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Published Version

Ashraf, A., Mohareb, E. ORCID: https://orcid.org/0000-0003-0344-2253 and Vahdati, M. ORCID: https://orcid.org/0009-0009-8604-3004 (2024) Evaluation of life cycle cost for the comparison of decentralized waste to composting and landfilling of municipal solid waste. Discover Sustainability, 5 (1). 202. ISSN 2662-9984 doi: https://doi.org/10.1007/s43621-024-00409-w Available at https://centaur.reading.ac.uk/118655/

To link to this article DOI: http://dx.doi.org/10.1007/s43621-024-00409-w

Publisher: Springer Nature

Discover Sustainability

Research

Evaluation of life cycle cost for the comparison of decentralized waste to composting and landfilling of municipal solid waste

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Received: 30 March 2024 / Accepted: 12 August 2024
Published online: 19 August 2024

Abstract

Background Municipal solid waste (MSW) has increased dramatically in emerging economies like Bangladesh as a result of rapid urbanization and economic growth. Due to the high land requirements and nature of the waste, options of municipal waste management such as landfilling and waste-to-energy have proven to be expensive and inefficient. Previously, a pilot study on a waste-to-compost program in a decentralized facility was done in Dhaka to evaluate the effectiveness of municipal waste management.

Objective The aim of this study was to analyze the life cycle costs (LCCs) of a waste-to-composting facility in Dhaka, Bangladesh. The objective was to ensure economical and effective management of MSW by comparing overall spending to the current and proposed waste management process.

Methodology In order to evaluate the potential of the planned decentralized compost plant, LCC methods using UNEP/SETAC guidelines are used in the study. This includes an additional analysis of environmental and operational costs and benefits.

Result The research found that the overall cost of the decentralized compost facility was $857,110, much less than the expenditures associated with landfilling and conventional composting methods in Dhaka.

Conclusion This study shows that a decentralized waste-to-compost plant may be a profitable option for dealing with municipal solid waste. Its potential to ease stress on municipal governments is highlighted by its much lower price tag. Insightful for policymakers and urban planners in emerging nations confronting comparable waste management difficulties, this research stresses the need to implement such creative, cost-effective approaches in quickly rising metropolitan cities.

Keywords Life cycle cost · Waste · Dhaka · Bangladesh · Traditional waste management

1 Introduction

The worldwide production of MSW is expected to increase to 2.3 billion tonnes by 2025 [1]. MSW causes hazards to human health and the environment [2]. Biomass-heavy items like paper, food waste, wood, and textiles, as well as materials generated from fossil fuels like plastics, are all included in municipal solid waste (MSW) that is handled by municipalities [3]. The amount of municipal solid waste (MSW) generated by cities in 2016 was 2.01 billion tonnes; this number is expected to rise to 3.40 billion tonnes by 2050 [4]. MacArthur [5] reports that the organic component in municipal waste accounts for 46% of all matter on Earth and as much as 64% in low-income nations.

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In addition to contributing significantly to global warming, landfilling, a standard waste management practice, presents difficulties owing to space constraints and other greenhouse gas emissions [6]. Even when landfills are closed, they continue to release gases, highlighting the need for sustainable waste management [7]. Composting is widely recognized as a sustainable practice for biodegradable organic waste and is one of the strategies that have been developed to have a long term solution this problem [8].

Composting is unique among aerobic degradation processes since it is inexpensive to implement and yield valuable compost [9]. Due to waste management challenges, approximately 40 to 60 percent of Dhaka's 6000 metric tons of MSW per day, primarily comprising organic kitchen waste, is disposed of improperly [10]. Inadequate waste management and considerable greenhouse gas emissions result from current waste management systems causes tremendous environmental burden[11]. Dhaka's MSW collection system is divided into primary and secondary waste collection categories. The Municipal government admits that waste management is insufficient for the daily 6000 tons/day of waste produced from greater Dhaka city. Therefore, Dhaka City Corporation (DCC), which was recently divided into Dhaka North (DNCC) and Dhaka South (DSCC), is responsible for overseeing the overall solid waste management of Dhaka's 360 km^2 area [12]. The primary destination for waste generated and initially stored at residences is the secondary storage places established by DCC, which comprise dustbins, containers, and secondary storage sites. The primary collection and transportation services are provided by non-governmental organizations (NGOs), community-based organizations (CBOs), DCC deployments, and rarely by individuals. The principal collection mechanism is based on a three-wheeled vehicle with a driver and a helper. In 2002, the DCC permitted the provision of door-to-door waste collection services to NGOs, CBOs, and commercial entities [12].

Dhaka's municipal government and the Ministry of the Environment have looked at waste-to-energy solutions. However, the high moisture content of food waste makes it difficult to generate heat and electricity directly [13]. It is recognized that for Dhaka to have a sustainable future, new approaches to waste management are necessary. A thorough literature review did not reveal any study on composting to offer a viable path for sustainable urban waste management in Dhaka using the LCA analysis. Composting is simple, effective, and reduces greenhouse gas emissions [14]. The goal of this work was to conduct a life cycle costing on four different waste management processes including the current practice of unsanitary landfilling, proposed sanitary landfilling, a decentralized waste-to-compost using PV-solar based automated machine, and conventional windrow composting. The specific objective was to investigate the potential of decentralized waste-to-compost facility as a long-term sustainable solution to Dhaka's municipal solid waste issue.

