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Calculation of life-cycle greenhouse gas emissions of urban rail transit systems: A case study of Shanghai Metro

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ABSTRACT

In China, although per capita energy consumption is lower in the urban rail transit system than other modes of transportation, the total energy consumption and greenhouse gas emissions will reach considerable levels based on the current speed of urban rail transit system development. The objective of this research is to use the life cycle assessment (LCA) type method to define the system boundaries of the life cycle of Shanghai Metro and to inventory the associated resource inputs and emission outputs based on actual observed data. A comparative analysis of GHG emissions of different urban rail transit systems around the world is also provided. The results show that the total life-cycle GHG emissions per construction length of the entire Shanghai Metro are 109,642.81 t CO_2e (with a service life of 50 years), and materials production, materials transportation, on-site construction, operation, and maintenance generated, respectively, about 4.1%, <0.1%, 0.4%, 92.1%, and 3.4% of the total emissions. Although the traction emissions per passenger-km traveled of Shanghai Metro are competitive at the global level, there is still great energy-saving potential in the operation phase, especially in ornately designed train stations. The preliminary conclusions of this study may help shed light on the emission reduction potential of urban rail transit systems and the emission reduction targets in China and serve as a source of information and data for future LCAs.

1. Introduction

One challenge in mitigating global climate change is motivating state and local transportation agencies to investigate strategies to reduce the life-cycle greenhouse gas (GHG) emissions associated with transportation infrastructure (Long, 2014). In recent years, China has been rapidly developing its urban rail transit system, generally considered a low-carbon mode of transportation. According to statistics from the China Rail Transit Network, by the end of 2014, China had approved rail transit network planning and construction in 37 cities (China Rail Transit Network, 2014). Thus far, 95 lines and 1947 stations in 22 cities have been put into use, with a total mileage of 2933.26 km. Although the per capita energy consumption of urban rail transit in China is currently less than that of other modes of transportation, the rail system's high rate of development will lead to considerable total energy consumption and GHG emissions in view of the complex construction and large operation capacity of the system. To investigate the emissions reduction potential of and targets for urban rail transit or to evaluate the efficacy of enormous public investment in urban rail transit over other modes of transportation in mitigating climate change, the GHG emissions of the entire life cycle of the system must be calculated.

A life cycle assessment (LCA) type method can be adopted to estimate GHG emissions (Cambero et al., 2015). According to standard methodology (ISO, 1997), LCA is utilised to assess a product, a production process or a system over a number of impact categories, which helps to ensure that the strategy does not result in unintended consequences in terms of net increase or decrease of

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the burden (Wang et al., 2012). The result of a LCA is a quantified environmental impact through an official and standardized "Impact Category", the most used are: Global Warming Potential, Acidification, Eutrophication, Ozone Layer Depletion and Human Toxicity (Baldo et al., 2008). However, the methodology has yielded successful results in terms of assessing a single impact category, because it defines a reproducible, objective method of delimiting the system, and it can be used to define and quantify GHG emissions (Casey and Holden, 2005).

Some previous studies have investigated the GHG emissions of transportation systems using LCA. Some of them calculated GHG emissions produced in the life cycle of both the infrastructure and the management system, including phases of material production, construction, use, maintenance, and end-of-life. The others primarily focused on individual phases without considering the whole life cycle of the whole system, but because the calculations involved the life cycle GHG emissions of the associated resource inputs (materials, fuels, and equipment), they were also called life-cycle GHG emissions. For example, Chang and Kendall (2011) estimated the life cycle greenhouse gas inventory for construction of high-speed rail infrastructure from San Francisco to Anaheim. Wang et al. (2012) evaluated the energy consumption and GHG emission of material production phase, on-site construction phase, and use phase from pavement rehabilitation with different rolling resistance. Most existing literature on the GHG emissions of infrastructure belongs to the second type, and so is that of urban rail transit systems. Hong and Kim (2004) investigated the energy consumption of subway stations in four cities in Korea and examined the influence of several factors, such as the entrance, floor level, and number of passengers at each station. Doll and Balaban (2013) discussed the energy consumption of and carbon dioxide (CO_2) emissions from traction during the operational stage of the Delhi Metro in India. Anderson et al. (2009) explored practices and strategies available to metro managers and developers for minimizing total metro energy consumption. Del Pero et al. (2015) provided a predictive LCA for a heavy metro train vehicle, rather than the entire infrastructure, that will operate in the urban area of Rome.

