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Performance evaluation and benchmarking of global waste management systems

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ABSTRACT

This paper presents the environmental and economic benefits of global waste management systems in the context of zero waste practices. The study analysed the waste management performance of 168 countries around the globe and evaluated their performance using the zero waste tool. The Zero Waste Index measures the material substitution potential of waste. This is done by taking into account the amount of materials recovered from waste, which potentially substitute the demand for virgin materials. By substituting virgin materials' demand, we could potentially substitute the demand for energy, water, and avoid greenhouse gas (GHG) emission. The study analysed waste management systems in 168 countries and presented its findings using the mapping techniques of Geographic Information Systems (GIS). The findings of the study suggested that globally, an average person generated around 435 kg of waste each year, out of which an estimated 50 kg of materials (paper, plastic, metal, glass and others) potentially substitute the demand for the extraction of virgin materials. By substituting the demand for virgin materials, through 'zero waste activities', an average person could potentially save around 216 kWh of energy, 0.05 kg GHG and 36 L of processed water. Globally, each person would then potentially save around $61.3 annually, of which $17 would arise from materials substitution, and $44 from energy substitution. The study suggested that energy substitution potentially contributed over twice the economic benefits as materials substitution in resource recovery from waste.

1. Introduction

Sustainable waste management is one of the most important global environmental agendas in the twenty- first century (UNEP, 2012). The quantity of global waste increases as the population and the level of resource consumption rise over time (Chalkias and Lasaridi, 2011). The increased generation of waste is also causing greater environmental degradation: in particular pollution of land, water, and air due to unsustainable waste disposal and management methods. According to the Intergovernmental Panel on Climate Change (IPCC) report, the waste sector contributes less than 5% of global GHG emissions, which is very low compared to the energy and industrial sectors (more than 65%) (Bogner et al., 2007). As a result, the waste sector has been given lower priority in climatic adaptation and problem mitigation. This study argues that even though the waste sector contributes lesser GHG emissions into the atmosphere, there are greater opportunities that are ignored and often not considered, especially the benefits of recycling and resource recovery from waste.

Globally, a waste management system primarily relies on technology driven 'end-of-life' waste collection, management and treatment systems. Till today, landfill is considered as one of the cheapest and most widely applied waste disposal options (Hoornweg and Bhada-Tata, 2012); however, landfill can be an expensive option if the cost of environmental pollution and depletion of resources are considered (Eriksson et al., 2005). Recycling of waste not only increases the efficiency of resources, but also reduces environmental burdens.

Material recovery from waste by the 'up-cycling' and 'recycling' techniques have direct (primary and secondary materials) and indirect (energy, water and emissions) benefits (Giugliano et al., 2011; Zaman and Lehmann, 2013). For instance, the material that is recovered from waste paper substitutes the demand of primary virgin material(lumber) for the production of new paper goods. By substituting the demand for virgin materials, it also substitutes the need for energy, water and emissions during the extraction of resources (Zaman and Lehmann, 2013). In addition, the material and environmental benefits of resource recovery from waste bears economic benefits as the material contributes to economic activities. Valu-

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able material loss through insufficient recycling and an inefficient resource recovery infrastructure also amounts to economic loss and causes sustainability problems (Xevgenos et al., 2015). Therefore, it is important to evaluate waste management performance based on the environmental and economic benefits of resource recovery activities.

This study aims to evaluate the benchmarking performance of global waste management systems by highlighting their environmental and economic benefits in different countries. The study considers non-hazardous household solid waste thatis usually managed by the local municipal authority. The environmental and economic benefits of waste management systems are analysed using the Zero Waste Index (ZWI), and the results are presented using the mapping techniques of Geographic Information Systems (GIS).

2. Literature review

Studies on global waste management performance are limited due to the lack of reliable and accurate data representing municipal solid waste. Researchers often relied on the reports published by the international government and non-government organisations such as the World Bank, the United Nations, and the European Union etc. to measure waste management performance on a global scale. The UN-Habitat published a report in 2010 which analysed the waste management strategy and performance of 22 cities around the globe (UN-Habitat, 2010). The World Bank published a report in 2012 where the collection, management, treatment, and disposal of waste in countries from various income groups were analysed (Hoornweg and Bhada-Tata, 2012). It is evident from both publications that the data used in analysing the state of the global waste management performance was often incompatible with the time of the reported data (as the reported years varied in different countries) and the types of waste (it significantly varies in different countries). Therefore, the lack of reliable data availability and compatibility made it difficult to benchmark the performance of global waste management systems.

