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Bioenergy Integration

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FEASIBILITY STUDY ON ANAEROBIC DIGESTION OF WASTE FROM DHAKA'S FRESH MARKETS

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ABSTRACT: Effectively collecting and disposing municipal solid waste in Dhaka has become a serious and challenging problem. The principal issues that undermine the city's waste management measures include limited funds to pay for the daily transportation costs, limited capacity to manage a constant citywide collection effort, and a scarcity of land for the establishment and expansion of landfill sites. Decentralised processing of biodegradable waste of fresh markets by anaerobic digestion is a potential alternative to the current waste disposal system. The feasibility was techno-economically analysed. A conceptual design was set up for a fresh market generating 18 m^3 waste per day, representing a medium sized fresh market. The biogas production, the related electricity generation, and required land area were estimated. The techno-economic analyses showed that, compared to the current collection, transport, and landfill costs, the total costs of the anaerobic digestion plant are 24% lower. The transport and landfill costs are strongly reduced. The labour, maintenance, and financing costs of the anaerobic digestion plant are nearly covered by the revenues from the offset of electricity. Moreover, it reduces greenhouse gas emissions and improves the circularity.
Keywords: anaerobic digestion, waste disposal, economics, circular economy

1 INTRODUCTION

The amount of waste generated in Dhaka is rapidly increasing due to population growth, industrial development, and rising prosperity. Nevertheless, there are only two official landfill sites that serve the city: Amin Bazar and Matuail. Although more land has been acquired to expand these existing landfill sites, they are expected to reach their capacity in a few years due to rising waste generation and efforts to increase the waste collection efficiency. Expanding the landfill sites is not regarded as a viable long-term and durable solution due to scarcity of land and high acquisition costs.

The total amount of waste collected and dumped at the landfills amounts up to 5,500 tonnes per day, but figures vary regarding seasonality and the amount of waste that remains uncollected [1]. The city corporations are primarily responsible for collecting and managing waste in Dhaka. The Dhaka North City Corporation (DNCC) states in its 2018-2019 waste report that 20% of the waste remains uncollected [2]. While no official numbers have been released by the Dhaka South City Corporation (DSCC), the collection efficiency can be assumed to be lower than DNCC, due to the lack of secondary (waste) transfer stations and the higher costs of disposal. Uncollected or improperly disposed waste creates significant health, social, and environmental impacts for the population. These impacts include foul odours, traffic congestion, and the spread of rodents that transmit diseases, pollution of the air and water, and the increased risk of fire. Therefore, as the waste management problem gets bigger it also becomes more problematic for the city.

City corporations are on the lookout for alternative methods to landfilling and uncontrolled dumping [3]. Better waste management, however, cannot be ensured through increased resources alone. Innovation is needed to face this challenge. A large part of the waste is generated in the city's fresh markets, which is mainly biodegradable. Treatment of waste from fresh market via waste to energy technologies can be part of an improved waste management strategy in Dhaka. The DNCC in its annual waste management report [2] acknowledges they do not yet have the expertise to implement a waste to energy plant, but appreciate these developments. They have outlined biogas production and composting as possible interventions as part of their future waste management plan. However, disruption of current practices threatens impacting the livelihoods of existing actors in the waste management system, who are most often the poor, could be problematic and requires sensitivity. Thus, proposed interventions should look to integrate the existing actors in some capacity.

2 FRESH MARKET WASTE SURVEY

Given the urgency of the situation an alternative and fresh look on the waste management issue is required. On account of the problems discussed, a fresh market waste survey in the Dhaka Metropolitan Area was performed to analyse the feasibility of implementing alternative waste management solutions. The survey started in December 2019 and was completed in January 2020.

From the survey it became clear that each market has its own waste management system in place. The waste management systems in fresh markets are diverse, but usually involve shop owners and cleaners employed by the city corporations and market committees.

