Construction and Building Materials 136 (2017) 405–413

Contents lists available at ScienceDirect

Construction and Building Materials

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

Characterizing the generation and flows of construction and demolition waste in China

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HIGHLIGHTS

- An novel method to quantify C&D waste in China was developed.
- 2.36 billion tonnes of C&D waste were generated in China annually 2003–2013.
- Potential recycling value of C&D waste is up to 401 billion USD in 2013.
- With the current dumping rate, C&D waste could occupy an area of 7.5 billion m^3.

ARTICLE INFO

Article history:
Received 25 July 2016
Received in revised form 14 January 2017
Accepted 16 January 2017

Keywords:
C&D waste
Waste characterization
Economic values
Land space
China

ABSTRACT

Associated with the continuing increase of construction activities such as infrastructure projects, commercial buildings, and housing programs, China has been experiencing a rapid increase of construction and demolition (C&D) waste. Till now, the generation and flows of China's C&D waste has not been well understood. This paper aims to provide an explicit analysis of this based on a weight-per-construction-area method. Our results show that approximately 2.36 billion tonnes of C&D waste were generated in China annually during the period of 2003–2013, of which demolition waste and construction waste contributed to 97% and 3%, respectively, in 2013. East China contributed over half of the total C&D waste in China due to their rapid economic development and expansion of cities, followed by Middle China (21%) and South China (11%). Potential economic values from the recycling of C&D waste were found to vary from 201 billion (the worst scenario, i.e., the current practice of C&D waste management) to 401 billion US dollars in 2013 (the most optimistic scenario, i.e., C&D waste is assumed to be well recycled); and the landfill space demands were estimated to range from 7504 million m^3 (the worst scenario) to 706 million m^3 (the most optimistic scenario) accordingly. Consequently, increasing the recycling rate and reducing landfill rate of C&D waste could not only improve the potential recycling economic values, but also dramatically reduce land use and potential environmental impacts.

1. Introduction

With the rapid urbanization of China, its building industry has contributed to 26.7% of the national GDP. In addition, the building area under construction and completed building area has reached 12.4 billion m^2 and 4 billion m^2 respectively in 2015 [33]. Rapid urbanization means massive construction and demolition activities across the country, which resulted in massive construction and demolition (C&D) waste. C&D waste is therefore becoming one of the largest solid waste streams in China [51].

C&D waste is usually considered as inert solid waste, which has large quantities and complex compositions. C&D waste mainly consists of metal, concrete, mortar, brick and block, timber, and plastic [1,11]. Theoretically, C&D waste have high potentials of recycling and high economic value, 80% of which could be reused [16]. However, massive C&D waste has been disposed via simple landfilling or dumping in China, which would become a potential

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http://dx.doi.org/10.1016/j.conbuildmat.2017.01.055

risk that threatens regional ecological security and sustainable development [37,51]. First, they occupy large areas of land, which is already scare during a rapid urbanization process. Second, while the vast majority of construction materials are inert, buildings may have used some materials which would absorb harmful elements [12]. These harmful C&D waste could cause soil and water pollutions due to the leaching of toxic heavy metals (e.g., As, Pb, Hg, Cr, Cd, Cu, and Zn) [42] and brominates flame retardant (e.g. hexabromocyclododecane -HBCD and Poly Brominated Diphenyl Ethers -PBDEs) which was classified as Persistent Organic Pollutants [11]. Third, the massive volume of dumped C&D waste may result in safety hazards such as landslide [48].

At present, the majority of C&D waste in China is disposed via landfilling or directly sent to dumping sites without any environmental protection measures. The recycling rate in China is relatively low compared to many developed economics. The EU-28 has a recycling rate between less than 10% and over 90% (from Eurostat, 94% for the Netherland by, 87% for the UK, 76% for Italy, and 34% for Germany) [15]. This is comparable to the U.S (70%) [31] and Japan (95%) (Yonetani, 2014). For many cities in China, material recovery and recycling are not normally carried out by the local authorities or landfill operators due to low recovery value [11]. Waste dumping sites included gravel pits, farm land, abandoned residential land, borrow pits, river side, and low lying areas. Due to the limited landfill disposal capacity and high cost of land resource in big cities, it is not unusual C&D waste is transferred to less-developed neighboring regions. In fact, there is no national or local regulation to guide the disposal of C&D waste via landfilling. Even worse, there is no specific regulations on sorting and safe treatment measures for non-inert or hazardous C&D waste debris, such as the asbestos, brominated flame retardant thermal insulation material, and lead paint debris used in old buildings [13]. On the contrary, based on the explicit C&D waste inventory data, effective management and industrialization model have been established in developed countries. In the United States, for example, the hazardous waste from C&D waste is well managed under the Resource Conservation and Recovery Act (RCRA) [24]. In addition, C&D waste management has been taken into full consideration for several decades in Germany, and many initiatives have been in place, at both the state and the local level. Germany has released more than 180 laws and regulations related to a waste disposal since 1970s [39], and till 2012, its recycling rate of C&D waste has reached 68% [9]. Nevertheless, a pre-requisite for tackling the C&D waste issue is to fully understand its generation, composition, flows, and the recycling potentials