Various tools are available for evaluating the benchmarking performance of waste management, such as life cycle assessment, multi-criteria decision analysis, etc. Often these tools are the simplifications of the actual facts as the waste management systems are complex and difficult to generalise from case studies (Finnveden et al., 2007). A number of studies have applied various decision making tools to evaluate waste management performances, such as life cycle assessment (Christensen et al., 2007; De Benedetto and Klemeš, 2009), life cycle costing (Gluch and Baumann, 2004; Nakamura and Kondo, 2006), cost-benefit analysis (Yuan et al., 2011; Weng and Fujiwara, 2011), multi-criteria decision making (Tseng, 2009; Vego et al., 2008), consensus analysis model (Hung et al., 2007; Petts, 1995), material and substance flow analysis (Belevi, 2002; Chancerel, 2010), integrated solid waste management framework (Wilson et al., 2012; Wilson et al., 2013), analytical hierarchy model (Jamasb and Nepal, 2010; Su et al., 2007), and system dynamic model (Dyson and Chang, 2005; Kollikkathara et al., 2010).

Along with these decision making tools, Geographic Information Systems (GIS) have been used to promulgate better decisions in waste management planning. GIS mapping has been applied in various studies to analyse waste avoidance (Li et al., 2005), waste collection and transportation (Lovett et al., 1997; Tavares et al., 2009), suitable location of waste-to-energy plants (Baetz, 1990), and selection of landfill sites (Chang et al., 2008; Sumathi et al., 2008). The study applies the GIS mapping technique to visualize waste management performance on a global scale.

2.1. Methods

The study compiled and updated national waste management data from various sources, including the United Nations waste data (United Nations, 2011), the World Bank waste data (Hoornweg and Bhada-Tata, 2012), the OECD waste data (OECD, 2015), the Eurostat waste data (Eurostat, 2015), and the data from various published sources (IADB, 2015; Indexmundi, 2015; UNEP, 2012; etc.). The annual waste data were generated in different years, ranging from 2000 to 2014 in different sources. Due to data unavailability it is not possible to refer a specific year for all the countries considered in the study, thus, waste performance is evaluated based on a generic annual benchmarking context rather thana specific year. A total of 168 countries are deliberated on in this study to analyse waste management performance and the results presented in the GIS mapping technique. The countries are categorised into four different groups: high- income country (HIC), upper middle-income country (UMIC), lower middle- income country (LMIC) and low-income country (LIC), based on their per capita income or gross domestic product (GDP), as stated by the World Bank (Hoornweg and Bhada-Tata, 2012); Eurostat, 2015; OECD, 2015.

Zero waste is an emerging philosophy which is referred as "designing and managing products and processes to systematically avoid and eliminate the volume and toxicity of waste and materials, conserve and recover all resources, and not burn or bury them" (ZWIA, 2009). One of the key focues of the zero waste strategies is conservation of resources. There is a growing popularity in considering zero waste strategies as best practices. The study applied the Zero Waste Index (ZWI) tool to measure the environmental benefits of waste management systems. The ZWI measures the potentiality of virgin materials to be offset by waste management systems. It is assumed that the amount of material that is recovered from waste would offset the extraction of the same amount of virgin material, and this eventually saves and avoids energy, GHG and water usage during the extraction process. Therefore, the ZWI measures the material substitution efficiency and energy, as well as GHG and water savings of the waste management systems. The ZWI is calculated by using the following Eq. (1):

Zero waste index (ZWI):

$$\mathrm{ZWI}=\frac{\sum_{1}^{n}\mathrm{MSWij}\times\mathrm{SFij}}{\sum_{1}^{n}\mathrm{MSW}i} \tag{1}$$

where,

MSWi j = amount of waste stream i (i = 1, 2, 3. . ..n = paper, plastic, metal, etc.) managed by system j (j = 1, 2, 3 . . . n = amount of waste avoided, recycled, treated, etc.)

SFi j = Substitution factor for the amount of waste stream i (i = 1, 2, 3. . ..n = paper, plastic, metal, etc.) managed by system j (j = 1, 2, 3 . . . n = amount of waste avoided, recycled, treated, etc.)

MSWi = Total amount of municipal solid waste managed (i = 1, 2, 3. . ..n = paper, plastic, metal, etc.)

The performance of resource recovery is measured by considering the virgin materials' substitution efficiency presented by Zaman and Lehmann (2013). In addition, the ZWI measures energy, GHG and water savings by taking into account the recovered materials. The material substitution efficiency is calculated by using the material substation factor used in Table 1.

The ZWI is used to analyse waste management performance of Adelaide, Stockholm and San Francisco (Zaman and Lehmann, 2013). The study asserted that the ZWI could provide more precise analysis of environmental benefits in the presence of high quality data. It is also evident from the previous publications (Zaman and Lehamnn, 2013; Zaman, 2014) that the tool can be used at a country or global scale. However, the outcome of the model is depends on the quality of data used for evaluating the performance and this