2 Related studies

Innovative solutions, such as decentralized waste-to-compost plants, have emerged in response to the changing dynamics of MSW management. Because they are more efficient at handling organic waste on a local level, these decentralized initiatives have gained popularity [15]. Aligning with the Sustainable Development Goals outlined in the 2030 Agenda [16], governments have increasingly supported composting initiatives to reduce the dumping of organic waste in landfills.

Alam estimates that the combined amount of MSW produced daily by Bangladesh's metropolitan areas is 23,688 tons, with organic solid waste accounting for almost 70% of this total. The average moisture content is 50%, while the average collecting efficiency is 56%. The two most popular methods of disposing of waste are dumping and open burning. Anaerobic degradation, pyrolysis, and gasification are processes used to produce sustainable energy/fuel from biomass, agricultural wastes, abandoned tires, and animal wastes. This demonstrates unequivocally Bangladesh's research deficit and its effects on the nation [11].

India, the second most populous nation in the world has similar trend of waste management problems like Bangladesh. India has one of the fastest expanding economies and it is experiencing an increase in the creation of MSW in its cities, according to Kishan. Indian cities are producing an estimated 1–1.33% more MSW annually as a result of changing lifestyles. Only 15–20% of MSW is now separated in India, while 21.45% of it is processed or treated. The remaining 78.55% of MSW is dumped in unhygienic landfills. Furthermore, the estimate of MSW generation for urban residents showed that the rate of MSW generation (kg/capita/day) is around twice that of urban agglomeration [17]. This also shows how food waste is not considered in a large scale.

Life Cycle Assessment (LCA) has helped understand the effects of different waste management methods on the environment [18]. As shown in Fig. 1, there has been a sharp rise in life cycle assessment (LCA) studies focusing on municipal solid waste in recent decades, a trend that reflects the growing interest in assessing the environmental effects of current waste management methods.

Despite the increase in LCA research, thorough evaluations of composting techniques with LCA have not been conducted. Composting, especially in decentralized settings, is underexplored in LCA literature [19], but data on landfilling and other waste management approaches is abundant.

Simultaneously, the economic aspect of refuse management has been the subject of heated discussion. The common perception is that composting is more expensive than landfilling. Nuanced research, however, contradicts these assumptions. Zhu's [20] study found that decentralized composting systems are preferable since the actual cost of on-site composting over 20 years is much cheaper than landfilling expenditures. When long-term advantages like reduced greenhouse gas emissions and compost use are taken into account, on-site composting becomes economically viable, as was also emphasized by Lee et al. [21].

Despite these results, the argument over the relative merits of centralized vs decentralized community composting continues to go beyond this [22]. This is due in large part to a lack of reliable economic and environmental evaluations. This study seeks to fill this knowledge gap by analyzing the financial sustainability of Dhaka's decentralized composting facilities. An in-depth investigation of the economic and environmental viability of composting solutions is possible with the use of a Life Cycle Cost (LCC) study, environmental emissions analysis, and the inclusion of advantages like carbon credits. This research not only aids in the economic assessment of MSW management but also marries the importance of both economic and environmental preservation for more well-rounded waste management decisions.

3 Methodology

3.1 Background

Waste management, particularly in Dhaka, has become an urgent problem as development in Bangladesh quickens. By 2025, it is projected that 47,000 tonnes of urban solid waste will be generated daily, making effective waste management a critical issue. Dhaka North City Cooperation (DNCC) is now in charge of municipal waste pickup, with waste being taken to the Amin Bazar dump. This research examines the life cycle cost of four different waste management processes. These are the current practice of the existing landfill in DNCC, a proposed sanitary landfill, an alternative PV solar based waste-to-compost machine (EP-1000) in a decentralized facility situated next to a secondary transfer station (STS), and a return to traditional windrow composting in the decentralized facility as potential solutions to this growing problem at DNCC. The objective is to evaluate their relative costs and environmental impacts to propose long-term waste management strategies for Dhaka, Bangladesh.

