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Environmental impact assessment on the construction and operation of municipal solid waste sanitary landfills in developing countries: China case study

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ABSTRACT

An inventory of material and energy consumption during the construction and operation (C&O) of a typical sanitary landfill site in China was calculated based on Chinese industrial standards for landfill management and design reports. The environmental impacts of landfill C&O were evaluated through life cycle assessment (LCA). The amounts of materials and energy used during this type of undertaking in China are comparable to those in developed countries, except that the consumption of concrete and asphalt is significantly higher in China. A comparison of the normalized impact potential between landfill C&O and the total landfilling technology implies that the contribution of C&O to overall landfill emissions is not negligible. The non-toxic impacts induced by C&O can be attributed mainly to the consumption of diesel used for daily operation, while the toxic impacts are primarily due to the use of mineral materials. To test the influences of different landfill C&O approaches on environmental impacts, six baseline alternatives were assessed through sensitivity analysis. If geomembranes and geonets were utilized to replace daily and intermediate soil covers and gravel drainage systems, respectively, the environmental burdens of C&O could be mitigated by between 2% and 27%. During the LCA of landfill C&O, the research scope or system boundary has to be declared when referring to material consumption values taken from the literature; for example, the misapplication of data could lead to an underestimation of diesel consumption by 60–80%.

1. Introduction

Nowadays, landfilling is still the most commonly used method for municipal solid waste (MSW) treatment in many countries. Taking China as an example, 100 million tonnes of MSW were disposed of in landfills during 2011, which accounted for 77% of the total amount of treatable waste (National Bureau of Statistics of China, 2012). Life cycle assessment (LCA) can be used to evaluate the environmental impacts associated with all stages of a product/service's life cycle, and through this assessment it provides useful insights into improving the whole process from an environmental perspective. Therefore, the LCA of MSW landfilling is important in supporting decision-making in integrated MSW management. The impacts of generating and treating landfill gas (LFG) and leachate have been the primary concerns of researchers as the major environmental issues with regards to MSW landfilling (El-Fadel et al., 1997; Kirkeby et al., 2007; Niskanen et al., 2009). Nevertheless, approaching landfill sites as products, their construction and operation (C&O) consume certain amounts of materials and energy, and the manufacturing and utilization of these materials could lead to environmental burdens. Frischknecht et al. (2007) investigated the contributions of capital goods in the LCA of a large number of product/service systems. It was argued

Abbreviations: AC, acidification; C&O, construction and operation; CM, construction of the main parts of the landfill body; COF, construction of other facilities in the landfill site; EDIP, Environmental Development of Industrial Products; ETs, ecotoxicity in soil; ETwc, eco-toxicity in water-chronic; GCL, geosynthetic clay liner; GW, global warming; HDPE, high-density polyethylene; HTa, human toxicity via air; HTs, human toxicity via soil; HTw, human toxicity via water; ISO, International Standardization Organization; LCA, life cycle assessment; LCI, life cycle inventory; LCIA, life cycle impact assessment; LFG, landfill gas; MSW, municipal solid waste; NE, nutrient enrichment; OL, operation of the landfill; POF, photochemical ozone formation; SOD, stratospheric ozone depletion; SP, site preparation.

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that the lower the pollutant content of the assessed waste, the higher the environmental burden contribution from capital goods. Their study also demonstrated that the burden from capital goods was important for landfilling, but not as significant for other waste treatment technologies such as waste incineration, especially when considering climate change, acidification, and eutrophication.

The majority of published works on the LCA of MSW landfilling employ an energy consumption amount (e.g. as megajoules of energy or liters of diesel) to represent the environmental impacts of the landfill C&O process (Damgaard et al., 2011; Khoo et al., 2012; Manfredi et al., 2009). Although Manfredi et al. (2010) and Niskanen et al. (2009) considered the C&O process during the LCA of landfilling, they did not include the original data in their papers, which limited the applicability of these data for further research. Of studies that did cover C&O in detail, Ecobalance Inc. (Camobreco et al., 1999; Ecobalance Inc., 1999) collected and summarized the consumption of materials and energy for more than 20 landfill sites in the United States as a life cycle inventory (LCI) report. Menard et al. (2004) demonstrated that differences in materials and energy inputs between an engineered landfill and a bioreactor landfill were due to different waste density. A detailed quantification of the capital goods used for constructing a typical hill-type landfill (Brogaard et al., 2013) indicated that gravel and clay were used in the greatest amounts. In addition, an environmental impact assessment by Brogaard et al. (2013) revealed that the potential impacts of capital goods consumption were low-to-insignificant compared to the overall impacts of landfill processes (direct and indirect emissions), except for the impact category of resource depletion. In China, researchers usually refer to energy consumption figures published in developed countries during LCA of waste treatment processes (Hu, 2009; Xu, 2003). The only published paper possessing original data, to the authors' knowledge, was by Wei et al. (2009), who reported the usage of water, soil, pesticide, diesel, and electricity in a landfill located in the city of Suzhou.

