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Energy, Economic, and Environmental benefit Analysis of organic fraction of MSW through anaerobic digestion technology in Bangladesh

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ABSTRACT

MSW management is one of the main challenges of developing countries like Bangladesh as it is created an environmental problem. The purpose of this paper is to generate municipal solid waste (MSW) generation as well as electricity generation potential from it in Bangladesh for several years through anaerobic digestion (AD) technology. The economic feasibility of the proposed anaerobic digestion project is analyzed by means of net present value (NPV), payback period (PBP), and Levelized cost of energy (LCOE). The NPV of the project is 54760.67 million US$. Additionally, the IPBP of the projects is 9.78 years. The LCOE of electricity generation is 0.07 $/kWh. The economic feasibility of the proposed anaerobic digestion project is analyzed by means of net present value (NPV), payback period (PBP), and Levelized cost of energy (LCOE). It was found that the MSW generation rate is about 61.81 Mt/year which is capable to produce 4365.35 MW/year. The NPV of the project is 54,760.67 million US$. Additionally, the IPBP of the projects is 9.78 years. The LCOE of electricity generation is 0.07 $/kWh. On the other hand, the reduction of the CO_2 emission footprint of the projects is 150.09 Mt through the projects.

Keywords: Municipal solid waste (MSW), anaerobic digestion (AD), electricity generation, economic feasibility, CO_2 reduction.

1. Introduction

The management of Municipal solid waste (MSW) is a challenging task for developing as well as under-developed countries nowadays. MSW management is a major problem in developing countries like Bangladesh, as it is related to cost [1]. Moreover, people give little experience in waste management. The generation of MSW is proportionally related to population growth and urbanization. The mismanagement of MSW can cause huge environmental pollution and various hazardous effects on the inhabitants. The annual increase in population is 6 % which is concentrated mostly in six major cities, i.e., Dhaka, Rajshahi, Chattogram, Barisal, Sylhet, and Khulna. The per capita generation of waste is about 0.5 kg/day, but only 0.2 kg/day is carried to disposal sites and the other 0.3 kg/day is disposed of locally which creates environmental as well as health problems [2]. The government of Bangladesh is trying to efficient MSW management for ensuring eco-friendly cities. There are various techniques for MSW to energy generation. Among them, AD is sustainable and eco-friendly for MSW treatment. AD is a process where the organic matter is converted into biogas and digestate in the absence of oxygen. It provides multiple environmental benefits including green energy production, organic waste disposal, GHG reduction, environmental protection, etc.

The main objectives of this research is to forecast the MSW generation as well as electricity generation potential in Bangladesh. This work is also provided a suitable guideline for waste management and convert it into useful energy. Moreover, techno-economic analysis of the proposed anaerobic digestion plant has been analyzed and CO_2 reduction as well as organic fertilizer generation potential has also been evaluated.

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2. Materials and method

2.1 Methane and electricity generation potential from FW

The AD plant for biogas production from MSW is presented in Fig. 1. The MSW is stored in the storage tank, then after pretreatment, it is sent to the slurry tank. After that, it is then passed to the digester tank. From the digester, we get the biogas as well as digestrate for fertilizing application.

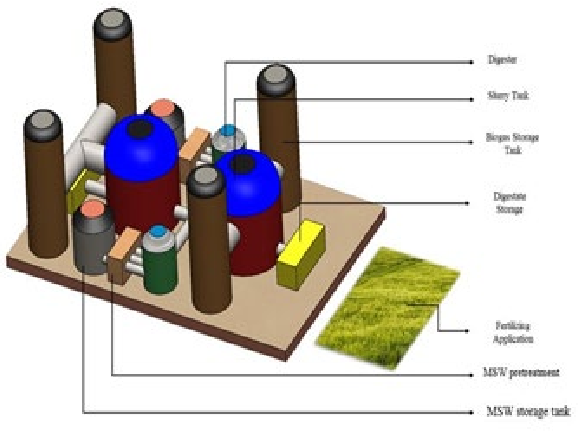

Fig. 1 Anaerobic digestion plant for treating MSW

This section is used to present the methods to estimate the food waste generation potential, biogas (methane) generation potential, and electricity generation potential of biogas from MSW. FW generation potential (t/y) of Bangladesh was estimated using Eq. (1) [3].