3.2 Life cycle costing (LCC) framework

In this study, the economic impacts of a Life Cycle Assessment (LCA) system were evaluated using the Life Cycle Costing (LCC) framework depicted in Fig. 2. The main approach started with establishing the study's purpose and scope, identifying the functional unit, and outlining the system boundaries, all following the United Nations Environment Programme (UNEP) and the International Organisation for Standardisation (ISO) 14,040. Then, all the expenses connected with each step of the life cycle were accounted for in a detailed inventory analysis performed at the unit process level. All of the

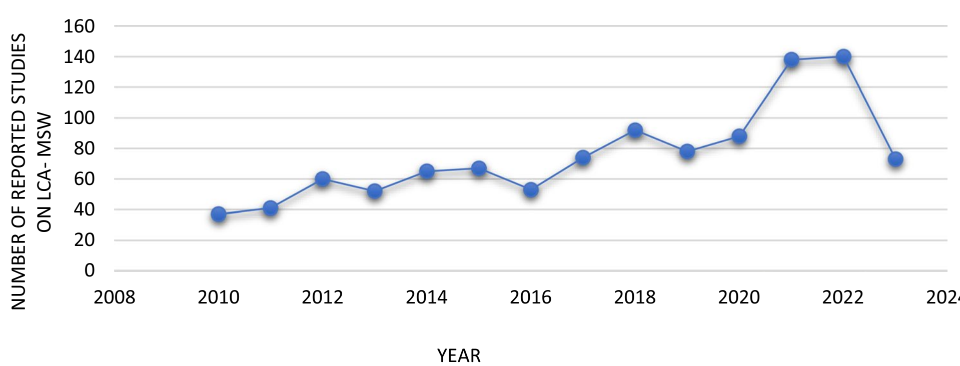
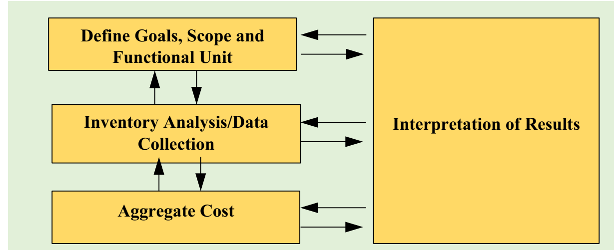


Fig. 1 Number of published studies on Life cycle Assessment (LCA) of Municipal Solid Waste

Fig. 2 Defining the LCC Framework



information was thoroughly compiled using the standard LCC technique. Following the recommended procedure from Lu, et al. [23] an in-depth investigation was conducted. The technique is laid out in detail in the LCC framework, which is shown graphically in Fig. 2. The economic ramifications were deduced from the acquired data and their interpretation. To better implement LCA systems in real-world circumstances, this study also recommends topics for further research and critical evaluations.

3.3 Goals and scope

This research aimed to compare and contrast traditional composting techniques with those that use a decentralized composting facility following MSW collection to reduce costs and landfill usage. The standardized analysis allows for more relevant comparisons, and the functional unit (FU) is the management of 1 tonne of municipal solid waste with 60% organics [24]. Within the LCC system border cradle to gate scenario was considered where cradle is considered when the waste is collected, sent to a decentralized facility, and final composted materials in bag is considered as gate. From this process just 10% of the waste is condereed to be going to landfills. Figure 3 is a visual depiction of the system boundaries for the three situations that help to clarify our method [24].

3.4 Life cycle inventory

Photovoltaic solar (PV) panel-based decentralized waste-to-composting done with the help of an automated waste-to-compost converter (EP-1000) is termed as PV panel-based EP-1000 method (Table 1). A PV solar based automated EP 1000 machine, a waste-to-compost converter made by an Indian company that is known for its rapid conversion of one tonne of food waste into compost in only 24 to 48 h, was taken into consideration for a decentralized composting plant. This cutting-edge converter runs only on a 6 kW solar panel, so there's no need for grid energy; in addition, it has a battery storage system for backup power. The total quantity of waste to be composted is 60% of the 6000 tons per day produced in Dhaka (approximately 60–70% of which is organic and 90% of this organic waste is intended to turn into compost). A total of 6000 ft^2 has been set aside for ward-based waste to compost facility (decentralized facilities) for the converter and other necessary components, assuming efficient operations. Figure 4 depicts the composting machine's architecture and settings in detail. One of the primary assumptions was that in order to remove landfills for DNCC, it would require approximately 10 decentralized PV-based waste to compost facilities and 5 equivalents of windrow composting based decentralized facilities which has a larger capacity than PV-based waste to compost machine to replace the local landfills. The community-based centralized composting of MSW with an option of open dumping is termed unsanitary landfilling and that with closed dumping is called sanitary landfilling.

Windrow composting is a non-mechanized decentralized aerobic and thermophile composting process, also termed as "Indonesian Windrow Technique", which involves composting of MSW by combining additives, packing waste into a triangle aerator constructed of bamboo, letting the compost mature without stirring or watering, and screening before packaging. Typically, the entire composting process takes about 50 to 55 days.

Table 1 also provides a clear breakdown of the investment needed by outlining optional extras. This research technique is firmly based on these components, which together create an economically viable and environment friendly waste management system.

For windrow composting, sanitary and unsanitary landfill, secondary data were collected from the DNCC Report 2019 and Waste Concern's Waste Database 2014 [25].

