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An emergy-LCA analysis of municipal solid waste management

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ABSTRACT

Waste management is a specific practice aimed at reducing the effects of waste materials on the environment and increasing material and energy recovery. The Beijing Municipal Solid Waste Collection and Treatment System has been slow to adopt new technologies capable to enable better treatment results. The aim of the present ecological-economic evaluation of different treatment technologies is to achieve the maximum practical benefits from investments and to ensure the minimum environmental impacts of waste flows based on variable source-separated collection and transportation rates. This paper compared four garbage treatment systems, including separate collection and transportation, sanitary landfills systems, fluidized bed incineration system, and the composting system in Beijing. Results show that as far as the Source Separation Rate (SSR) increased, the yield of recycled materials and sorted waste also rose. High SSR and Separated Transportation Rate (STR) could make recycling more beneficial: however, if more than one approach is applied, it is possible to organize the different steps in a way that minimizes costs and losses. A joint emergy-LCA method is applied in this study to assess the environmental impact of input and output flows and suggest process improvement. The integration offers a way to quantitatively and qualitatively assess costs and benefits, for aware and sound MSW management.

1. Introduction

1.1. The challenge of municipal solid waste (MSW) good practices in Beijing

Municipal Solid Waste management is a complex task requiring the simultaneous modeling of collection, transportation, disposal and recycling. The United Nations Environmental Program (UNEP, 2011) endeavors to implement a hierarchy of waste management practices to extract the highest possible energy, material and environmental benefits out of the waste flows. Source Reduction is the first tier of the solid waste management hierarchy. The separation of materials at the point of collection results in a more homogenous and higher quality waste stream. Source separated material streams are less contaminated by other materials, and easier and less costly for recyclers to recover. Therefore, source separated materials represent a higher value to recycling markets and may improve the environmental performance and economic efficiencies of waste treatment options. However, just like other megacities (Agostinho et al., 2013), almost 90% of MSW collected in Beijing is disposed in sanitary landfills, 2% is incinerated and less than 8% is composted.[1] The municipal solid waste collection and treatment system in Beijing is characterized by a garbage disposal mode that overlooks the front-end section and emphasizes the back-end. Specifically, garbage collection in Beijing is collected and transported to landfill sites for disposal as a mixed material instead of being sorted, which causes a huge waste of valuable resources.

All these problems lead to a diversity and complexity of municipal solid waste collection and treatment procedures which do not

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[1] http://www.chinabaike.com/t/31251/2014/0422/2110639.html.

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facilitate the planning and operation of source-separated collection neither to know in depth the related transportation conditions. For instance, the majority of domestic garbage in Beijing is food waste, which could be converted to valuable products like compost and mulch. However, since Beijing has not implemented a complete source separation of garbage, and the present separation and transportation recycling system achieves an insufficient sorting, the quality of the produced compost cannot be guaranteed. Moreover, the garbage transportation is an essential step within the garbage separation and collection system. If the garbage is sorted when delivered by the households, but mixed when transported, it is far from allowing appropriate and safe reuse. Therefore, in order to improve the quality of materials collected for recovery, the sorted garbage should be transported separately (with likely higher costs) in order to reduce the volume of residual waste to be landfilled. According to investigations in Beijing, almost every manager of garbage separation and collection considers hard to find a factory that is ready to receive separated garbage and reuse it. At present, the main way of Beijing's garbage management system is the mixed collection. The primary reason for this is that there's no separation at the frontend, as well as a lack of corresponding facilities for garbage separation, collection and transportation. This short-sighted practice is likely to lead to exhaustion of the available and suitable landfill areas in a small number of years and therefore is not sustainable nor desirable. Without a deep understanding of capabilities and effects of the different source-separated collection phases and transportation rates, there is a real risk to slow down not only the operational practices but also the future development of sustainable municipal solid waste collection and treatment system.