$$SW_{est}(y) = \frac{P_O(\mathrm{y}) * \mathrm{X} * WG_{pc}(\mathrm{y})}{1000}$$

$$or, SW_{est}(y) = \frac{\{P_{(old)} * (1+P_{rate})^y\} * \mathrm{X} * \{WG_{pc\,(old)} * (1+GDP_r)^y\}}{1000} \quad (1)$$

Where, $P_o(y)$ is the predicted population of Bangladesh, X is the number of days (365) in a year, $WG_{pc}(y)$ is the projected per capita food waste generation rate of Bangladesh, and y is the period of calculation (20 y). $P_{(old)}$ is the present population and P_{rate} is the population growth rate of Bangladesh. $WG_{pc\,(old)}$ is the current per capita FW generation rate of Bangladesh, and GDP_r is the per capita gross domestic product (GDP) growth rate of Bangladesh. This section determines the electricity generation potential of actual methane produced from the food waste fed to the anaerobic digester. The electricity generation potential (kWh/y), as well as the size of the anaerobic digestion plant (kW), was determined using Eq. (2-3) [4].

$$AD_{EP} = \frac{CH_{4(act)} \times HV_{CH_4} \times GEN_{eff} \times CAP_{fact}}{3.6} \quad (2)$$

$$AD_{plant} = \frac{AD_{EP}}{D_{hr} \times X} \quad (3)$$

HV_{CH_4} is the methane heating value and is given as 37.2 MJ/m^3 [5], GEN_{eff} is the electricity generation efficiency of biogas-fired generator and is provided as 26% [6], CAP_{fact} is the capacity factor and is given as 85% [7], and 3.6 is the conversion factor from MJ to kWh. Besides, the size of the AD plant was determined in kW, assuming that the projects operate throughout the year. Here, D_{hr} is the number of hours in a day (24 h), and X is the number of days in a year (365 d).

Therefore, the digester's actual methane production can be estimated using Eq. (4-6) [8].

$$CH_{4\,(act)} = \frac{CH_4\ (kg)}{0.717 \left(\frac{\mathrm{kg}}{m^3}\right)} * FW_{AD} * OW_{syn} \quad (4)$$

$$FW_{AD} = SW_{est}(y) * W_{col} * FW_{AD} \quad (5)$$

$$or,\ FW_{AD} = \frac{P_o(\mathrm{y}) * \mathrm{X} * WG_{pc}(\mathrm{y})}{1000} * W_{col} * COMP_{FW} \quad (6)$$

Where 0.717 (kg/m^3) is the density of methane. FW_{AD} is the quantity of FW that can be fed in the digester, OW_{syn} is the fraction of organic matter which is utilized for cell tissue synthesis and taken as 85% [9], W_{col} is the waste collection efficiency of Bangladesh taken as 40-80 % [10], and $COMP_{MSW}$ is the organic matter content in MSW of Bangladesh and given as 74 % [10].