All the relevant costs within the system boundaries are considered. The system boundary was previously shown in Fig. 3. Both internal and external costs are considered in this study. The costs have been all converted to the 2023 Present

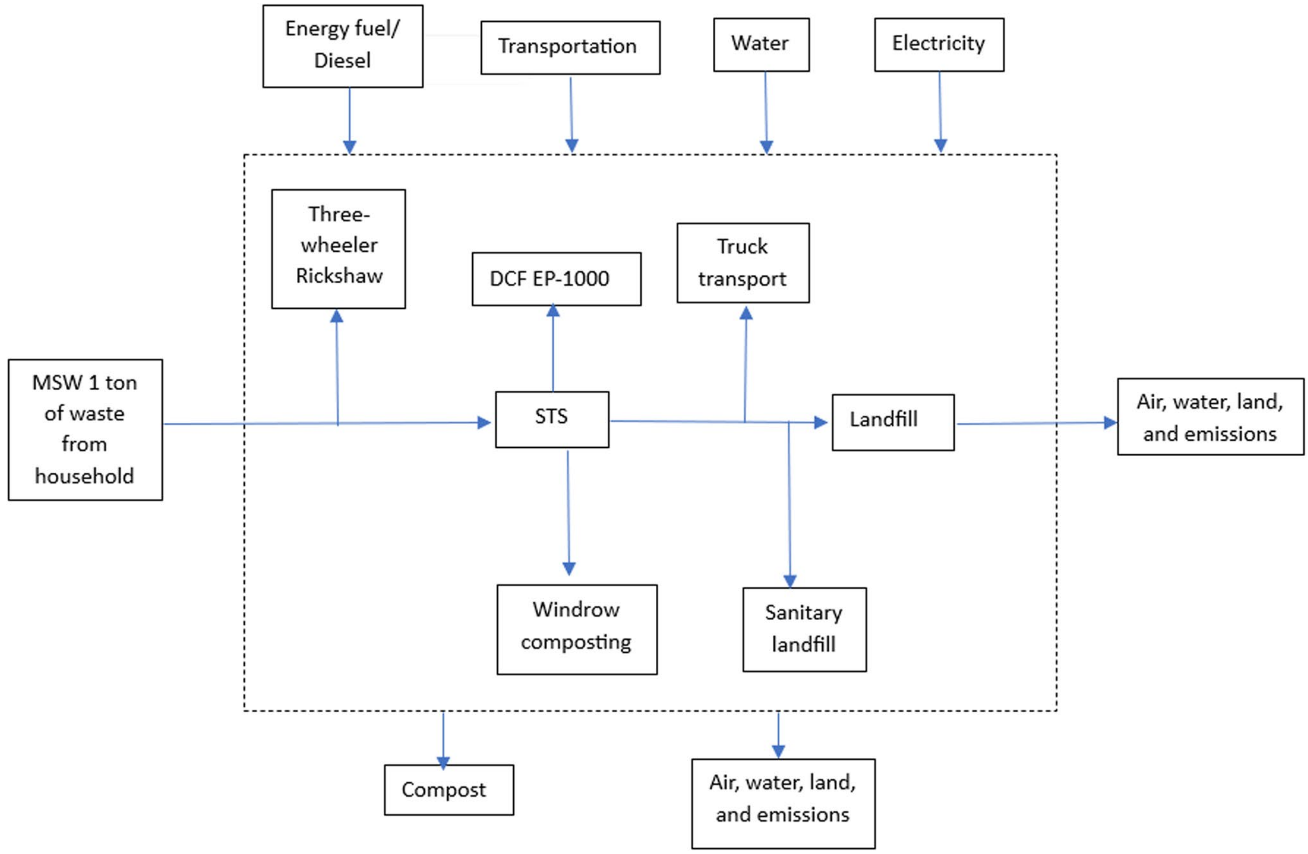


Fig. 3 System Boundary for MSW treatment: EP-1000, an automated waste-to-compost facility, a windrow composting facility, and sanitary and unsanitary landfill

Table 1 List of significant components for PV Solar panel-based decentralized waste-to-compost EP-1000 machine

Major Components for EP1000	Vehicle unloading station
	Waste crusher
	Screw conveyor
	Composting machines
	Rotary composting machine
	Centralized control room
	Odour treatment system (Optional)
	Oil and water separator (Optional)

Value (PV) in the US dollar. An Excel spreadsheet is used for LCC calculation. The assumptions and parameters of the LCC are obtained from [23] which are presented below:

$$Total\ \cos t = \left(CC\ \times \frac{i}{1-(1+i)^{n}} \right) + OC - OB + EC - EB$$

CC: Capital cost: initial investment in land purchase, EP 2500, Solar panels, Storage materials, batteries, vans, invertors.
I = interest rate and (4% present day) (Bangladesh).
n = number of years (25 years).
OC = Operational costs: Man hours, Fuel (for transportation), Lubricants, utilities, maintenance, transportation cost.
OB = Operational benefits: compost value.
EC = Environmental costs: Environmental regulations such as cost due to air pollution and water pollution.