1.2. Evaluating and integrating technological progress, welfare and environmental care

Due to the complexity of the aspects involved for effectively integrated MSW management, several approaches have been developed worldwide to improve decision making. Traditional methods are Analytical Hierarchy Process/Analytical Network Process (Erkut and Moran, 1991; Gemitzi et al., 2007; Alavi et al., 2013), Preference Ranking Organization Method for Enrichment Evaluations (Vaillancourt and Waaub, 2002; Herva and Roca, 2013), Elimination Et Choix Traduisant la REalité (Hokkanen et al., 1995; Aydi et al., 2012), Technique for Order Preference by Similarity to Ideal Solution (Cheng et al., 2002, 2003; Su et al., 2010) and a combination of newer methods (Xi et al., 2010; Yesilnacar et al., 2012; Karmperis et al., 2013). In recent years, biophysical assessment methods have been applied to analyze the performances of a variety of technological systems. Material/Energy Flow Analysis, Cumulative Exergy and Extended Exergy Analysis and Emergy Accounting have been suggested, among others, to assess the appropriate resource use and environmental impact assessment, within a larger Life Cycle perspective. Brown and Buranakarn (2003) first developed an integrated LCA-Emergy perspective by developing emergy-based indices of reuse and recycling, with case studies of construction materials. Much of the early research occurred within different case studies, e.g. management alternatives for urban solid waste in Rome (Italy) (Cherubini et al., 2009); a Sulfuric Acid production system and a Titanium Dioxide production system in Panzhihua in China (Zhang et al., 2011); an e-waste treatment trial project in Macau (Song et al., 2013); investigating scenarios for MSW management in São Paulo Municipality in Brazil (Mendes et al., 2003) and São Paulo's Sorting and Composting Waste Treatment Plant (Agostinho et al., 2013). Gala et al. (2015) assess still open methodological issues in LCA and emergy methods when dealing with waste management and suggest improvements and potential synergies. Hornsby et al. (2017) outline the work carried out in Naples (Italy) as an example of a solid waste management case study that is used to test and validate a much broader strategy, namely the need for appropriate participatory and scientifically sound decision making processes summarised in a Roadmap. Besides, biomass fuel with a marketable quality for CHP plants (Ripa et al., 2017) and four scenarios for urban waste management (Fiorentino et al., 2015) based on the EU Waste Framework Directive (WFD) are evaluated.

In this study, we applied the emergy method in order to point out the main advantages and potential problems of selected approaches for waste management. Every single waste management facility is considered a priori by its supporter of manager as environmentally friendly. However, solid waste management facilities require land (in the case of landfills), consume non-renewable natural resources for their operation (in the case of transportation and infrastructures) and release a series of airborne pollutants and leachates. Therefore, waste management facilities most often place a huge environmental burden on the natural environment. The trade-offs between environmental gains of waste treatment and burdens generated by the process have to be assessed in each case, which calls for the development of suitable evaluation methods. The application of Emergy Analysis in MSW management is a very challenging task to provide a comprehensive assessment of all factors including material, energy, labor/capital as well as environmental impacts. Emergy analysis facilitates the comparison of diverse economic and ecological costs and services in common units. It's therefore a well suited tool to evaluate the relative sustainability of the MSW systems.

Being the emergy method a supply-side approach, focused on the environmental quality of resource flows used in a process, most of the previous emergy studies did not focus on the impact of emissions on ecosystem and human health integrity, although some authors calculated the resource costs of emissions and included them in the calculation of performance and sustainability indicators. Ulgiati et al. (1995) first pointed out that the impact of emissions on natural and human-dominated ecosystems requires additional emergy investment to take care of the damage or altered dynamics and make a system or process sustainable. In following papers, the additional emergy was calculated for the environmental services required to dilute emissions (Ulgiati and Brown, 2002), without however accounting for atmospheric diffusion and chemistry. The use of disability adjusted life years (DALYs) from the Eco-Indicator 99 impact assessment method (E.I. 99) was also proposed to evaluate the impact of emissions on human health by using ecological cumulative exergy consumption (ECEC) analysis (Hau and Bakshi, 2004). Brown and Ulgiati (2005) applied the emergy method to suggest a system view to ecosystem's integrity and also assess the emergy investment needed to restore ecosystem health. In seeking an effective model in the analysis of pollutants, other authors developed hybrid LCA-based methodologies (Udo de Haes and Lindeijer, 2001), where emissions are characterized by end-point impact factors related to human and ecosystems health. Vassallo et al. (2009) evaluated the environmental externalities of a wastewater treatment plant located along the Ligurian coast. All these authors point out that, while the environmental services provided by nature for waste load dilution and buffering are generally considered as free by analysts, they should be counted as a further cost in the total emergy budget of a process, in order to account for airborne, waterborne and solid waste release to the environment.

This study aims at 1) estimating the cost and environmental performance of four municipal solid waste collection and treatment systems in Beijing, based on LCA and emergy methodology; 2) comparing the efficiencies of waste management based on different source separation rates (SSR) and source-separated transportation rates (STR). The case studies addressed can provide beneficial suggestions for integrated evaluation of local urban solid waste management.