Eco. Env. & Cons. 27 (February Suppl. Issue) : 2021; pp. (S62-S70)
Copyright@ EM International
ISSN 0971–765X

Economic feasibility analysis of biogas plant integrated with municipal waste management system

Prasanna Kumar L. Duvvi* and Senthil Kumaar J.S.

Mechanical Engineering, Madanapalle Institute of Technology & Science, Madanapalle, Andhra Pradesh, India

(Received 3 July, 2020; Accepted 7 August, 2020)

ABSTRACT

Handling and avoiding food waste are one of the major issues in many developing countries and India is no exception. Around 67 million Tons of food is wasted in India every year. Most of this food waste ends up in landfills or composting facilities. Municipal solid food waste in landfills release methane into the atmosphere and this methane acts as a potent greenhouse gas with an impact on global warming roughly 20 times stronger than carbon dioxide. Along with the soil contamination due to landfills and the methane gas released into the atmosphere, usage of fossil fuels for power generation and transportation releases Tons of CO_2 into the atmosphere. Average utility emission per kWh of energy generation is 0.6 Kg of carbon dioxide and 3 Kg of CO_2 is released into the atmosphere for every litre of gasoline combusted. Conversion of waste food into biogas is the best alternative and rationale for the bureaucracies to adopt this process. In this report, we calculated the economic feasibility of running a biogas plant in the town of Madanapalle, located in the state of Andhra Pradesh, India. Madanapalle produces 25000 tons per year of biodegradable food waste. The capital budgeting methods used to determine if it makes sense to invest funds in the Biogas plant project are the Net Present Value (NPV), internal rate of return (IRR) and Pay-off period. The produced biogas is either used for generation of electricity or converted into CNG. NPV calculations are provided for an optimum use of CNG conversion percentage for earning profits. The effect of Feed-in-tariff, tipping fee and CNG conversion percentage on NPV is reported.

Key words : *Biogas, Anaerobic digestion, Feasibility analysis, Life cycle analysis, Waste management*

Introduction

According to the Food and Agriculture Organization, approximately 1.3 Billion tons, which is one-third of the edible food produced in the world, gets wasted. Food wastage amounts to a loss of approximately US$ 680 billion in industrialized countries and US$ 310 billion in developing countries (FAO, 2016). Around 67 million tons of food is wasted in India every year. This is approximately 1/3rd of India's annual production and has a value of more than US$14 billion (Haq, 2016). Statistics provided by the United Nations Development Program states that India wastes 40 percent of the food it produces. This food wastage in India is either due to over buying or lack of proper refrigeration storages or due to logistic issues (Khanna, 2016). It has been widely published that only 10 percent of foods get cold storage facility in India. Along with the lack of cold storage facilities in rural India and due to the lack of proper supply chain management, India has become a significant contributor toward food wastage (Ghosh *et al.*, 2015). Viswanadham (2012) mentions in his study that a lack of cold chain infrastructure and also a food processing industry, about 20 percent of all foods produced, valued at $7 billion, is wasted (Viswanadham, 2012).

Huge land, along with pesticides and other chemicals that are detrimental to the environment are also used to cultivate that wasted food (Hall *et al.,* 2009). In addition to this, the transportation of the food waste to landfills and the equipment necessary to process them result in additional burning of fossil fuels (Franchetti, 2009). Also, food waste that has been disposed of in landfills becomes a major source of methane emissions. Landfills account for 17.5% of all anthropogenic methane emissions in the United States (EPA, 2011). Methane is a potent greenhouse gas, with an impact on global warming roughly 20 times stronger than carbon dioxide (NRDC, 2012). Along with the direct emissions from production and transportation, food waste is a significant cause of global warming (IPCC, 2007).

Anaerobic Digestion (AD) is not a new technology. Emission of flammable gas from rotting waste was first recorded in the 17th century. By the early 1900s scientists had identified the microorganisms responsible for the various steps in the anaerobic digestion process. In 1897, the first known anaerobic digester was developed in India when a colony of lepers used gas from human waste for their lighting needs (Abbasi *et al*., 2012).

