Journal of Cleaner Production 198 (2018) 847–858

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

A quota-based GHG emissions quantification model for the construction of subway stations in China

Minghui Liu*, Siyi Jia, Xiaotong He

School of Civil Engineering, Beijing Jiaotong University, Beijing, 100044, PR China

ARTICLE INFO

Article history:
Received 15 October 2017
Received in revised form
28 May 2018
Accepted 7 July 2018
Available online 11 July 2018

Keywords:
Greenhouse gas emissions
Quota
Subway station
Buried depth

ABSTRACT

Subway construction in China has experienced a surge during the past decade. Though subway is often viewed as a clean commute mode, the construction of its stations and tunnel sections requires large quantities of energy consumption, generating multiple pollutants, among which the Green-house gas (GHG) emissions would be a major issue in the context of a worldwide plea for carbon reduction, and it has to be quantified for the interest of a comprehensive assessment with regard to the GHG emissions of subway system. This paper proposed a GHG emissions quantification model for the construction of the subway stations based on a quota. A quota-based GHG emissions quantification model is able to estimate GHG emissions during the planning stage of subway projects, providing designers with the environmental consciousness on their design choices, as well as a reference for reduction potential of GHG emissions within or among schemes. Specifically, GHG emissions in the construction of subway stations are attributed to the contribution of each sub-project, a database for the GHG emissions of those sub projects is established through their construction quota. Case study for an open-excavation station shows 69% of the GHG emissions come from the construction of main structures. In terms of emission sources, embodied emissions account for 90.72% of the totality, of which concrete and steel components are the two major contributors. Besides, parameter on the buried depth of top slab shows that GHG emissions from each sub-projects increase with buried depth.

1. Introduction

Public concerns on the GHG emissions of transportation sector has been growing these years, it is a major contributor to GHG emissions in developed and developing countries (Glassom, 2007; Francois et al., 2017; Gangwar and Sharma, 2014; Alkhathlan and Javid, 2015). In 2010, 23% of anthropogenic GHGs are from the emissions of passenger and freight vehicles (IPCC, 2014). While it varies a lot between countries, the growing economy of developing countries are likely to change the distribution in the future (Taptich et al., 2016). As the largest developing country in the world, China's transportation sector is responsible for 15.9% of the total final CO_2 emissions in 2008 and will contribute about one-third of CO_2 emissions in 2030 (Zhou et al., 2013).

Some work has been done to investigate the GHG emissions from urban transit rail (UTR), of which a majority chose to focus on the GHG emissions from its operation phase, such as GHG emissions from traction (Doll and Balaban, 2013; Wang, 2016), that from lightening and power consumption in stations (Hong and Kim, 2004; Li et al., 2018) and equipment spoilage (Baron and Martinetti, 2011). In other studies, efforts have been made on the exploration of GHG emissions reduction methods in its operation stage i.e. changing level-of-service (Cheng et al., 2016), optimizing network (Mandanat et al., 2016) and operation optimization (Grissword et al., 2013; González-Gil et al., 2013). UTR's efficiency in terms of mitigating GHG emissions were justified by quantifying the reduced carbon print due to mode shift from other commute types (Chen et al., 2017; Huang et al., 2015; Saxe et al., 2017; Saxe et al., 2017), congestion relief (Andrade and D'Agosto, 2016) and change of land use (Andrade and D'Agosto, 2016, Saxe and Denman, 2017). Nonetheless, the validity of the quantification of GHGs mitigation is hinged on the uncertainty in ridership prediction, and a more holistic assessment scope including GHG emissions from UTR's infrastructures.

GHG emissions from the construction of URT's infrastructures, especially those in underground sections, are more intensive as it involves large quantities of energy consumption and building materials. Data show that GHG emissions from the construction of

* Corresponding author. NO. 3 Shang Yuan Cun, Hai Dian District, Beijing, PR China.

E-mail address: mhl@bjtu.edu.cn (M. Liu).

https://doi.org/10.1016/j.jclepro.2018.07.067
0959-6526/

1 km subway projects are 79468 t CO_2 eq. in Shenzhen, 46 times higher than that from 1 km highway construction (Mao, 2017). Therefore, to appropriately access the emissions-mitigating superiority of urban transit to alternative commute modes, it is necessary to take into accounts its infrastructure-related GHG emissions (Chester and Horvath, 2009).