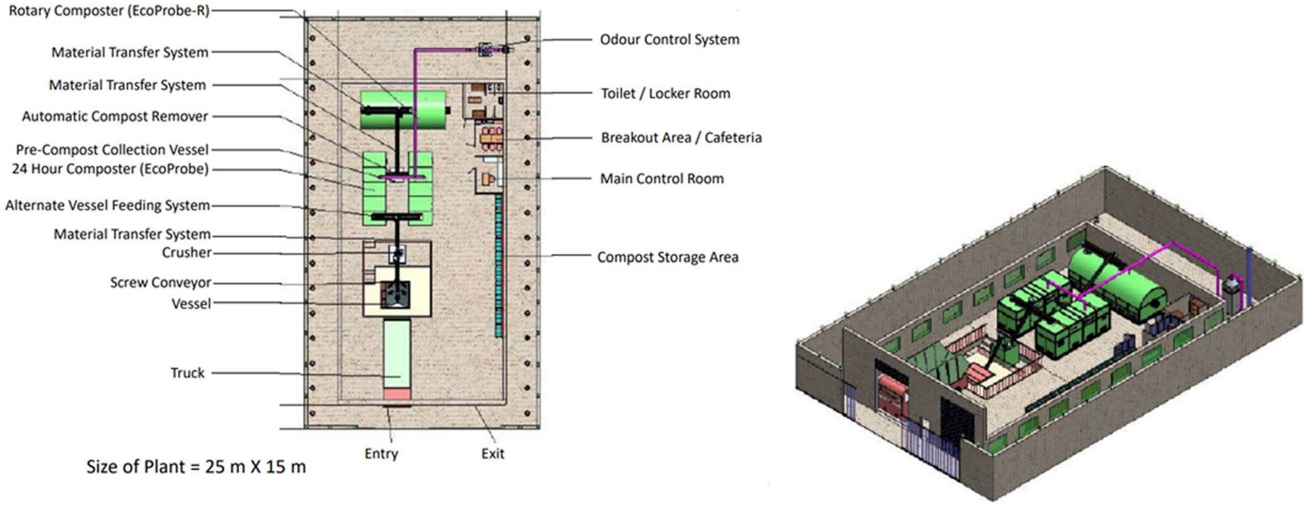


Fig. 4 Configuration of the designed facility

EB = Environmental benefits: Avoided waste benefits considered as monetary value, such as Carbon capture or reduction of CO_2 and CH_4.

DF = Decentralized facility.

3.5 Assumptions

The following assumptions are based on the 2019 DNCC report [25].

i. All costs are assumed to be present values in 2023.
ii. We assume 90% of waste to composting and 10% go to the landfill for EP1000 (Decentralized Facility)
iii. *Decentralized Facility* The area needed for 1 plant/factory design is around 375 m^2 (4036.466 ft^2). The total land area for this study is assumed to be 6000 ft^2 (557.418 m^2)
iv. Landfill: Currently, in Dhaka, a total of 200,000 m^2 of landfill area accepts the incoming waste (Corporation 2019–2020)
v. Conventional Composting: Windrow composting (facility producing 10 tons/day based on waste concern) was assumed for comparison purposes. An area of 5351.213 m^2 was taken for windrow from the literature. Values are converted to PV using a rate of 3%
vi. The present cost to build the plant is taken to be around 300,000 BDT/m^2 (2773.73 USD/m.^{2}) for all 3 processes for uniformity. A construction cost for the storage area is assumed to be 200,000 BDT(1849.15 USD)
vii. For the Capital Cost of Conventional Composting, a total land + upfront cost is taken into account, for operational costs, including daily electricity charge, daily labor charge, and total daily supplementary price, are taken into account [26].
viii. For the DF, 5 trucks will be purchased to carry out the activities; 1 truck costs 5,485,500 BDT (51,047 USD); hence, the capital cost for 5 trucks would be 255,235 USD (Wheeler)
ix. For the DF, Labor cost is assumed to be 60,000 BDT (554.73 USD) for 6 laborers. Maintenance cost for equipment is assumed to be around 30,000 BDT (3,328 USD), Machine spare parts (BDT 50,000) cost and oil and grease cost (BDT 20,000) is also taken into account in maintenance.
x. The Solar Panel is assumed to be operated at BDT 2700,000 (25,126 USD). The maintenance cost for the solar panel is also added and is taken to be around $720 annually.
xi. The assumed operating cost is per year for 10 tonne waste to compost/per day (waste concern).

4 Results

Table 2 gives a detailed comparison of four waste management strategies: EP-1000 composting at a decentralized facility, sanitary and unsanitary landfill disposal, and conventional composting at a decentralized facility. Capital costs, operating costs, and environmental costs are all broken out in-depth for each approach. Capital expenditures consist of things like buying property, composting gear, solar panels, building storage, buying cars, hooking up to utilities, and installing inverters. Wages, gas, electricity, water, and depreciation are all part of the operational expenditures that a business incurs. Air pollution compounds and other environmental expenses are also factored in. Experts and policymakers in the field of waste management may benefit significantly from the study, as it will help them make more well-informed choices that will lead to more environmentally friendly waste management procedures.

