A Framework for Managing Construction Demolition Waste: Economic determinants of recycling

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ABSTRACT

The significant amount of waste generated from construction demolition has become a chronic problem in several developing countries. Using data obtained from demolition contractors and various other sources, this paper proposes a framework for proper handling of construction demolition waste (CDW) in countries suffering from lack of national CDW management procedures and facilities. This framework, which serves as a decision support tool, is then applied to the case of Beirut, and a sensitivity analysis is carried out to examine the economic feasibility of developing a recycling facility. The analysis shows that the feasibility of introducing a new recycling facility is highly dependent of the interrelationship between the landfill tipping fee and the recycling gate fee coupled with the marketability of the by-product as well as regulatory enforcement to control illegal dumping and properly manage engineered landfills.

INTRODUCTION

Construction and demolition waste is a term commonly used when referring to waste resulting from the construction industry. It encompasses a wide variety of materials resulting from various activities including soil, rocks and vegetation resulting from excavation, land leveling, civil works and site clearance (Fatta et al., 2003). They also include roadwork materials (e.g., aggregates, pavement), worksite waste materials (e.g., wood, plastic, paper, glass, metals), and demolition waste (e.g., bricks, concrete, soil, gravel, gypsum, steel). This paper focuses on the latter; i.e., construction demolition waste (CDW), which usually constitute 20-30 times the quantity of waste generated from construction activities (EPA 2009).

In many countries, CDW is commonly disposed of at designated landfills with only small amounts being recycled. Depletion of natural resources and scarcity of, and difficulty in siting, landfills encouraged the consideration of alternative ways for managing CDW (Poon et al. 2001, Fatta et al. 2003, and Hettiaratchi et al. 2010). Proposed strategies include reducing the amount of waste produced and diverting it from landfills by implementing and promoting recycling/re-using programs (Lennon 2005 and Zhao et al. 2010). Recycling CDW is not new to the construction industry and has been adopted in various countries in Western Europe (Symonds Group Ltd 1999) and North America (Lennon 2005). In the US, regulations and recycling practices vary by locality. While some cities, such as San Jose, CA, boast recycling rates greater than 50 percent, others, such as Kansas City, MO, have low diversion rates of CDW (Warren et al. 2007). These regulations and guidelines are usually an integral element of a waste management plan, which results from an assessment of various waste management options (e.g., landfilling, recycling). A typical plan would specify recycling goals (e.g., 75 percent), training of contractors on how to handle waste (e.g., sorting, recordkeeping), identifying the type and quantity of waste generated, determining how each type of waste will be managed (e.g., separated on or off-site, stored, disposed), and identifying potential markets for recycled materials (Winkler 2010).

In contrast, recycling of CDW in many developing countries has proven to be challenging, because the amount of waste generated is not well documented, its final destination, and the feasibility of recycling, are scarce, and awareness with regards to best practices and benefits of recycling CDW is limited. For example, in Lebanon, the construction industry is continuously active and is accompanied by significant amounts of waste generated through the construction and demolition processes. According to the Order of Engineers of Beirut the construction permits increased by 36 percent from 2007 to 2008 (CAS 2009). Given the limited space, this level of construction activity is resulting in an increase in the amount of CDW resulting from replacing existing two or three-storey buildings with multi-storey buildings. An interview with a representative of the ministry of environment revealed that there are no designated landfills for CDW in Lebanon (Tamraz et al. 2011). This, coupled with the lack of regulations on proper disposal of CDW, leads to haphazard dumping of waste thereby creating a major threat to the environment. A recent report on the state of practice in Tripoli, the second largest city in Lebanon, found that CDW is being thrown haphazardly inside the city and on road sides.

This paper proposes a framework for CDW management where recycling efforts are absent and examines methods for adopting sustainable waste management concepts (e.g., recycling of CDW through the proposed framework) by the construction industry. This is done by taking the country of Lebanon as a testing case study and building on field data to assess the economic feasibility for recycling CDW.

RESEARCH OBJECTIVE

The objective of this study is to assess the feasibility of recycling CDW in a typical developing market (Lebanon) as part of an over-arching waste management plan under limiting constraints: no existing recycling facilities or designated landfills to accommodate CDW and no specific regulatory procedures for its disposal.

A theoretical framework or multi-step process for managing CDW is proposed and tested on a case study. The framework is the result of a literature review covering the economics of recycling CDW (e.g., NTUA 2002, Fatta et al. 2003, Nunes et al.