So far, there are indeed some studies which have already developed estimation approaches to investigate the generation, flows and composition of C&D waste. To summarize, four approaches have been used in the scientific literature to quantify the C&D waste generation:

- Records-based accounting: Kartam et al. [22] estimated the generation of C&D waste in a region of Kuwait based on the records of loading capacity of trucks to the construction site, and conducted a further investigation on waste collection activities and the waste handling systems. However, this method was rarely employed to quantify the C&D waste generation, because few countries have detailed records to describe the on-site situation.
- Material flow analysis (MFA) approach: MFA could examine the input and output of construction materials that come into service in given years and also figure out materials flows through the whole construction activity. Cochran and Townsend [5] adopted a MFA approach for estimating C&D waste generation and composition in the U.S. This study differs from others by accommodating waste generated from road, bridges engineering, and other non-building structures. Bergsdal et al. [2] developed the stocks and flows model to evaluate the generation of C&D waste in Norway. To make the results more robust, Monte Carlo simulation has been employed in the computational procedure in order to capture the uncertainties related to the input parameters.
- A method with an aid of Geographic Information System (GIS): Gallardo et al. [19] suggested it is possible to obtain a spatial distribution of solid waste within a specific geographic area taking into account its generation, composition and variation throughout the year by GIS. De Feo and De Gisi [8] combined a multi-criteria decision analysis (MCDA) approach with GIS to obtain an initial screening so that unsuitable areas can be eliminated.
- A weight-per-construction-area estimation method: Lage et al. [23] presented a calculation procedure to ascertain the production of C&D waste and determine its composition for Spain. Practically, that study paid attention to Galicia in Spain alone, and was lack of estimation of C&D waste at national level. Sáez et al. [38] developed weight-per-construction-area by taking some parameters into account. That research quantified the waste generated in the construction activities of Mediterranean by considering the total floor area of the project and the number of dwellings. However, residential building is the only type of buildings examined in that research, which was lack of integrated and comprehensive analysis.
- These methods have also been deployed in a few case studies for C&D waste in China:
- Material flow analysis (MFA) approach: Based on the combination of MFA and weight-per-construction-area method, Ding and Xiao [10] estimated that approximately 13.7 million tonnes of C&D wastes were produced in Shanghai in 2012, among which concrete, bricks and blocks accounted for more than 80%. Hu et al. [20] developed a dynamic MFA model for ascertaining resource demand and waste generation through dividing the Chinese dwelling stock into urban and rural subsystems. In addition, Hu et al. [21] forecasted the relationship for housing and steel demand in China in the future, which has been conducted by using the dynamic MFA. However, this study includes only selected one construction material (steel) and only residential buildings. Ye and G. [50] designed a system dynamics model to incorporate the inter-related factors into the waste management process. The software "i Think" could be used to depict the interrelations of impacts on C&D waste management, such as waste deduction rate, compulsory policy, landfill charge, technical level and so on. However, that research mainly focuses on proposing the model without the verification of the quantitative results.
- A method with aid of Geographic Information System (GIS): Wu et al. [45] developed an innovative approach based on GIS to estimate demolition waste generation and trends economic values in Shenzhen. Specifically, this method needs to define the questions, to state the aims and contents, and then import the DW-GIS database into GIS software, i.e. generation index of demolition waste, demolition time of buildings, building types, and recycling potential. Consequently, calculation and analysis can be conducted. Li et al. [25] presented a study on reducing C&D waste by integrating Global Position System (GPS) and GIS. Although this method is innovative, it is difficult obtain massive geographic informations.
- Weight-per-construction-area method: Shi and Xu [40] estimated the amount of concrete waste based on annual cement production, and examined the building area by gray forecast. Wu et al. [46] developed an innovative method to estimate the quantity of demolition waste (DW) produced from different structures of buildings. Lu et al. [29] summarized the waste pro-