Table 3 presents a detailed scientific evaluation of the costs per kilogramme of air pollutant compounds released during waste treatment procedures in both current USD and present values in 2023. The research separates the emissions caused by waste transportation, landfill gas emissions, and composting gas emissions. Specific pollutants are taken into account, including CO_2, NOx, CH_4, SO_2, $PM_{2.5}$, PM_{10}, N_2O, and NH_3, and their associated emission rates and costs are calculated. Helping policymakers and environmental researchers make educated choices for sustainable waste management practises, this comprehensive evaluation provides significant insights into the environmental and economic consequences of various waste management strategies.

5 Sensitivity analysis

With 2% and 6% interest rate (based on Bangladesh's past 30 years economic growth and plunge, Bangladesh Bank report 2015) a sensitivity analysis is also conducted in the following tables to assess the fluctuation within the Bangladesh economic context (Table 4).

Table 5 provides vital parameters and associated values in the context of waste management, with values provided in both Australian dollars (AUD) and United States dollars (USD). The discount rate represents the current value of future expenses, whereas the other components, P_p, P_k, and P_N, indicate particular cost elements in waste management procedures. In addition, it includes the prices of waste management operations' must-haves, such as diesel fuel, petrol, and electricity. The carbon price, which indicates the monetary value attached to carbon emissions and is therefore necessary for such computations, is also included in the table. These metrics are crucial for policymakers and stakeholders in sustainable waste management plans to have a firm grasp on the financial implications of waste management systems.

The values are adopted from [29] for the year 2019 and are converted to present values in the year 2023 in USD using the exchange rate (1AUS $ = 0.64 USD), using the formula provided below.

$F = P(1+i)^n$, where F denotes future value, P denotes present value, i denotes discount rate, and n denotes number of years.

$$V_{compost} = P_p * qc_p + P_k * qc_k + 0.14ha.t^{-1} * 7.2\% * (P_P * qBase_P + P_k * qBase_k + P_N * qBase_N) + P_{GHG} * q_{GHG} \quad (1)$$

P_P = the existing market price of P [2.93$/kg]

qc_P = the quantity of P in compost, [3.04 kg/t]

P_K = the existing market price of K, [2.1098 $/t]

qc_K = the amount of K in compost,[6.913 kg/t]

P_N = the existing market price of N fertilizer,[1.06 $/t]

P_{GHG} = the economic benefit arising from GHG emission reductions and

q_{GHG} = the amount of GHG emissions reduced by applying compost. (85.04USD,

a = the conversion factor (0.14 ha t^{-1}) was assumed according to [6]

e = the improved fertilizer use efficiency (in this study, e = 7.2% was assumed based on (Roberts et al. [6]

qBaseP, qBaseK, qBaseN are defined as the quantities of 'P', 'K', and 'N' fertilizers usage under base circumstances. In this study, the average fertilizer application rates were assumed to be 154.4, 64.9, and 94.0 kg ha^{-1} for N, P_2O_5, and K_2O, respectively, according to [6].

Table 2 Comparison of total cost of the four waste management processes including waste-to-compost using (i) conventional windrow composting, (ii) PV Solar panel-based decentralized automated machine, (iii) sanitary and (iv) unsanitary landfills with 4% interest rate

Type of cost	Category	Decentralized facility using Conventional Composting (USD)	PV Solar panel-based decentralized waste-to-compost EP-1000 machine (USD)	Sanitary Landfill (USD)	Unsanitary Landfill (USD)
Capital cost	Land	14,842,820	1,542,890	554,000,000	554,000,000
	Composting machine EP 1000/ Equipment for Composting for Conventional DF composting	15,350	50,000		
	Solar Panel (30 kW)		25,126 (Stall)		
	Storage area construction	1000 (100 ft^2 @ 500/ft^2)	1849.15 (100 ft^2)	12,700 (100ft^2)	5000 (100 ft^2)
	Battery storage		18,000 (Alibaba)		
	Trucks / Van/ waste collection vehicles	250,000	250,000	800,000	1,000,000
	Electricity and Water connection	100,000	50,000	340,460	170,230
	Inverters		143.31 (Stall)		
Total Capital Cost		14,846,720	1938,008	555,153,161	555,175,230
Operational Cost	Salary for labour/yr	460,080	39,940	595,806	740,502
	Transportation	69,168	69,168	1702,303	3106,909
	Utilities (Water, oil/lubricants, electricity)	28,800	3600	42,557	500,000
	Maintenance	1953,620	11,814	383,018	500,000
	Equipment depreciation cost/ year	500,000	152,002	510,691	700,000
Total Operating Costs		3,012,389	276,527	3,617,394	5,547,411
Environmental Cost	Air pollutant compound	912	91	5,162,805	11,086,192
Operational benefits	Compost value $V_{compost}$	96,000	314,013	0	0
Environmental benefits	Avoided waste benefits/carbon credit	1668	948	1581 (Lam, Iris et. al. 2018)	1581 (Lam, Iris et. al. 2018)
Total Cost	Using Eq. (1)	3866,001	85,711	44,315,061	52,169,878
Total Cost: to replace landfill	Assumptions: 5 windrow composting and 10 PV-based waste-to-compost facilities	19,330,005	857,110	Not applicable	Not applicable