DNCC and DSCC both have a city-level landfill facility, however, the costs of collection and transportation of waste, is extremely burdensome on the city government's budget. Transportation and collection make up about 90% of the total waste disposal costs in DNCC and DSCC as shown in Table I. The substantial amount of waste that needs managing means that, unless cost savings can be achieved, these two components will continue to contribute to a large portion of expenditure of the city's budget. Besides high costs, the trucks and the methane emission in the landfill result insignificant greenhouse gas emissions. Furthermore, the two landfills are approaching maximum capacity, meaning sooner or later more investment will be required.

Table I: Waste disposal costs in Bangladeshi Tk and €

	DNCC		**DSCC**		**Average**	
	Tk/ tonne	€/ tonne	Tk/ tonne	€/ tonne	Tk/ tonne	€/ tonne
Collection	965	10.4	1,900	20.4	1,433	15.4
Transport	600	6.5	800	8.6	700	7.5
Landfill	235	2.5	300	3.2	268	2.9
Total	**1,800**	**19.4**	**3,000**	**32.3**	**2,400**	**25.8**

There is a pressing need to identify and implement alternate solutions to landfilling and bring changes to the existing waste management structures in place. The survey of the waste management systems of DNCC and DSCC showed that the current system is both costly and unsustainable in the long run. The waste data collected suggests that it is possible to utilize the vast amount of biodegradable waste for energy recovery by anaerobic digestion (AD). Anaerobic digesting of biodegradable waste in strategic locations will lead to a reduction of transport and the use of landfills. Furthermore, the obtained biogas can be converted into electricity. The renewable energy that can be produced has commercial value.

3 ANAEROBIC DIGESTION

The fresh market survey revealed that most of the waste, on average 85%, comprises biodegradable matter, which can be degraded by anaerobic digestion. These are materials such as vegetables, fruits, bread, grains and oils. The non-biodegradable parts are plastics, metals, glass, sand and stones. Currently, source separation of recyclables is already taking place informally in some markets, which suggests that segregated collection, which will yield a waste type that is largely biodegradable, is expected to be easily implantable,

Anaerobic digestion is a biological process in which biodegradable matter is converted by bacteria under anaerobic conditions (without oxygen). This biological process yields biogas, a mixture of methane and carbon dioxide, which can be used as a fuel for example in the generation of electricity.

In this process, the biodegradable waste is chopped and introduced in a closed tank reactor in which it stays about 1.5 months. Besides biogas, digestate is produced. Digestate can be separated in a solid fraction and wastewater. The solid fraction should be composted to stabilize it. After composting, it can be a potential revenue source if sold to farmers as nutrient rich compost. The wastewater can be discharged into the municipal sewer. The solid fraction has an order of magnitude lower volume than the original waste. The biodigester may be constructed on or near the site of the secondary transfer station.

4 SCENARIO DEFENITION

A conceptual design was set up for the current waste disposal and waste disposal incorporating an AD plant for a medium sized fresh market. In the survey an amount of 18 m^3 (13.5 tonnes) waste per day was considered representative for a medium sized fresh market.

4.1 Current waste disposal

Waste from fresh markets is collected and transferred to secondary transfer stations using small vans. From the secondary transfer stations the waste is transported by trucks to landfill sites on the outskirts of Dhaka. The current situation is illustrated in Figure 1.

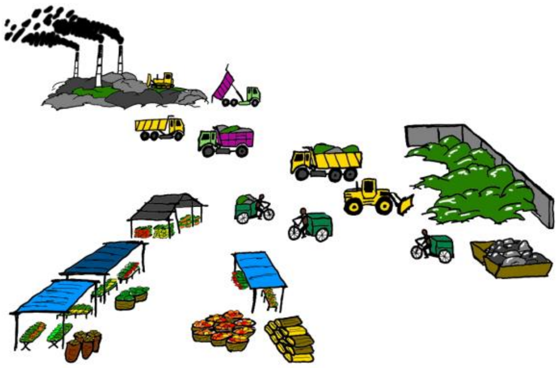

Figure 1: Current waste disposal: collection and disposal of waste from fresh markets. Waste is collected and transferred to the secondary transfer station using vans. The waste is transported from the secondary transfer station to the landfill using trucks.

