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Assessing the costs of municipal solid waste treatment technologies in developing Asian countries

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A R T I C L E I N F O

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A B S T R A C T

The management of municipal solid waste (MSW) is one of the main costs incurred by local authorities in developing countries. According to some estimates, these costs can account for up to 50% of city government budgets. It is therefore of importance that policymakers, urban planners and practitioners have an adequate understanding of what these costs consist of, from collection to final waste disposal. This article focuses on a specific stage of the MSW value chain, the treatment of waste, and it aims to identify cost patterns associated with the implementation and operation of waste treatment approaches in developing Asian countries. An analysis of the capital (CAPEX) and operational expenditures (OPEX) of a number of facilities located in countries of the region was conducted based on a database gathering nearly 100 projects and which served as basis for assessing four technology categories: composting, anaerobic digestion (AD), thermal treatment, and the production of refuse-derived fuel (RDF). Among these, it was found that the least costly to invest, as a function of the capacity to process waste, are composting facilities, with an average CAPEX per ton of 21,493 USD_{2015}/ton. Conversely, at the upper end featured incineration plants, with an average CAPEX of 81,880 USD_{2015}/ton, with this treatment approach ranking by and large as the most capital intensive of the four categories assessed. OPEX figures of the plants, normalized and analyzed in the form of OPEX/ton, were also found to be higher for incineration than for biological treatment methods, although on this component differences amongst the technology groups were less pronounced than those observed for CAPEX. While the results indicated the existence of distinct cost implications for available treatment approaches in the developing Asian context, the analysis also underscored the importance of understanding the local context as a means to properly identify the cost structure of each specific plant. Moreover, even though CAPEX and OPEX figures are important elements to assess the costs of a waste treatment system, these should not be considered on a standalone basis for decision making purposes. In complement to this internal cost dimension, the broader impacts – to the economy, society and the environment – resulting from the adoption of a certain treatment approach should be properly understood and, ideally, measured and expressed in monetary terms.

1. Introduction and objectives

The management of municipal solid waste (MSW) represents a significant cost incurred by local government authorities in developing Asian countries. According to the World Bank (2014), these costs can account for more than half of local governments' budgets.

Costs associated with the management of MSW are incurred throughout the whole value chain, where three main stages can be identified, as for example discussed in Aleluia and Ferrão (2016): (i) collection & transportation; (ii) treatment & processing of waste; and (iii) final disposal.

Regarding the first stage, there is a generalized understanding that the provision of waste collection and transportation services is a duty of local governments and a basic indicator of human health standards and a clean environment. The costs associated with carrying out these services typically depend on the frequency of collection, adequacy and characteristics of the transportation fleet, and the optimization of collection and transportation routes, including the deployment of transfer stations (e.g. Sukholthaman and Shirahada, 2015) and the use of information and communication technologies (e.g. Hannan et al., 2015). The involvement of the informal sector is also a frequently discussed topic (e.g. GIZ, 2011; World Bank, 2014), especially in view of their participation in the collection of waste in areas not "formally" covered by local authorities (e.g. Asim et al., 2012; Nandy et al., 2015; UN-Habitat, 2010),

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as well as on several benefits to society that can result from their activities. These include, for instance, the savings accrued to local governments through the provision of waste collection services by informal waste sector members (Velis et al., 2012), opportunities for income generation by the urban poor (e.g. Medina, 2008; Sasaki et al., 2014), and the environmental benefits associated with the recovery of recyclable materials (Al-Salem et al., 2009; Kaseva and Gupta, 1996; Lazarevic et al., 2010).

There is, however, less consensus among researchers and practitioners on which are the least costly, most appropriate and context-specific solutions for treating or processing MSW in developing Asian countries. This is illustrated, for example, in the tension between the proponents of thermal combustion technologies as the preferred set of solutions to the developing country context (e.g. Dong et al., 2014; Nazmul Islam, 2016; Ofori-Boateng et al., 2013), and those who strongly advocate for the recovery of recyclables and the valuation of the organic component of waste through the adoption of biological methods, such as composting or anaerobic digestion (e.g. ADB, 2011; Bengtson et al., 2012; Storey et al., 2015).

The cost of waste treatment solutions should not, however, be seen as an isolated or one-dimensional "variable". In fact, a number of factors related to the local context are embedded in cost and need to be given due consideration, such as the physical characteristics of the waste (e.g. composition, moisture content, calorific value) (Mohee and Mudhoo, 2012), opportunities for economies of scale (i.e. quantities of waste generated in a given area; few centralized vs. many decentralized treatment plants), availability and cost of land (i.e. densely populated areas tend to be associated with more costly land, which may affect the location and dimension of a treatment plant) (UN-Habitat, 2011), cost of materials and workforce, proximity to sources of demand for the resources generated from waste (e.g. demand for electricity in the case of an incineration plant; agriculture crops in the case of composting) (Raha et al., 2014), availability of the technology in the country and experience in handling it (Sukholthaman and Shirahada, 2015), etc.