Table 3 External environmental costs of emissions

Category	Air pollutant compound	USD/Kg emission compound	USD/ Kg emission compound (present value in 2023)[c]	Decentralized facility using a solar powered PV waste to compost machine	Unsanitary Landfill	Conventional windrow composting	Sanitary landfill
Waste transport	$CO2^a$ (Fossil)	0.01	0.02	6.72	6.72	6.72	6.72
	NOx^a	4.92	7.07	–	–	–	–
	$CH4^b$ (Fossil)	0.819	0.98	0.0098	0.0098	0.0098	0.0098
	$SO2^a$	7.91	11.4	–	–	–	–
	$PM_{2.5}{}^b$	342	408	− 0.09	0.15	0.07	0.085
	$PM_{10}{}^b$	2.95	3.52	− 0.02	0.09	0.07	0.056
Emissions from landfill	$CO2^a$	0.013	0.02	0	3674	0	2156
	CH_4	0.82	0.98	0	17.4	0	11.4
	NOx^a (NO+NO3+NO2)	2.32	3.34	0	10.8	0	8.56
	$SO_2{}^a$	3.97	5.71	0	15.6	0	11.2
	RSP^a	50.8	72.9	0	0.06	0	0.04
Emission from Waste to compost	$CH_4{}^b$	0.819	0.98	− 4.28	0	13.1	0
	$CO_2{}^a$	0.013	0.02	− 2131	0	1545	0
	N_2O^b	11.62	13.9	0.54	0	0.54	0
	$NH_3{}^b$	25.5	30.4	3.7E−05	0	3.7E−05	0

RSP Respirable suspended particulates

[a]Adopted from Woon and Lo [27]. The base year for the values of 2014

[b] Adopted from Martinez-Sanchez, Levis et al. [28] (Discount rate 3%)

[c] Converted to present values in year 2023, using formula $F = P(1+i)^n$, where F denotes future value, P denotes present value, i denotes discount rate, and n denotes number of years

Table 4 Comparison of total cost of decentralized waste to compost using automated machine, windrow composting and landfill with 2 and 6% interest rates

Interest rates	Calculation technique	Decentralized facility using conventional composting (USD)	PV Solar panel-based decentralized waste-to-compost EP-1000 machine (USD)	Sanitary landfill (USD)	Unsanitary landfill (USD)
2 percent	Using Eq. (1)	18,380,445	611,897	37,213,806	45,068,340
6 percent	Using Eq. (1)	20,385,218	1,136,695	52,206,428	60,061,558

Table 5 A comparative price list of compost value

Parameters $/kg	Australian, $/kg	USD ($)/kg
P_p	4.58	2.93
P_k	1.60	2.11
P_N	1.66	1.06
Discount rate	4.90%	4.90%
Diesel fuel cost	1.49	0.95
Gasoline	1.51	0.97
Electricity cost	0.27	0.17
Carbon Price	35.1	22.5

6 Discussion

This study examines Municipal Solid Waste Management (MSWM), a pressing problem in modern cities like Dhaka, the capital of Bangladesh. Landfilling, traditional composting, and a decentralized facility with an PV solar based EP-1000 composting machine are just a few of the waste management strategies that are thoroughly examined and compared in this research. Despite their long history of use, landfills are often seen as harmful to the environment owing to the large amounts of the area they need, the hazards of leakage into the air, water, and soil, and the low levels of energy recovery they achieve. This evaluation is consistent with the findings of Dijkgraaf and Vollebergh (2004), which found that the use of conventional landfills was not sustainable [30].

The study devotes a substantial amount of time to contrasting various waste management approaches. Life Cycle Analysis (LCA) is used by Yay and Erses [31] to determine whether practises are good for the environment. The report acknowledges that the present waste management system in Dhaka has limits, making new techniques necessary. Like Islam [32] and Hai and Ali [33], findings of this study may have possible answers in community-based programmes that include composting, recycling, and improved waste management. Composting can reduce negative impacts and increase landfill longevity, as noted by Enayetullah and Sinha [7].

The research provides a critical analysis of windrow composting, pointing out its limitations in areas including space, odour, and bioaerosol production. Soto-Paz et al. [34] and Liu et al. [27] note that improvements in composting technology have alleviated some of these fears. The use of specialized equipment has increased the efficiency of composting while decreasing the amount of work required and the overall impact on the environment.

The emphasis of the research is a quantitative examination of the differences between various approaches to waste management. The most cost-effective by far is the PV solar based EP-1000 machine in a decentralized plant. According to the findings, there are substantial savings because of the decentralized facility's lower capital expenditures due to its smaller land footprint. The effective functioning of the composting machine also significantly reduces labour expenses. As mentioned in Tables 2, 3, 4 and Fig. 5, the research carefully contrasted four waste management techniques and it found that the projected decentralized facility project would cost about 857,110 USD on the whole. Compared to the costs of landfilling and conventional composting processes, total cost of PV-based decentralized facility is conveniently manageable. Notably, the decentralized facility showed much lower environmental costs than the other options, making it the most cost-effective choice. Land for the proposed plant cost roughly 9.6 times less than typical windrow composting, and labour costs were highly decreased when compared to the traditional techniques, with landfill operations employing the most people at 740,502 USD yearly.

