These questions remain to be answered: What are the life cycle environmental impacts of China's HSR system? How does China's HSR system perform in comparison to other transportation modes? In this paper, we construct a life cycle inventory of environmental impacts of China's HSR system. We also compare our results with other transportation modes.

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Previous LCA studies on rail systems primarily focused on conventional rail systems. For example, it was found that the US conventional rail system had relatively low energy consumption, greenhouse gas (GHG) emissions, and air pollutant emissions (including CO_2, NO_x, PM_{10}, CO, and SO_2) compared to air and road freight systems, but relatively high SO_2 emissions in passenger transportation due to coal-fired power for vehicle operation and removal of sulfur from gasoline and diesel fuels (Chester and Horvath, 2009; Facanha and Horvath, 2007; Facanha and Horvath, 2006). Spielmann and Scholz (2005) conducted a life cycle inventory analysis of freight transport systems and found that rail systems have the lowest environmental impacts compared to barge and lorry systems, except for PM_{10} due to abrasion processes. Using attributional LCA, Spielmann et al. (2005) found that rail system is the best alternative for Switzerland's future regional transport in terms of environmental impacts.

The limited previous studies on life cycle environmental impacts of HSR systems mainly focused on HSR systems in the developed countries or regions including the US, Japan and Europe. Chester (2008) compiled a Life Cycle Inventory (LCI) of energy use, GHG emissions, and criteria air pollutant emissions for diverse passenger transportation modes in the US including the proposed California High Speed Railway (CAHSR). Chester and Horvath (2010) studied the life cycle environmental performance of CAHSR in comparison with alternative transportation modes. The results showed that CAHSR had lower GHG emissions and end-use energy consumption at high capacity utilization, and higher SO_2 emissions at low capacity utilization as it is mainly powered by fossil fuel-based electricity. In addition, CO, NO_x, VOC, and PM_{10} emissions mostly came from infrastructure construction instead of vehicle operation. Chester and Horvath (2012) also found that HSR could achieve considerable life cycle environmental benefits over other current transportation modes with state-of-the-art vehicles, renewable energy, and high ridership. Chang and Kendall (2011) examined GHG emission in the construction of CAHSR infrastructure with several specific infrastructure types depending on terrains. It was found that 80% of the infrastructure emissions were from material production. Tunneling and aerial structures, covering only 15% of the route's length, contributed 60% of the total emissions from the life cycle. Von Rozycki et al. (2003) found that energy use of a German HSR system mainly came from traction, tunnel construction, and rail point heating during winter. Åkerman (2011) examined a proposed Swedish HSR track and found significant GHG emission reduction potential due to transportation modes shifting to HSR, even though new railway construction and maintenance generate GHG emissions. Moreover, Lee et al. (2008), Miyauchi et al. (1999), and Ueda et al. (1999) studied environmental impacts of individual HSR components including infrastructure, vehicle, and materials, respectively. Although HSR offers multiple environmental benefits from replacing oil consumption during the operation, the life cycle environmental impacts of China's HSR may not be desirable, and they may be very different from HSR systems in the developed countries as well as conventional rail systems. First, China's HSR system uses considerable amount of bridges to cross diverse terrains, leading to massive material and energy consumption for infrastructure development. Second, the fuel mix for electricity generation in China is dominated by coal, which undermines the benefits of emission reduction from the operation. Therefore, life cycle assessment is needed to understand the environmental impacts of China's HSR across the entire life cycle. The results can potentially help design future HSR systems for better environmental performance.

In this study, we conduct an LCA for the 1318-km long HSR between Beijing and Shanghai, which is one of the flagship projects of China's HSR development and the world's second longest HSR line (Li, 2007), as a case study to evaluate life cycle environmental impacts of China's HSR system. Our study focuses on life cycle inventory of the Beijing–Shanghai HSR line and multiple environmental impacts from different life cycle stages under various scenarios concerning factors such as infrastructure composition, electricity mix, and capacity utilization rate.

Methods and data

Life cycle stages and data sources

We divide the life cycle of the Beijing–Shanghai HSR system into three stages: (1) vehicle, including vehicle manufacture, maintenance, and disposal; (2) infrastructure, including infrastructure construction; and (3) operation, including vehicle operation. As China just built HSR systems in recent years, we exclude infrastructure operation, maintenance, and disposal due to data unavailability as well as their limited life cycle environmental impacts according to other HSR LCA studies (e.g., Chang and Kendall, 2011; Chester and Horvath, 2010). The system boundary also excludes facilities used and material, energy and equipment transportation due to lack of data and intention to be consistent with other previous studies (e.g., Chester and Horvath, 2010; Yang et al., 2013) for easier comparison. The function of the analyzed system is to transport passengers between Beijing and Shanghai. The functional unit is per seat per kilometer traveled (SKM). In the analysis of different capacity utilization rate scenarios, the functional unit is converted into per passenger per kilometer traveled (PKM).

There are currently no data for China's HSR vehicles (including vehicle manufacturing, maintenance, and disposal stages, but excluding the operation stage for which we obtain China-specific data). We estimate the LCI of China's HSR vehicles by adjusting LCI of Germany's Inter-City Express (ICE) HSR vehicle from the Ecoinvent 3.0 database, since China's HSR vehicle CRH3 uses Siemens's Velaro, or Germany's ICE-3, as a prototype with mostly the same structure and vehicle material (Li and Jin, 2011; Siemens, 2005). In particular, the LCI for China's CRH3 vehicle is estimated by multiplying the LCI of Germany's ICE-3 vehicle with the weight ratio of China's CRH3 vehicle to ICE-3 vehicle (details shown in the SI). Due to data unavailability, we choose not to make arbitrary assumptions on the actual efficiency differences between China and Germany in