2.2 Economic feasibility analysis of the project

The economic feasibility of a project means the net benefit obtained from a project. A project is said to be economically feasible if the economic advantage obtained from a project is greater than the economic cost. The economic feasibility of this proposed project was calculated using total life cycle cost (TLCC), net present value (NPV), investment payback period (IPBP), and Levelized cost of energy (LCOE). The project's useful life is the same period (i.e., from 2023 to 2042) the organic waste availability study was carried out. The total life cycle cost of a project includes the total cost of ownership and operation. It is the function of initial investment cost (INV_{cst}) as well as fixed and variable operation & maintenance costs ($O\&M_{cst}$) in each year [11]. NPV of a project is the addition of both positive and negative cash flow. If the NPV is positive, it is called economically feasible but negative cash flow represents an infeasible project [11]. IPBP of a project is the period when the investments of the project start to pay off. LCOE is an important economic indicator for measuring the visibility of the project which determines the minimum cost of electricity generation of the project (\$/kWh) at the project breaks even [11]. The, INV_{cst}, $O\&M_{cst}$ and $TLCC$ of the project is calculated using Eq. 7-9 [11][12].

$$INV_{cst} = \$4339 \times AD_{plant} \quad (7)$$

$$O\&M_{cst} = \{0.03 * INV_{cst}\} + \{0.005 \times AD_{EP}\} \quad (8)$$

$$TLCC = INV_{cst} + \sum_{n=1}^{y} \frac{O\&M_{cst}}{(1+\alpha)^n} \quad (9)$$

The specific cost of the anaerobic digestion plant is considered 4339 \$/kW and the percentage of fixed operation and maintenance costs of the plant is assumed as 3% whereas the percentage of plant power generation is assumed as 5%The economic period of the project is considered to be 20 y and the nominal discount rate α is 10%.Tax paid on profit (T_{paid}), Profit (AD_{profit}), Revenue (AD_{rev}) and Net Cash Flow (L_n) is calculated using Eq. 10-13 [11].

$$T_{paid} = AD_{profit} \times T_r \quad (10)$$

$$AD_{profit} = AD_{rev} - O\&M_{cst} \quad (11)$$

$$AD_{rev} = AD_{EP} \times r_{fit} \quad (12)$$

$$L_n = AD_{rev} - O\&M_{cst} - INV_{cst} - T_{paid} \quad (13)$$

The profit gained from the project is represented as AD_{profit} and marginal tax rate, T_r as 25%. The revenue earned from the project is represented asAD_{rev}. The feed-in tariff (r_{fit}) of biomass source electricity generation for Bangladesh is considered as 0.106 \$/kWh.

The Net Present Value (NPV), Investment Payback Period (IPBP) and Levelized Cost of Energy (LCOE) are calculated using Eq. 14-16 [11][13].

$$NPV = \sum_{n=0}^{y} \frac{L_n}{(1+\alpha_r)^n} = INV_{cst} + \frac{L_1}{(1+\alpha_r)^1} + \cdots \frac{L_y}{(1+\alpha_r)^y} \quad (14)$$

Where, α_r is the annual real discount rate and calculated using Eq. $\alpha_r = [\frac{1+\alpha}{1+ln_r}]$

$$IPBP = \frac{TLCC\ (\$)}{AD_{profit}\left(\frac{\$}{y}\right)} \tag{15}$$

$$LCOE = [\frac{TLCC}{AD_{EP}} \times \frac{\alpha(1+\alpha)^y}{(1+\alpha)^y - 1}] \tag{16}$$

The net cash flow of the project is represented as L_n and the annual real discount rate as α_r. Besides, NPV represents the net present value of the project. The nominal discount rate, α of the project is taken as 10 % as well as the inflation rate, ln_r as 9.3%.

2.3 CO_2 reduction potential

Biogas could reduce carbon dioxide emissions by replacing fossil fuels such as coal. It was assumed that biogas is used to generate electricity, and the carbon dioxide emissions reduction by replacing standard coal with biogas to generate an equivalent amount of electricity. But, here only CO_2 emissions from std. coal and biogas to generate electricity are considered. CO_2 emissions reduction, CO_2 emissions from biogas combustion, CO_2 emissions from standard coal combustion, and standard coal consumption for the equivalent amount of electricity are calculated by Eq. (17)-(20) [14].