This study aimed to answer the following questions:

1. How much GHGs does the Shanghai Metro emit in its whole life cycle?
2. What is the level of emissions of the Shanghai Metro when comparing with other case studies around the world?

To figure out these questions, this study tries to calculate the GHG emissions of the Shanghai Metro in its all life cycle phases: raw materials production and transportation, on-site construction, operation, maintenance, dismantling and recycling. The results are compared with those from other case studies around the world for global context on the level of emissions of the urban rail transit system in China and guidance for future efforts to reduce emissions.

The organization of this paper is as follows. Section 2 introduces the goal, system boundary, unit function and calculation methods used in this study. Section 3 performs the calculation of GHGs in life cycle of Shanghai Metro. Section 4 discusses the differences in emissions of several urban rail transit systems around the world. Finally, the conclusions and suggestions for future research are outlined in Section 5.

2. Methods

LCA is a well-established and internationally standardised methodology for quantifying emissions from specified products or systems over their entire life cycle (Lazzerini et al., 2016). However, performing an LCA on rail system may be much more complex than for general consumer products. Since the urban rail transit system is not just a product, cooperate or project, none of the standards can fit it completely. Choices regarding system boundaries definition, model parameterisation, and data selection can significantly affect the calculated results (Finnveden, 1999). In this study, the GHG emission calculation is performed as far as possible in accordance with the GHG Protocol Product Standard from the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) (WRI and WBCSD, 2011), which is based on a life cycle and attributional approach and builds on the ISO standards for LCA (Guinée et al., 2002; ISO, 2006a,b) and the first version of PAS 2050 (BSI, 2008).

2.1. Goal and scope definition

In this study, the goal is to use the life cycle assessment type method to define the system boundaries of the urban rail transit

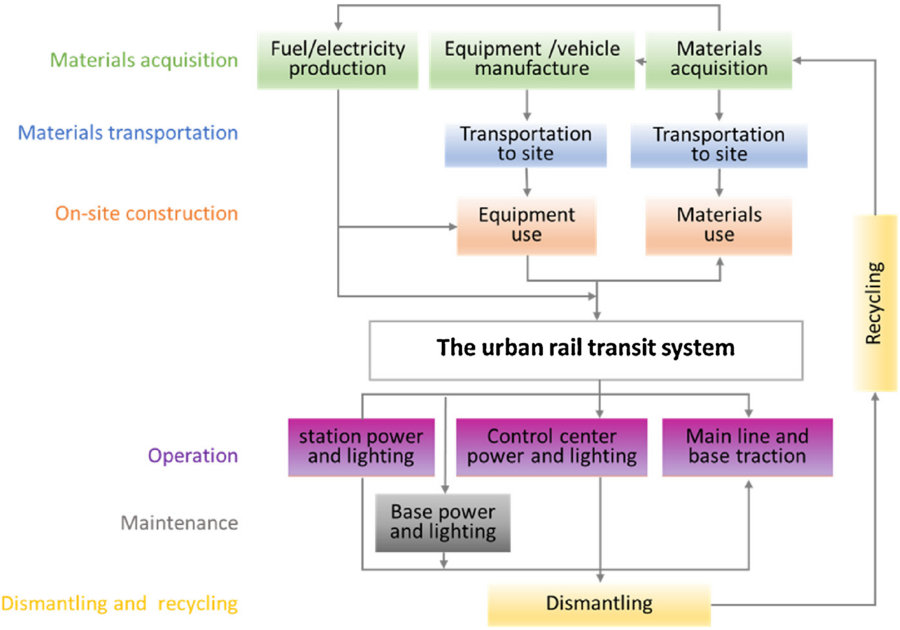

Fig. 1. System boundary of GHG emission calculation of the urban rail transit system.

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