2007, Zhao et al. 2010). At the core of the framework is a cost-benefit analysis which serves as a decision support tool that helps in defining scenarios for the feasibility of recycling CDW.

THEORETICAL FRAMEWORK

Figure 1 illustrates the proposed framework. The first step is to estimate the rate of waste generation and its composition. Such information is a critical input to various parameters such as size of the recycling facility, location and size of landfills, and technologies for demolition, sorting, and crushing. The second step consists of defining recycling gate fees and landfilling tipping fees. In places with little to no regulations governing waste disposal, haphazard dumping is often the cheapest option. However, when proper legislation is in-place, recycling may be favored. For this to materialize, landfill tipping fees, *Cl*, should be higher than the recycling gate fees, *Cr*.

The third step estimates the recycling cost, *Rc*, and identifies the location and size of the recycling facility. This cost includes the capital and operational costs as well as land acquisition/rental costs. Identifying the optimum location of the facility depends on factors such as proximity to the city (where demolition activities are very likely), land prices, and nearby land depreciation. The cost of land is typically included in the recycling cost if the facility is fixed, as opposed to mobile, and/or requires sorting and storage spaces. The capital and operational costs depend on the type of recycling technology implemented. In turn, the type of technology/facility and its size are related to the quantity and type of waste generated, the sorting required, and market demand.

The fourth step entails setting the price of selling secondary or recycled material, *RCp*. For recycling to be a viable option, the price of the secondary material that is generated from recycling should be greater than the difference between the cost of recycling and the gate fee charged at the recycling facility:

$$RCp \geq Rc - Cr \qquad (1)$$

Recycled material is usually less attractive than raw or primary material. To ensure that there is a market for recycled material, the selling price should be significantly lower than the cost of primary material, *Pm* (Nunes et al. 2007). For this purpose, a multiplier, α, which falls in the range of 0 to 1, is introduced:

$$RCp \leq \alpha Pm \qquad (2)$$

The theoretical framework translates into a cost-benefit analysis of various waste management options (e.g., recycling versus landfilling) where the overall net present value (*NPV*) for the option of investing in a recycling facility, thereby diverting waste from landfills, is represented by Equation (3), with negative and positive cash flows depending on the parameter: price of land (PV_{land}), capital costs (PV_{cap}), operational costs (PV_{oper}) for running the recycling facility, environmental savings (PV_{env}), gate fee (PV_{gate}), and price of *Recycled product* (PV_{sell}).

$$NPV = (PV_{gate} + PV_{sell} + PV_{env}) - (PV_{cap} + PV_{oper} + PV_{land}) \quad (3)$$

The fifth and last step in the framework is to identify potential markets for recycled materials, which is crucial for the feasibility of the recycling facility (Kohler 1997). Evidently, the success of implementing the proposed theoretical framework is highly dependent on legislative support including setting and enforcing appropriate landfill tipping fees, providing economic incentives (e.g. reduce taxes on imported equipment that is used for recycling), and favoring contractors who use recycled materials on public projects.

APPLICATION: RESULTS AND DISCUSSION

The proposed stepwise framework was tested in the City of Beirut and immediate surroundings with the first step requiring an examination of case-studies consisting of buildings as well as interviews with demolition contractors and officials from the Ministry of Environment and municipalities. A set of 12 mostly residential buildings were examined for the purpose of estimating the total amount, and composition of CDW generated over two years. Using existing design drawings, coupled with site visits, a quantity takeoff for 9 of the 12 buildings was conducted to define the composition of CDW and the average built-up area.

The average building in the examined sample has a built-up area of 2,633 m^2. Weight wise, concrete makes up 58 percent of the average building, followed by masonry units (20 percent) and terrazzo/stone tiles (9 percent). Using this information and the total number of buildings demolished in 2009 and 2010, which was obtained from the record of the municipalities, the total amount of CDW generated was estimated at nearly 1 M metric ton of CDW in the study area over the two-year period. The vast majority of this amount (~90%) consisted of concrete, masonry units, stone tiles, and ceramic tiles most of which is disposed of haphazardly in valleys and empty quarries because there are no designated landfills and the few existing solid waste landfills do not accept CDW. Recycling is limited to backfilling operations for a few large projects. The remaining material, which is mostly steel, is sorted onsite and sold to recycling plants in Egypt and Turkey. Hence, the cost of CDW transport (0.5-3 USD/ton) is the only tangible cost incurred by demolition contractors. With a recycling policy and a facility in operation, the expected gate fee may vary widely depending on several factors outlined above. In this application, a range of 0 (government subsidy) to 3 USD / ton (private sector) was used.