Along with the adoption of life-cycle methodology, the infrastructure-related GHG emissions in rail projects have received more attention. GHG emissions from the construction of high speed railway has been investigated (Saxe et al., 2016; Chang, 2009; Chester and Horvath, 2010), the results varies as the composition of a HSR line would significantly affect the GHGs investment. For example, GHG emissions from tunnel construction have a disproportionate contribution of the totality (Saxe et al., 2016; Chang and Kendall, 2011). In cases of underground UTR projects, GHG emissions are more intensive for the large quantities of GHGs emitted from the construction of its tunnel sections. GHG emissions from the construction of underground sections and stations of Crossrail in London are estimated to be 1.7 Mt CO_2, contributing about 20% of life-cycle totality (Crossrail, 2014). Similar case studies in Asia show that construction-related GHG emissions (those from building materials and construction machine) account for 4.9% of life-cycle totality in Shanghai metro (Li et al., 2018), 10%, 20% and 30% for urban transit in Kunming, Ho Chi Minh City and Bangalore respectively (Clean Air Asian Cooperates, 2015). The variation in these percentages is dictated by assessment duration, which might belie the fact that GHG emissions from urban transit's infrastructures are huge in absolute volume.

However, the environmental-efficient thinking in construction section is still lacking, and one of the major objectives for the sustainable construction is to establish the environmental-consciousness among engineers and designers, making them aware of the environmental implication of their choices on materials, design, construction methods and facility siting (Horvath, 1999). The existing criterion of economics and safety in engineering should be incorporated with 'the third bottom line'- environment, and a design code with environmental consideration would benefit this process greatly.

A GHG emissions database on the basis of Chinese quota system provides us the chance to do so. Quota system in China has a wide range of adaption, thousands of specified quotas have been issued for each industry. By definition, a quota is an officially-issued database that decomposes the production into many standardized element processes with specific technical routines, quality standards and range of applicability, prescribing the average consumption of manpower, materials and machine shifts and frequently updated unit price of production factors involved in each element process. The standardization of routine and resource input in one element process is achieved through a long-term maturity process of its technology as it is adopted by many individual manufacturers, therefore a statistically-average database for consumption can represent the production level within a region. In practice, the consumption data in quotas serves as the benchmark in bidding from which any significant deviation would cause potential quality problems or, on the other side, less economical competitiveness of a proposal. As for the construction industry, quota is indispensable in that it is the common language among different roles throughout the project. Design schemes and inventory should be compiled in accordance with the element processes in quota, and construction plan is also organized in the form of the combination of these elements. Moreover, acceptance check and payment are also performed on the basis of quota.

In this paper, the standardized element processes and their consumption data are utilized to construct a quota-based GHG emissions database to quantify the GHG emissions from the construction of subway stations. Such a database is capable of estimating the GHG emissions from different schemes of UTR engineering, providing reference to scheme selections. Besides, it is inherent with the convention of contractors, owners and designers, thus being helpful in improving their perception of the environmental implication of their choice such as scheme selection and construction plan. The major differences between quota-based method and traditional method are listed in Table 1.

The layout of this paper is as follows: In section 2, the decomposition for the construction of open-excavation subway stations is defined, following which the GHG emission quantification model for the construction of subway stations is constructed by integrating the GHG emissions from labor force, construction materials and construction machines in each element process and upscaling them to each level of sub-projects. The established model is used in section 3 for the case study of an open-excavation subway station in Beijing, GHG emissions among different sub-projects and emission sources are analyzed. Section 4 gives a demonstration on the quota-based model's role in scheme selection. Parameter analysis is made on how the buried depth, the most essential parameter for the construction, affects the GHG emissions from construction. Some implication of the results is discussed in section 5.

2. Modelling the GHG emissions qualification model of subway station during its construction period

2.1. Methodology

The quota-based GHG emissions quantification model follows the procedure of ISO/TS 14067 (ISO/TS, 2013), in which the single impact category of GHG emissions is assessed. A few modifications were made to serve the goal of this study:

Scope: Referring to the notion of Partial CFP (Carbon Foot Print) in ISO/TS 14067, this study aims to quantify GHG emissions from all unit processes ahead of the operation of a subway station, which are classified into two categories: (I). GHG emissions from construction material and (II). those from construction machine. System boundary is defined as in Fig. 1. The post-construction GHGs impacts of the infrastructure, i.e. GHG emissions from operation and its impacts on commuters' behaviors are not within this scope.

Common practice in quantification of GHG emissions takes the equivalent CO_2 emissions as a benchmark, equivalent carbon dioxide emissions of gas *i* can be calculated through global warming potential of gas *i*

$$CO_2eq_i = M_i \times GWP_i \tag{1}$$

The quantification of GHGs focuses on the three major GHG sources, i.e. CO_2, CH_4 and NO_x. Global warming potentials are updated according to the latest IPCC report (IPCC, 2013) (see Table 2).

2.2. Modeling

2.2.1. Decomposition of the construction process of open-excavation subway station

Open-excavation method, characterized by high efficiency and

Table 1
Major differences between quota-based method and traditional method.

	Quota method	Traditional method
Element unit	Element process	Material/energy
Function	Estimation	accounting
Input data	Engineering quantities	Material/energy quantities
Functioning stage	Pre-construction stage	Post-construction