Abbasi et al., (2012) describes various designs used to treat manures in the developing world (Abbasi *et al*., 2012). The design most commonly used in India and China, is known as the "floating-dome biogas plant". In the United States the primary designs used for large-scale biogas production from animal waste are "plug flow". Other common reactor designs are Kompogas (one-stage dry), BTA (multi-stage), Valorga (one-stage dry), DRANCO (one-stage dry) and Waasa (one-stage wet). The type of digester to be used is dependent on many factors, such as, quantity and type of feed, availability of wastewater etc., (Abbasi *et al*., 2012). Many plants for the AD of Municipal Solid Waste (MSW) suffer from technical or financial difficulties. One of the issues is the relatively long digestion time of food waste. This results in larger digester requirements and therefore higher capital costs. This issue is prevalent in many kinds of AD substrates, particularly sewage sludge, but is particularly so in the case of food waste, which has higher amounts of organic carbon particulates (Eastman and Ferguson, 1981). Appels *et al*., (2011) concludes that the presorting necessary to process non-segregated waste greatly increases costs (Appels *et al.,* 2011). A lack of source-separated organics (SSO) programs, along with the above-mentioned technical challenges, appears to be a greater barrier to AD plants that process organics, especially in the absence of comparable government support. AD plants become economically feasible once tipping fees is cheaper for the waste producers to dispose at an AD facility than at a landfill (Spencer, 2010). Ultrasonication, that assist in the digestion of sewage sludge, can increase the methane yield of food waste digestion when performed prior to or during the first stage of a two-stage AD process (Elbeshbishy and Nakhla, 2011). Immense research has also been performed on the co-digestion of food waste with other wastes such as sewage sludge (Kim *et al*., 2004; Li , 2010) dairy manure (El-Mashad and Zhang, 2010) and meat industry wastes (Buendia *et al*., 2009). Zhang *et al.,* (2011) found that co-digestion of food waste with pig farm wastewater increased the yield of methane (Zhang *et al*., 2011).

Some municipalities around the world, example South Korea, are moving away from the landfilling of food waste and dedicating state resources, such as loans, to help develop alternatives, including AD (MDEP, 2013). Governments should provide funding to AD projects or technologies in the form of direct subsidies, soft loans or guaranteed electricity generation revenues in the form of Feed-in Tariffs. The U.S. Energy Policy Act of 1992 offers similar subsidies for alternative energy (CIWMB, 2006). Life cycle analysis (LCA) is one of the most widely employed tools to compare between various available methods for a particular problem. Cherubini and Francesco compared four different methods for the disposal of MSW: landfill with and without biogas collection, incineration, and biogas production from sorted organics. The authors used various assessment methods for evaluating the economic impact. Foley *et al.,* (2010) compared various methods for waste water treatment. The authors compared conventional AD to two other methods, microbial fuel cell (MFC) treatment and microbial electrolysis cell (MEC), and found the MEC treatment to be more beneficial than AD (Cherubini *et al*., 2009). South Korea banned the landfilling of food waste in 2005. Kim *et al.* (2004) from South Korea compared the environmental impacts of AD, dryer-incineration and co-digestion with sewage sludge for food waste produced in South Korea. The authors concluded that dryer-incineration was found to be the best alternative, contrary to many other studies (Foley *et* *al.*, 2010). Levis and Barlaz, (2011) utilized LCA to compare AD with composting and landfilling of food waste. Their studies concluded that AD is the most environmentally beneficial method for handling food waste (Kim *et al.*, 2004).

Methodology, data collection and Analysis

Project study area description

Madanapalle is a municipality, Mandal and also revenue headquarters of Chittoor district in Andhra Pradesh state and located in southern part of India (13° 33' 0.0000'' N and 78° 30' 0.0000'' E). The economic indicators described in this section will be employed to determine the feasibility of constructing a Biogas plant in the city of Madanapalle. The projected population for Madanapalle and the average per-capita generation of household food waste is shown in Table 1.

In this study, the financial possibility of the biogas production plant was based on cash flow and acquired benefit-based analysis. It was expected that the task is an investment movement where capital assets are used to produce an advantage from which benefits will be collected over an all-inclusive timeframe for example the monetary feasibility of the biogas plant depended on cash flow. The applied processes are constructed as flow diagram shown in Figure 1 below.

In this section, we elaborate the methods used to determine whether capital assets are worth investing in running the Biogas plant using Municipal Solid Waste. The capital budgeting methods used to determine if it makes sense to invest funds in the Biogas plant project are the Net Present Value (NPV), Internal rate of return (IRR) and Pay-off period. The formulae used for calculating each of these economic parameters are provided below in Equations 1, 2 and 3 respectively. Based on the biogas plant design and capacity, total investment required and annual cost that would be incurred was calculated. It was assumed that the net cash flow would change every year to account for the inflation changes. This leads to a non-uniform annual cash flow and will be discounted to the present value using an 8% discount rate. For every set of variables, such as the tipping fee, CNG conversion percentage, feed-in-tariff, capital grants, volatile solids destruction efficiency, tonnage of food waste, energy charges, CNG charges etc. NPV, IRR and Payback period is calculated. This leads to a multi-variable analysis which yields different NPV, IRR and Payback periods as the variables are changing. The developed model calculates all the mentioned economic parameters seamlessly. The financial viability decision can be made based on the calculated NPV, internal rate of return and payback period.

$$NPV = \left(\frac{CashFlow}{(1+i)^t}\right) - (Initial\ Investment) \qquad (1)$$

Where

i = Required return or Discount Rate

t = Number of time periods

$$NPV = \left(\frac{CashFlow}{(1+IRR)^t}\right) - (Initial\ Investment) \qquad ..\ (2)$$

