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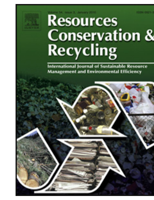

Environmental and economic impact assessment of construction and demolition waste disposal using system dynamics

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A B S T R A C T

Construction and demolition wastes (CDW) have increasingly serious problems in environmental, social, and economic realms. There is no coherent framework for utilization of these wastes which are disposed both legally and illegally. This harms the environment, contributes to the increase of energy consumption, and depletes finite landfills resources. The aim of this paper is to evaluate the impacts of two alternatives for the management of CDW, recycling and disposing. The evaluation is carried out through developing a dynamic model with aid STELLA software by conducting the following steps: (1) quantifying the total cost incurred to mitigate the impacts of CDW landfills and uncollected waste on the environment and human health; (2) quantifying the total avoided emissions and saved energy by recycling waste; (3) estimating total external cost saved by recycling waste and; (4) providing a decision support tool that helps in re-thinking about waste disposal. The proposed evaluation methodology allows activating the stringent regulations that restrict waste disposal and developing incentives to encourage constructors to recycle their wastes. The research findings show that recycling CDW leads to significant reductions in emissions, energy use, global warming potential (GWP), and conserves landfills space when compared to disposal of wastes in landfills. Furthermore, the cost of mitigating the impact of disposal is extremely high. Therefore, it is necessary to recycle construction and demolition wastes.

1. Introduction

The construction/demolition industry is considered one of the largest producers of solid wastes globally. The huge amount of construction and demolition wastes (CDW) has been generated from increasing the building of new structures, renovation, rebuilding, repair, demolition works, and infrastructure development projects. Large quantities of construction and demolition wastes (CDW) cause harmful effects on the environment if they are not managed in proper manner. As such, these huge amounts of wastes need to be properly managed. The current situation of waste management in Egypt lies in disposed waste either legally or illegally and there is no coherent framework for making the most of these wastes. It is very important to give priority to the environment in addition to conventional project objectives, such as cost, duration, quality and safety (Liyin et al., 2006). Thinking about waste management from a limited perspective gives rise to some economic concerns. This is because a large amount of money is spent on dumping the waste in landfills and mitigating the effects of dumping on the environment. The environmental problems include: (1) diminishing landfill space due to incremental quantities of these disposed wastes in it; (2) the depleted building materials; (3) the increase in contamination from landfills that lead to serious negative health effects; (4) damage to the environment; and (5) the increase in energy consumption for transportation and manufacturing new materials instead of those materials dumped and which require energy production. The later problem is attributed to the loss of embodied energy of the disposed wastes that can be used to produce new construction materials. It is worth noting that CDW recycling saves the embodied energy in waste materials by the replacement of virgin raw materials with recycled materials (Roussat et al., 2009). Therefore, energy savings are often the driving force behind emissions savings (Choate et al., 2005).

CDW are adding to the phenomenon of global warming. Hotter temperatures due to Global Warming Potential (GWP) lead to increased weather extremes including heat waves and worsening of air quality. Epidemiological studies of deaths during the heat waves refer to the fact that a substantial portion of the mortality might be attributed to elevated ozone and particulate levels that occurred during the heat waves (American lung Association, 2004). The California Air Resources Board indicated that the health effects of increasing concentrations of particulate matter and ozone are: 6500 premature deaths, 4000 hospital admissions for respiratory disease, 3000 hospital admissions for cardiovascular disease, 350,000 asthma attacks, 2000 asthma-related emergency room visits, elevated school absences due to respiratory conditions,

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including asthma, and reduced lung function growth rate in children. Sensitive groups, including seniors, people with heart or lung disease, children and infants are the most vulnerable to the harmful effects of air pollution.

On the other hand, CDW recycling technique has recently attracted the attention of many researchers due to its economic and environmental benefits. In economic terms, plenty of studies have been conducted on the economic situation of CDW recycling plants such as (Coelho and de Brito, 2013a; Zhao et al., 2010). Both of these studies confirmed the economic feasibility of recycling CDW, but with different results due to the conditions of each study. Coelho and de Brito (2013a) conducted a study on a large-scale recycling plant in Portugal to evaluate the economic viability of the plant for serving a densely populated urban area. This study concluded that despite the absence of regulatory government policy the initial investment required for recycling may be high, but there is a high profit potential for CDW recycling with the return of invested capital in around two years. Zhao et al. (2010) developed a study of the situation in Chongqing in China to assess the economic viability of the implementation of fixed recycling CDW plant facilities and mobile recycling stations and compared it with recycling centers (mobile stations) in the Netherlands to find out successful factors for recycling centers. This study has concluded that fixed and mobile recycling centers with used equipment have higher economy viability than centers with new equipment and that is due to their ability to achieve a higher profit margin in contrast to the second case. Also, the revenue increases owing to the location advantage (e.g. mobile stations) and the recycling cost decreases with the economy of scale (e.g. fixed centers). This study has also suggested the use of economic and political instruments to face the investment risks.