In China, a representative developing country, the national industrial standard for MSW sanitary landfill management is still under development and has been updated twice in the last two decades (Ministry of Construction of the People's Republic of China, 2001, 2004). This could make landfill C&O in China different from that in developed countries. If a study refers to the literature data reported in developed countries directly, it may thus lead to wrong assessment results. In addition, from a spatial aspect, China is a large country with diverse geographic and economic conditions, which could induce lots of different choices regarding landfill C&O approaches. When researchers conduct a LCA of waste landfilling, they would be more precise in the assessment if they considered the aforementioned differences as much as possible.

The present study will provide a comprehensive LCI of materials and energy consumption and evaluate environmental impacts through a LCA for the C&O process in a typical landfill site in China. The other purposes of this study are to estimate whether the diverse approaches to landfill C&O affect the studied environmental impacts significantly and to identify relatively better approaches with the intention of mitigating environmental burdens in a Chinese context.

2. Approach and method

In this study, the C&O process in a typical sanitary landfill site was taken as the object for a LCA. The functional unit was one tonne of waste disposed of in the landfill site. According to the "Chinese Technical Code for Municipal Solid Waste Sanitary Landfill" (CJJ17-2004) (Ministry of Construction of the People's Republic of China, 2004), in combination with engineering experience, the bulk density of waste buried in the landfill site was assumed to be 1.0 t m^{-3} and the overall height of the landfill body, including the liner and cover system, was assumed to be 30 m. The system boundary in this study is shown in Fig. 1, which consists of four stages: (1) site preparation (SP), for example, excavation and backfilling of soil and stone; (2) construction of the main parts of the landfill body (CM), including groundwater drainage, barrier layer, bottom liner, leachate and LFG collection, and top cover systems; (3) construction of other facilities in the landfill site (COF), such as monitoring wells, onsite roads, and official buildings; and (4) operation of the landfill (OL), for example, the placement and compaction of waste and intermediate soil covers. The treatment facilities for leachate and LFG were not considered in this paper, as they are closely associated with the pollution control features and treatment efficiencies of leachate and LFG. The C&O for leachate and LFG facilities will be analyzed together with the leachate and LFG associated emissions, in future works.

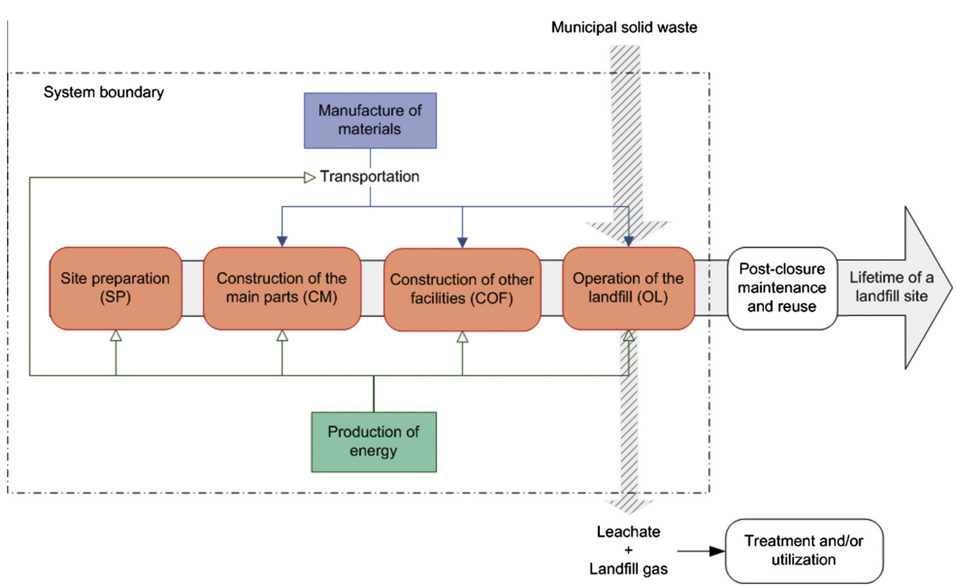

Fig. 1. System boundary for the construction and operation process of a landfill site.

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