The research not only provides ideas for improving the EP-1000 machine-based decentralized facility but also demonstrates the facility's economic feasibility. Regulation of waste collection, financial incentives for recycling, and public education campaigns are all seen as essential measures. This study lays a solid groundwork for Dhaka and maybe other cities across the world to implement a sustainable waste management system for the future.

7 Conclusion

This study concluded with a thorough evaluation of the Life Cycle Costing (LCC) of a decentralized facility in Dhaka, along with a 10% landfill allocation for municipal solid waste. The study's results provide specific recommendations for improving Dhaka and other cities like it with regard to waste management. These include the adoption of awareness

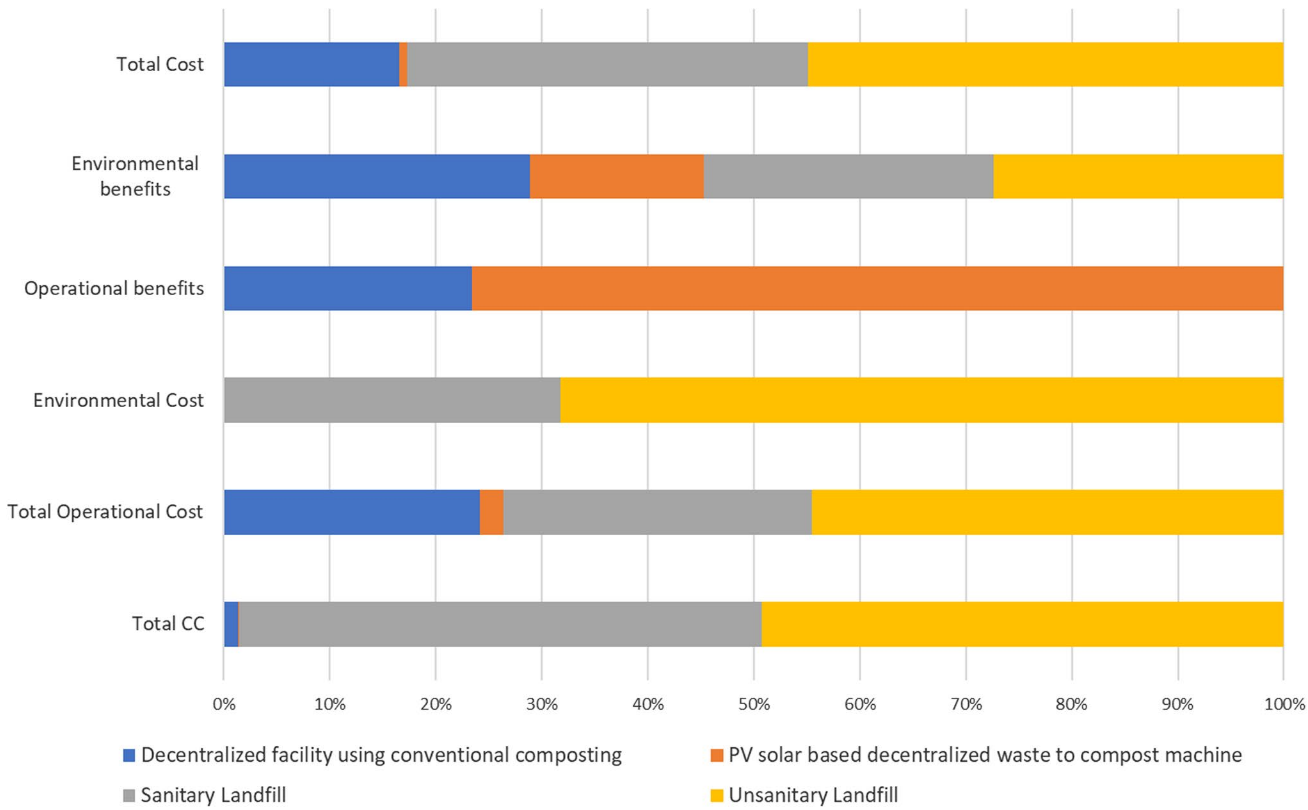


Fig. 5 Comparison of all four scenarios

programmes and effective management strategies, the execution of the planned decentralized facility employing EP-1000 technology, and strong and frequently enforced waste collection rules. The findings of this research provide policymakers and urban planners with valuable recommendations for improving waste management procedures and promoting environmental sustainability.

Acknowledgements The Qatar Research Development and Innovation (QRDI) Council is acknowledged for supporting this work under the grant UREP29-205-2-056.

Author contribution All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by AA (Azad ibn Ashraf), EM (Eugene Mohareb) and MV [Maria Vahdati] The first draft of the manuscript was written by [AA] and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data availability Data is provided within the manuscript.

Declarations

Competing Interests The authors declare no competing interests.

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