Regarding the environmental concerns from recycling plants, several studies have been conducted to evaluate the environmental impacts from CDW recycling plants. Coelho and de Brito (2013b) conducted a study using life cycle assessment of CDW recycling plant with a capacity of 350 ton/h and 60-year operating lifespan. This study has focused on the evaluation of two impacts of recycling plant, namely the primary energy consumption and CO_2eq emissions. The main conclusion of this study is that recycled materials always have significant environmental benefits where the avoided impacts of CO_2eq emissions are always higher than the generated impacts and energy savings exceed the energy consumed during the operating lifespan. F.I.R. (2005) pointed out for several studies conducted to assess the environmental impacts from recycling building materials using life cycle assessment approach from extraction to recovery or disposal of landfills. The first study is presented for assessing the greenhouse gases generated from primary and recycled aggregate. The study has concluded that the recycled aggregate was more environmentally useful than most of primary aggregate. The second study is presented for evaluating environmental impacts of production of 1 ton of concrete through comparing two different scenarios, which are landfilling and recycling. According to this study, the second scenario (recycling) is more environmentally friendly.

In order to overcome the above-listed growing problems caused by CDW disposal, it is important to consider a recycling solution. Recycling allows utilizing wastes as raw materials in some other ways. This paper proposes the use of system dynamics methodology to compare between two alternatives of CDW management techniques; recycling and landfill disposal. This model is capable of: (1) measuring the total emissions from the CDW landfilling and associated costs incurred to mitigate the impacts from these emissions; (2) predicting the total damage costs of disposed waste and from uncollected wastes; and (3) quantifying the total avoided emissions and the energy saved by waste recycling. The novelty of this research lies in adopting a system dynamics approach for all basic variables underlying the evaluation of the two alternatives during the lifetime of landfills. It outperforms previous studies which focus on assessing the two alternatives without taking into account the dynamic nature and relationships between variables.

Plenty of studies have been carried out to model CDW management using system dynamics, but they did not take into account the dynamic nature of the CDW disposal and interactions among major variables affecting on evaluation of economic and environmental effects of the CDW disposal as two important aspects of sustainability. This research is an attempt to provide the stakeholders of Egyptian construction sector with an empirical study that considers all variables that influence the CDW. Also, this study helps in mitigating the risks associated with CDW disposal and illustrates the benefits of recycling of construction wastes.

2. Theory and calculations

System dynamics is an approach for studying and managing complex feedback systems and is specially created to deal with large-scale and complex systems (Yuan et al., 2012). A system is a group of interacting or interdependent entities forming an integrated whole system dynamics modeling (Cheng, 2012). It was originated by Professor Jay W. Forrester of the Massachusetts Institute of Technology during the mid-1950s (Forrester, 1987). It has been widely used in different applications for understanding different economic, social, business, agricultural, and ecological systems. It deals with internal feedback loops and time delay that affect the behavior of the entire system. It has the ability to understand the relation between the behavior of system over time and its underlying structure and decision rule. Simulation helps explore "what-if" scenarios and policy tests in something that is like a laboratory setting, which causes confidence in particular strategies and policies to increase (Richardson and Otto, 2008). As a result, "system dynamics is often used as a methodology for improving the soundness and effectiveness of the decision-making process. It has become a popular technique for modeling construction project management" (Hao et al., 2007).

3. System dynamics applications in CDW

A big number of research works have utilized system dynamics modeling in waste management. Wager and Hilty (2002) have developed system dynamics model for waste management to support the assessment of the flow of materials, energy and costs of regional waste management with regard to their ecological and economic impacts. Chaerul et al. (2008) studied hospital waste management using system dynamics approach to capture its dynamic nature. The behavior of the waste management system depends on several factors including the changing nature of various systemic factors and the feedback generated by a dynamic and continuous interaction. Sliwa (1994) conducted a study on municipal solid waste management in Pueblo using the system dynamics approach. The study has tried to bridge the gap between traditional approaches so as to solve the public administration problems. Lang et al. (2002) developed a systematic methodology for natural and human resources optimization for waste management to achieve sustainable development using system dynamics modeling.

Several studies have been published for CDW management (Yuan, 2012; Hao et al., 2007; Rong, 2004; Hsiao et al., 2002; Zhao et al., 2011; Yuan et al., 2011). Yuan (2012) carried out a quantitative study to evaluate the social performance on construction waste management using system dynamics. Many indicators have been used to assess the social impacts of CDW. Hao et al.