4.2 Waste disposal incorporating an AD plant

The conceptual design of the AD plant was based on [4–6], a preliminary design by a Bangladesh based company, and expert knowledge of Wageningen Food & Biobased Research. This scenario is illustrated in Figure 2.

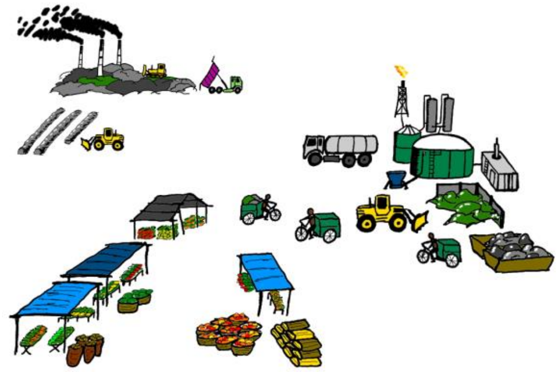

Figure 2: Anaerobic digestion of biodegradable waste. The secondary transfer station is partly replaced with an anaerobic digester, transport by trucks and landfilling are reduced, the solid fraction of the digestate is composted.

The assumptions regarding the current waste disposal and AD plant are shown in Table II. 15% (w/w) of the waste is assumed to be non-biodegradable (glass, metal, paper, plastic) and is still transported to the landfill by trucks. 85% of the waste is biodegradable. It is estimated that the biodegradable waste has a dry matter content of 14% of which 95% is organic matter (5% are minerals). Lignin cannot be converted due to its complex structure and is estimated to represent 2% of the dry matter. The biogas production is assumed to be 620 m^3 biogas per tonne organic matter minus the lignin. The fraction that is expected to be digested in 1.5 months is assumed to be 80% of the potential. Using these assumptions, the biogas production will be 741 m^3 per day with a methane content of 60% (v/v) and an energy content 6 kWh per m^3 biogas. The electricity generator is expected to have an efficiency of 35%, which results in and electricity production of 2.1 kWh per m^3 biogas.

Table II: Assumptions regarding current waste disposal and AD plant

Waste from fresh market	18	m^3/d
Bulk density	0.75	$tonne/m^3$
Mass flow	13.5	tonnes FW/d
Biodegradable fraction	85%	
Non-biodegradable waste	2.0	tonnes FW/d
Biodegradable waste	11.5	tonnes FW/d
Dry weight	14%	DW
Organic matter	95%	OM/DW
Lignin	2%	Lgn/DW
Max biogas yield	620	m^3/(tonne OM - Lgn)
Biomass conversion	80%	
Biogas production	741	m^3/d
Methane content biogas	60%	
Energy content	6	kWh/m^3 biogas
Efficiency generator	35%	
Electricity from biogas	2.1	kWh/m^3 biogas
Solid fraction digestate	21%	of DW
Dry weight	25%	DW
Mass flow	1.3	tonnes FW/d
Wastewater discharge	8.9	m^3/d

The anaerobic digestor is mixed and fed continuously or fed in daily batches and does not require heating or cooling. Besides biogas, the AD plant produces a solid fraction of the digestate. About 21% of the original dry matter will end up in this fraction. It comprises solid minerals (sand, clay, phosphate precipitates) and undigested organic matter e.g. lignin and lignocellulose. After dewatering this solid residue is expected to have a dry matter content of 25%. Therefore, 1.3 tonnes of solid fraction of the digestate per day will be produced.

The volume of the anaerobic digestor was estimated on 561 m^3 including a minimum of 10% head space. The head space may be flexible (inflatable balloon) to store biogas. The height of the liquid can be 8 m. The diameter was estimated on 9 m.

The AD plant is producing electricity, but the unit operations also consume power, e.g. shredding, pumping, mixing, and dewatering. This internal use is estimated on 21% of the generated electricity. The AD plant generates 65 kW electricity and uses 14 kW. This results in an electricity offset of 51 kW.