$$\Delta M_{CO_2} = M_{coal} - M_{biogas} \tag{17}$$

$$M_{biogas} = 1\ m^3 biogas * \left((x\%\ CH_4 * \rho_{CH_4} * 2.75) + \left(\rho_{CO_2} * (1 - x\%\ CH_4)\right)\right) \tag{18}$$

$$M_{coal} = W_{coal} * F_{coal} \tag{19}$$

$$W_{coal} = (3600 * AD_{EP})/(\eta_c * Q_{coal}) \tag{20}$$

where ΔM_{CO_2} is the carbon dioxide emission reduction (tonne CO_2),M_{biogas} is the carbon dioxide emission from biogas combustion (tons), M_{coal} is the carbon dioxide emission from standard coal combustion (tons), ρ_{CH_4} is the density of methane and given as 0.65 kg/m^3, ρ_{CO_2} is the density of CO_2 and given as 1.80 kg/m^3, x % CH_4 is the volumetric percentage content of methane in the biogas. It has been found that the total CO_2 emissions from 1 m^3 biogas combustion is the summation of CO_2 content in biogas as well as from the combustion of methane.. W_{coal} is the standard coal consumption for the equivalent amount of electricity generation (tons),F_{coal} is the carbon dioxide emission coefficients of standard coal and given as 2.4925 t CO2/t standard coal, AD_{EP} is the electrical energy potential (MWh/year), η_c is the engine-generator efficiency of coal and is given as 30%, Q_{coal} is the calorific value of standard coal (MJ/tonne) and is given as 29,307 MJ/t. By considering these issues the compost fertilizer's potential from FW is evaluated. Considering that the price of compost fertilizer is BDT 6/kg, the annual revenue from compost fertilizer is evaluated [15]. Besides, compost fertilizers are also produced from the AD of FW as a byproduct. 250-tonne compost fertilizers can be produced from 1,000 tons of MSW [16].

3. Results and discussions

The MSW generation potential as well as biogas generation potential are presented in Fig. 2. It has been found that biogas generation potential for the year 2023 is 11585.79 million m^3 and for the year 2042 is 16745.24 million m^3. The MSW generation for the year 2023 is 42.76 Mt but it has increased by 61.80 Mt for the year 2042. The electricity generation potential from biogas is presented in Fig. 3.

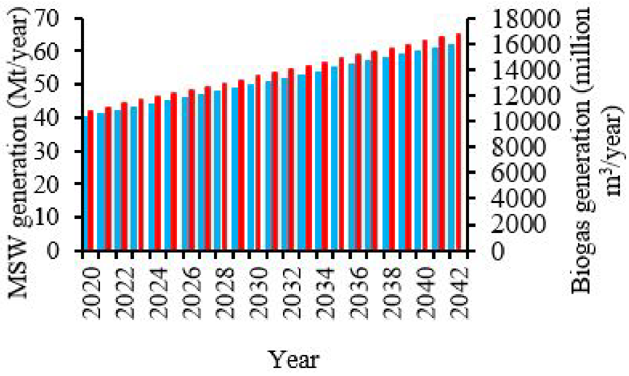

Fig.2 MSW and Biogas generation potential

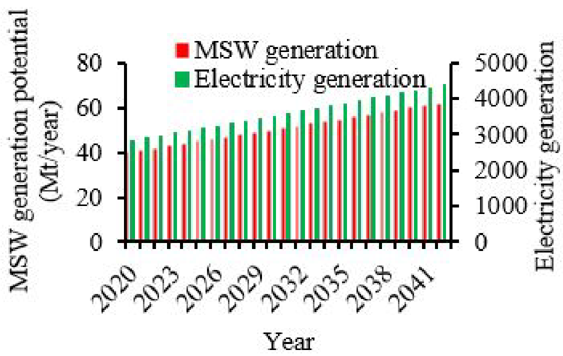

Fig.3 MSW and electricity generation potential

It has been found that it is possible to generate 4365.36 MW of electricity at the year 2042 by using 61.80 Mt MSW. The fertilizer generation potential and revenue from it are presented in Fig. 4. It has been found that the fertilizer generation potential by the year 2042 is about 1406.71 Mt and the revenue from it is about 1406.71 million US$. The CO_2 reduction potential by replacing the traditional energy sources with electricity from the AD of MSW. The CO_2 reduction potential is presented in Fig. 5. By the year 2042, it is possible to reduce 8.88 Mt CO_2.