On the other hand, currently, the average price of natural aggregates in Lebanon is \$18/m^3 excluding transportation and taxes (Cost of construction materials 2011), which is equivalent to \$11/ton (based on a density of 1.67 ton/m^3)[1]. As such, in the cost-benefit analysis, RCp was assumed to fall in the range of \$2 to \$7/ton. Using Equation (3), the present value of investing in a recycling plant was determined under various scenarios without the impact of externality factors such as environmental benefits, $PVenv$, which were set at 0 - to check if the recycling plant is feasible even without factoring in hard to quantify externalities.

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[1] Based on laboratory tests performed on a sample of CDW obtained from the case studies.

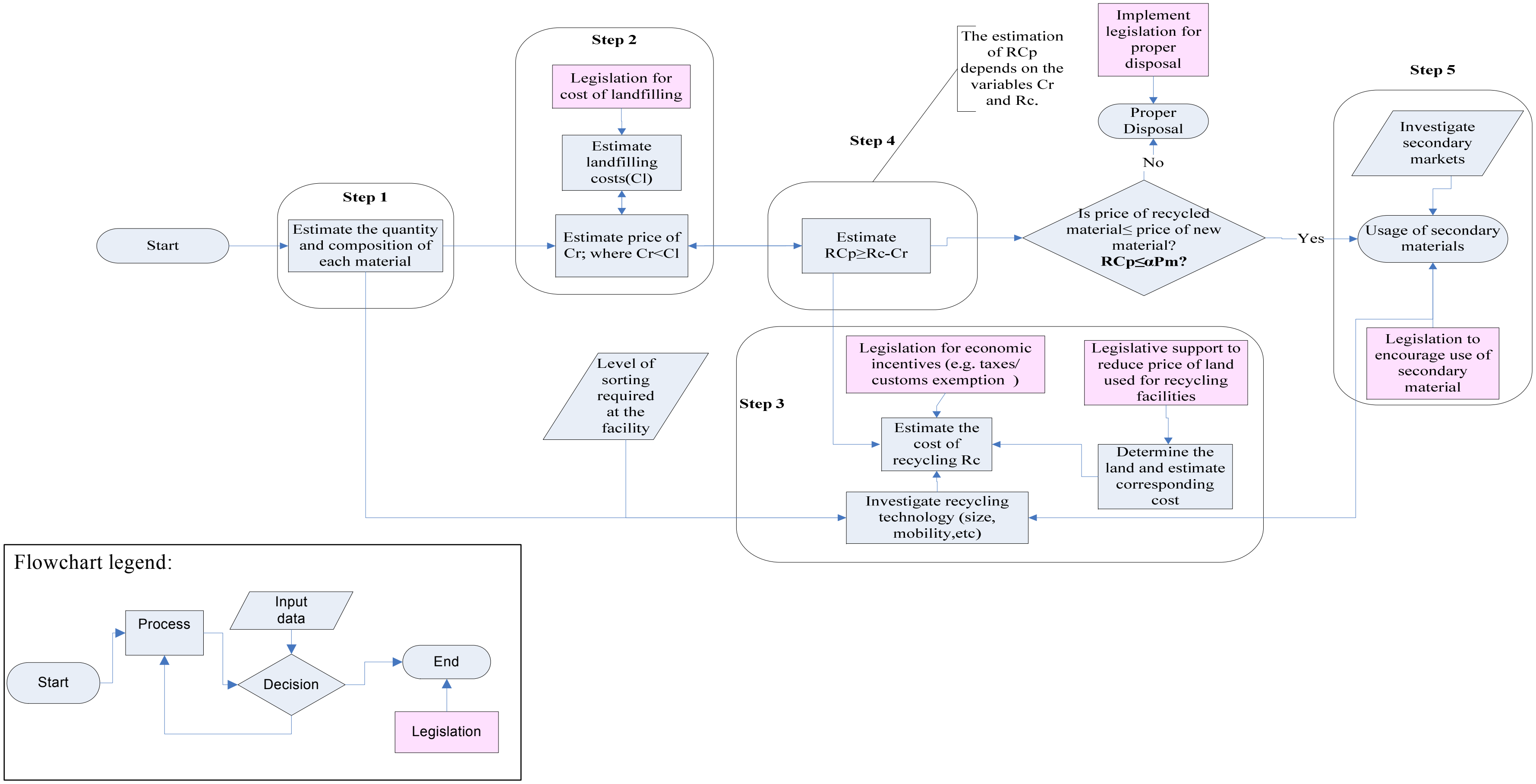

Figure 1. Theoretical Framework for Managing CDW

The following additional assumptions were made:

- The capacity of the recycling facility is greater than the amount generated. When operating ~260 days per year (8 hours per day) with a rejection rate of 20 percent[2], the required capacity becomes 170 ton/hr. A design capacity of 250 to 300 ton/hr was considered to allow for other types of waste such as excavation and construction waste, and/or considerations for increased demand in the future.
- The technology selected is relatively simple but labor intensive which is justified by the low daily labor rates in Lebanon (20 to 30 USD/day). Upon entering the recycling facility, trucks are weighed and the CDW is inspected and manually separated to remove contaminated material before loading a secondary separation line where it is cleaned while a magnetic band separates metals from the waste stream. The mineral material (concrete, masonry and mortar) is then crushed and sorted before storage. The equipment needed include a crusher, a screener, a magnetic separator and a loader. Equipment costs were obtained from international and local suppliers including freight and commissioning fees for a facility design life of 20 years
- The area of the site is approximately 10,000 m^2, allowing for storage space for five stockpiles of CDW (resulting from five buildings) and four recycled aggregates stockpiles. This amount of material is equivalent to the amount of CDW generated in a two-month period assuming a uniform rate of demolition activities across the city. In other words, the calculations assume that the recycled material will be sold within two-month from arrival to the recycling facility. Construction costs include: makeup levels where applicable ($100k), 70 m^2 prefabricated site offices ($25k), and a border fence ($10k). These are based on actual cost from local suppliers. The site offices can house 15 unskilled workers, 8 skilled workers, 1 manager and 1 loader operator (Zhao et al. 2010) Operating costs were assumed to increase at a rate of 3 percent per year (Duran et al. 2006).
- Building and operating a CDW facility is expected to have a negative impact on land prices in the neighboring areas. Given the lack of data pertaining to recycling facilities, land depreciation around the proposed facility is assumed to be similar to the reported depreciation surrounding landfills (estimated at ~14% in the US (Ready 2010)) and quarries (estimated at 16-70% in Lebanon (World Bank (2004)). In this study, a 20 percent decrease in land prices was assumed within a radius of 0.5 km from the recycling facility.
- Labor daily rates, construction costs, manager's fees, and crane operator's fees reflect the current local market prices (Cost of construction materials 2011). Energy costs are based on data obtained from the national power company. Maintenance and insurance of the equipment are considered as 7 percent of the equipment investment (Zhao et al. 2010). Finally, a contingency of 1 percent was added to the capital and operational expenditures.

Using these assumptions, three alternative sites were investigated. The sites were chosen based on land availability and proximity to the generation source (i.e. Beirut) in order to minimize transportation costs. Site 1 which is the nearest to the generation sources, is on a parcel of land that is owned by the government and serves as a temporary location for sorting and

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[2] Nearly 20 percent of the CDW that enters a recycling facility is rejected (Nunes et al. 2007). This includes materials' wastage due to contamination and mixing, which cannot be recycled.

storing of CDW. Site 2 is 12 km south of Beirut and in the vicinity of an existing municipal waste landfill. Site 3 is 18 km east of Beirut and near a landfill for inert and bulky waste. The major differences among the three sites lie in the price of land (highest in congested urban areas and lowest near existing landfills) and the depreciation of nearby residential properties which already happened near landfills (Table 1).

Table 1. Summary of Costs in $k for Each of the Three Sites

	Land (USD)	Capital (USD)	Annual Operation (USD)	Land Depreciation (USD)	NPV (USD)
Site 1	84,500[a]	1,781	595	1,210,020	1,304,145
Site 2	10,500[b]	1,881[d]	595	~0	20,320
Site 3	4,000[c]	1,881[d]	595	~0	13,820

[a] $8,450/m2, average price of two nearby parcels advertised for sale

[b] $1,050/m2, average price of two nearby parcels advertised for sale

[c] $400/m2, obtained from a property assessor at the Lebanese National Bank.

[d] require some leveling and grading work

Evidently, Site 3 is the most economical; and therefore, it served as the basis for a breakeven analysis whereby the NPV was determined for various combinations of *RCp* and *Cr* over a period of 20 years (Table 2). Figure 2 illustrates a typical case where *RCp* is equal to 2 and the gate fee, *Cr*, must be higher or equal to $2/ton for the facility to be economical, i.e. yielding a (simple) payback of less than 20 years. Obviously, the higher the gate fee the lower the payback period. The decreasing slope of the NPV over time is due to the 7 percent discount rate, which is higher than the inflation rate of 3 percent. The latter values were obtained from Duran et al. (2006) and Zhao et al. (2010). Naturally, the payback period can be decreased by increasing the value of *RCp* (Table 2) and therefore resulting in a more economically attractive investment in such a facility.