The unit operations require land area including space for pipelines and operators to walk around the equipment. In addition, loaders and trucks should have manoeuvre space. The total required area is estimated on 250 m^2.

The distances to be covered by vans and trucks are estimated to be 1km from market to secondary transfer station or AD plant, 15 km from secondary transfer station to landfill, and 15 km from AD plant to composting plant.

5 TECHNO-ECONOMIC ANALYSIS

Based on the conceptual design, a techno-economic evaluation was performed. The fixed capital (investment) of the anaerobic digestion plant was estimated on Tk 28,000,000 (k€ 300), including installation and engineering. The composting plant is not included in the fixed capital, instead a composting fee was used. The assumptions regarding the techno-economic analysis are shown in Table III.

Table III: Assumptions regarding the techno-economic analysis

Production hours	8760	h/y
Currency conversion	93	Tk/€
Electricity price	8.6	Tk/kWh
Operator salary	10,000	Tk/month
Operators AD plant	2	shift positions
	3	op./shift position
Supervision and overhead	25%	of op. salary
Total labour costs	0.9	M Tk/y
Fixed capital	28	M Tk
Maintenance	3%	of fixed capital/y
Financing	10%	of fixed capital/y

6 RESULTS

Based on the assumptions, the annual costs and revenues were estimated. The results are shown in Table IV. The costs for the wastewater discharge and the revenues of the compost are assumed to be marginal and therefore not included. The financing costs have a significant contribution to the total costs. It should be noted that the plant is amortized in 10 years, which means that the financing costs are only applicable in the first 10 years.

Table IV: Estimated annual costs and revenues for current waste disposal and waste disposal incorporating an AD plant for a fresh market generating 18 m^3 waste/day in Bangladeshi Tk and €

	Current waste disposal		**Anaerobic digestion plant**	
	M Tk/y	k€/y	M Tk/y	k€/y
Market waste				
Collection	7.1	76	7.1	76
Transport	3.4	37		
Landfill	1.3	14		
Non-biodegradable waste				
Transport			0.5	6
Landfill			0.2	2
Biodegradable waste				
Labour			0.9	10
Maintenance			0.8	9
Financing			2.8	30
Solid fraction digestate				
Transport			0.3	4
Composting			0.1	1
Wastewater discharge				
Sewer			-	-
Revenues				
Electricity			3.8	41
Compost			-	-
Total costs	**11.8**	**127**	**8.9**	**96**

Compared to the current collection, transport, and landfill costs, the total costs of the anaerobic digestion plant are estimated to be 24% lower. The transport and landfill costs are strongly reduced. The labour, maintenance, and financing costs of the anaerobic digestion plant are nearly covered by the significant revenues from the offset of electricity.

7 DISCUSSION

As land area in the Dhaka Metropolitan Area is scarce, the required area for the AD plant on or near to the secondary transfer station is an issue to be solved. A local company should be invited to make a more detailed design. In this design, minimizing required area should be an important aspect. Furthermore, a demonstration plant is required to gain experience with this new waste processing technology, to overcome operational issues, and to prove the technical and economic feasibility, which were accessed in this study.

8 CONCLUSIONS

The existing waste management setup of Dhaka City necessitates identification and implementation of alternate solutions to landfilling. The survey of the current waste management systems of DNCC and DSCC showed that the current set up is both costly and unsustainable in the long run.

Decentralised processing of biodegradable waste of fresh markets by anaerobic digestion seems economically interesting. Compared to the current collection, transport, and landfill costs, the total costs of waste disposal incorporating an AD plant are estimated to be 24% lower. The transport and landfill costs are strongly reduced. The labour, maintenance, and financing costs of the anaerobic digestion plant are nearly covered by the revenues from the offset of electricity. Moreover, it reduces greenhouse gas emissions and it improves the circularity.

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The project aims to improve the food system in the Dhaka metropolitan area to increase access of all inhabitants of Dhaka to affordable and qualitatively good food and offers supports to the city corporations.

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