Against this background, the purpose of this article is to assess the "internal" costs associated with the development and operation of waste treatment technologies in developing Asian countries. These internal or "direct" costs are restricted to those incurred within the spatial/physical boundary of a waste treatment facility. In other words, it is taken the perspective of the investor and/or plant operator, with two main cost components considered: capital and operational expenditures (CAPEX and OPEX). A broader perspective would take into account the wider impacts of a certain treatment approach beyond its physical boundary. These pertain to the economic, social and environmental impacts – which could be designated as "benefits" in case positive, and as "costs" if negative – that can be attributed to a certain pollution reduction intervention, and that can be determined and, in some circumstances, quantified and monetized. The analysis laid out in the article is limited to this internal perspective.

The analysis is based on the assumption that waste treatment technologies are preferred vis-à-vis alternatives that are at the bottom of the waste hierarchy pyramid, such as open dumping or landfilling. This implies that waste disposal approaches are considered the least desirable option, even though there could be the potential to capture landfill methane gas or the recovery of materials through landfill mining (e.g. Damingos et al., 2016; Wagner and Raymond, 2015). As such, the third stage of the MSW management value chain mentioned above is not analyzed in this article.

The remainder of the article is structured as follows: Section 2 elaborates on the rationale for conducting this study, identifying gaps in the research literature and highlighting the main contributions envisaged. The scope of the study is also further elaborated upon on this section, with a discussion of "internal" and "external" costs. Section 3 casts light on the research methods applied and the materials used, while Section 4 presents and discusses the findings of the analysis on CAPEX and OPEX figures. Section 5 reflects on the implications of the findings and concludes.

2. Literature review and scope of the study

In developing countries, including those of Asia, the handling of solid waste is one of the major expenditures incurred by local government authorities. It is therefore important that policymakers and practitioners have an appropriate understanding of the determinants, drivers and scale of the costs of available methods and solutions to deal with waste, from collection to disposal (GIZ, 2015; Tsilemou and Panagiotakopoulos, 2006). Here, the focus is on a specific stage of the waste management value chain – the treatment of waste – and, more specifically, on the costs associated with a set of waste processing "categories" or "technologies". The geographical scope of the analysis consists of developing countries of the Asian continent. These are defined as those ranking either as low-income, lower-middle income or upper-middle income, based on their levels of economic development as defined by the World Bank (2016a), as shown in Table 1.

When considering the costs associated with the implementation of waste treatment facilities, two dimensions should be considered: whether these costs are internal or external. Internal costs pertain to the financial expenditures associated with investing (CAPEX) and operating (OPEX) waste treatment facilities (EPA, 1997; Hogg, 2006; Weng and Fujiwara, 2011). These are costs that are incurred by the investor or project developer (either this is a private or public entity), and are therefore restricted to the spatial boundary of a waste treatment facility.

External costs refer to those that are directly or indirectly caused by the operation of the plant, but whose effects are borne by a party other than its owner or operator. These costs consist, essentially, of negative environmental and social externalities (Atkinson and Mourato, 2016; Ferrara, 2008; Jamasb and Nepal, 2010), and thus public policy intervention may be necessary to correct and "internalize" them. Examples of external environmental costs are the discharge of untreated leachate water from a composting plant, the release into the atmosphere of excess biogas from an anaerobic digestion facility thereby contributing to greenhouse gas emissions, or the emission of toxins from an incineration facility that may not be equipped with emission control technologies. Social costs could include, for example, the destruction of jobs in the informal sector as a result of large-scale mechanized waste treatment plants being implemented, or the higher incidence of respiratory-related diseases in communities residing in proximity to incineration plants (Cucchiella et al., 2014; Medina, 2008; UNEP, 2015). In principle, it should be possible to assess, quantify and express in monetary terms some of these external costs, even if such effort could be fraught with difficulties (e.g. in setting the

Table 1
Developing and developed countries of Asia, based on levels of economic development as defined by the World Bank. World . Source: Bank (2016a)

Developing Asia			Developed Asia
Afghanistan	Indonesia	Philippines	Brunei Darussalam
Armenia	Kazakhstan	Sri Lanka	Hong Kong (China)
Azerbaijan	Kyrgyz Republic	Tajikistan	Japan
Bangladesh	Lao P.D.R.	Thailand	Rep. of Korea
Bhutan	Malaysia	Timor-Leste	Singapore
Cambodia	Maldives	Turkmenistan	Taiwan
China	Mongolia	Uzbekistan	
D.P.R. Korea	Myanmar	Viet Nam	
Georgia	Nepal		
India	Pakistan		

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