Table 2. Payback period (in number of years) under various scenarios

RCp ($/ton) / *Cr* ($/ton)	2	3	4	5	6	7
0	N/A	N/A	13	7	5	4
1	N/A	11	6	5	3	3
2	9	6	4	4	3	2
3	5	4	3	3	2	2

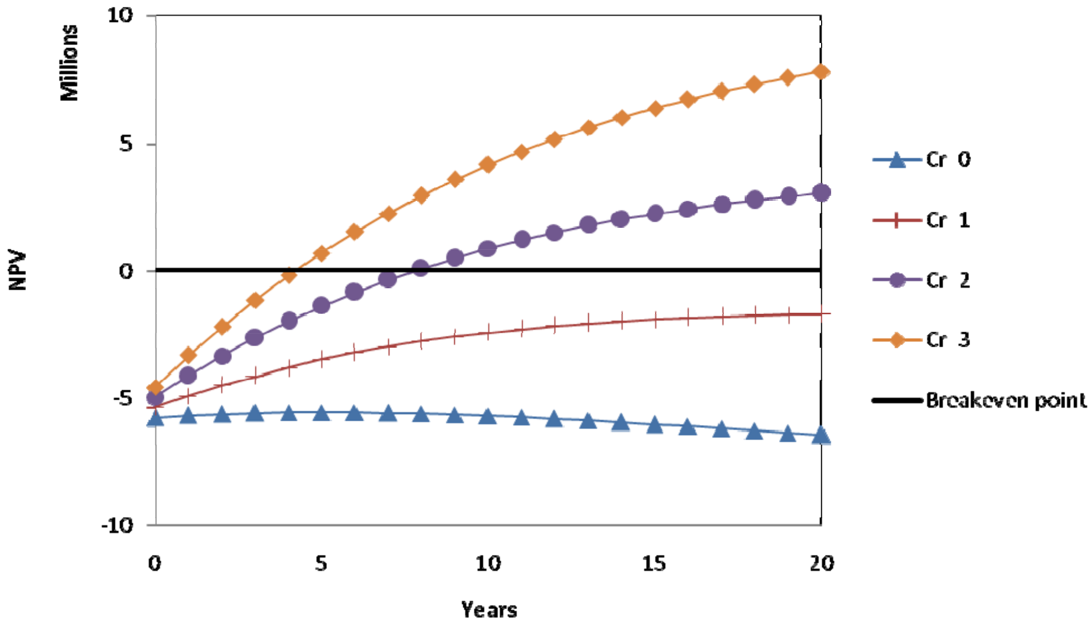

Figure 2. Breakeven analysis for the case of *RCp*=2

At the market level, recent tests showed the potential of replacing 20 percent of natural asphalt in roadways with secondary aggregates without negatively affecting structural integrity. This finding is in-line with results reported by neighboring countries (QCS 2011). Hence, once crushed and sorted, recycled CDW can replace natural aggregates in several applications including construction or rehabilitation of existing city and intercity roads. The recycled material can be used in asphalt mixtures and sub-grades layers of roadway projects. The roadway maintenance programs as well as the roadway master plan alone reveal an annual need far exceeding the recycling plant capacity (CDR 2010).

CONCLUSIONS AND EXTENSION FOR FUTURE WORK

The theoretical framework and subsequent economic analysis proved feasible in the test case presented and can be equally applied in other markets with similar attributes which are common occurrence in many developing countries. Evidently, the land price and property depreciation in residential urban areas play a vital role in siting a recycling facility particularly where land is scarce such is the case of Beirut city and its suburbs. Once a site is located, the recycling gate fee and the aggregate selling price must be defined in a way that allows recyclers to compete against the cost of the raw material and more importantly provide adequate incentive for contractors to opt for managing CDW through the recycling facility by raising the landfill tipping fees. This conclusion stresses the significance of a regulatory framework that needs to be concurrently adopted and properly enforced in order to protect the recycling market. Hence, future work must emphasize the regulatory role as well as incorporate environmental externalities that would naturally increase the socio-economic benefits and entice policy makers. Implementing the proposed framework in developing countries such as Lebanon allows for using waste as raw material in manufacturing processes thereby reducing demand for virgin materials and landfill space. Reusing CDW can potentially reduce greenhouse gas emissions during the material life cycle.

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