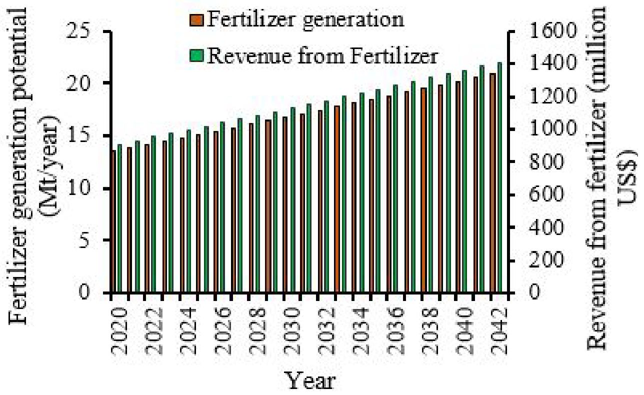

Fig.4 Fertilizer generation and revenue from it in various year

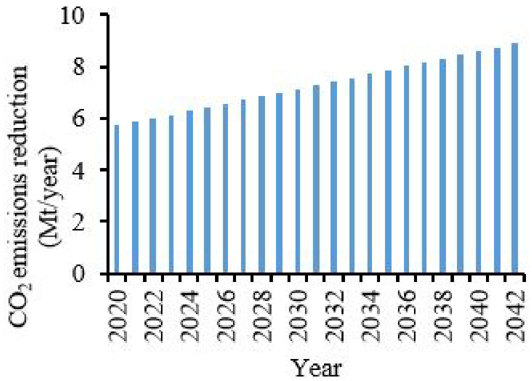

Fig.5 CO_2 emissions reduction potential

The techno-economic potential of the 20-year project (2023 to 2042) is presented in Table 1. It has been found that NPV is 54,760.67 million US$ which is positive i.e the project is economically feasible. Additionally, the IPBP of the project is only 9.77 years.

Table 1 The result of the economic feasibility analysis of the AD plant for Bangladesh

Components	**Unit**	**Value**
Cost		
Initial investment cost	million US$	18,941.29
Operation & maintenance cost	million US$	14,594.48
Total Life Cycle Cost	million US$	25,074.82
Tax paid on profit	million US$	12,822.89
Benefits		
Net present value	million US$	54,760.67
Investment Payback Period	Y	9.77
Levelized Cost of Energy	$/kWh	0.077
Revenue	million US$	65,886.07
Profit	million US$	51,291.58
Net Cash Flow	million US$	38,468.69

4. Conclusions

The anaerobic digestion of organic fraction of MSW waste provides satisfactory outcomes due to its physicochemical properties. It has been seen that the electricity generation potential at the initial stage (The year 2023) is 3020.33 MW and at the ending period of the project (The year 2042) is 4365.36 MW.

This amount of electricity is obtained by burning 10.83 and 15.65 million tons of coal (for the year 2023 and 2042). The CO_2 emission from this amount of coal is about 27 and 39 million tons respectively for the year 2023 and 2042 which are higher than CO_2 emissions from biogas combustion and also responsible for environmental pollution as well. The amount of CO_2 reduction for the year 2023 is about 6.15 million tons if we generate electricity from the AD of MSW instead of coal burning. The total revenue earned from compost fertilizer is about 973.28 million USD for the year 2023. Finally, without any hesitation, it can be said that AD of MSW is an attractive technique that is capable of generating a huge amount of energy for the future.

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