Where

IRR = Internal Rate of Return

t = Number of time periods

$$Payback\ Period = \frac{Initial\ Investment}{Average\ Annual\ Net\ Cash\ Flow}$$

Cash flow Investment Analysis

To calculate the NPV we will need to determine all future cash flows over the entire life of the invest-

Table 1. Projected Population and Per-Capita Food Waste Generation in Madanapalle

Year	Projected population	Per capita per year Generation with 1.3% Increase per capita per year As per MoUD guidelines	Waste quantity in MT/Day	Per capita generation (in Kg/Day)	Total waste quantity in MT/Year
2015	151298	151.60	62.84	0.4153	22936
2020	170509	161.71	75.54	0.4430	27573
2025	190983	172.50	90.26	0.4726	32944
2030	212718	184.00	107.24	0.5041	39141
2035	235715	196.28	126.76	0.5378	46266
2040	259973	209.37	149.13	0.5736	54432
2045	285494	223.34	174.69	0.6119	63763

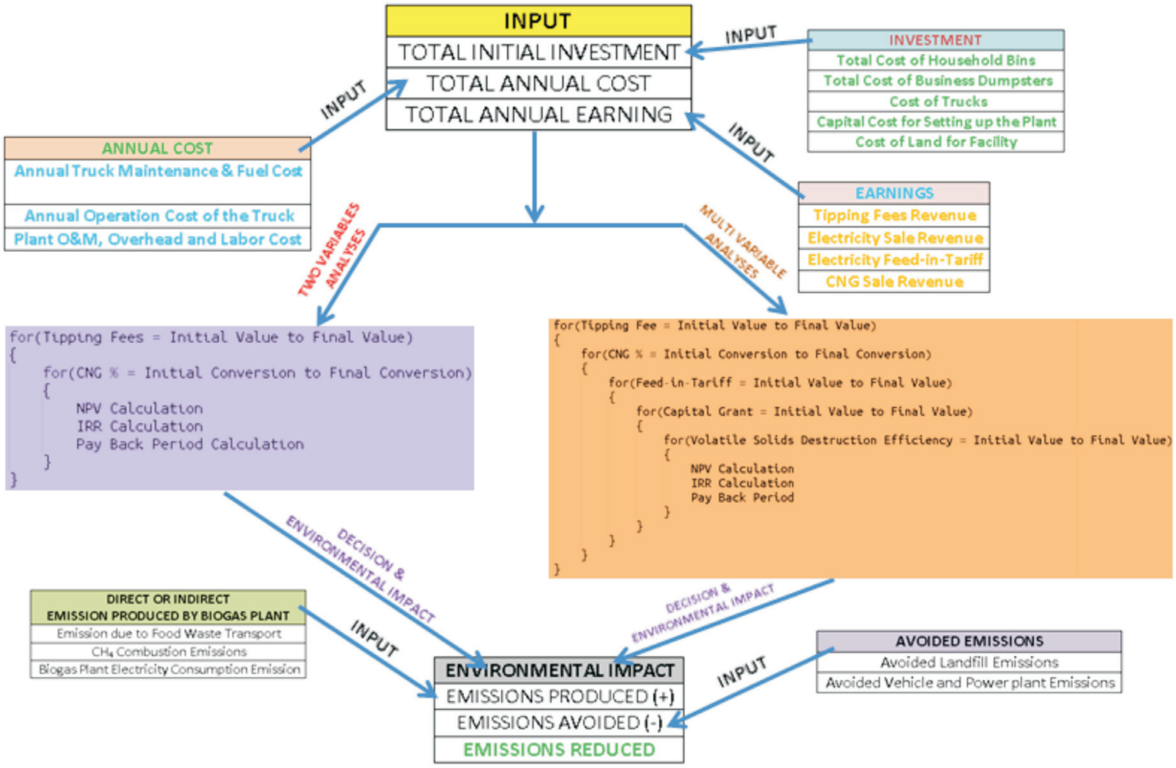

Fig. 1. Process flow diagram.

ment discounted to the present. In the present analysis, a 15 year investment period is considered. Cash flow for all future years is the difference between the earnings during that year and the costs incurred during the same year. Total Investment will be subtracted from the sum of all the cash flows discounted to the present to calculate the NPV. In order to use this economic indicator, we will need to determine the total investment necessary to construct the entire plant, cost of operating the plant and the benefits that are expected every year. Table 2, 3 and 4 describe the total investment required, annual cost to run the plant and the annual revenue that can be generated respectively.

This paper utilizes the method by Whyte and Perry (2001), which analyses empirical data from existing AD MSW facilities in order to find average O & M costs and Capital costs for setting up the plant based on annual per-ton throughput. The equations mentioned in Tables 2 and 3 are accounted for 2% inflation since the papers publication in 2001. In the biogas digester, the MSW is converted to biogas. Annual CH4 production is determined by the below equation. Equations 4, 5 and 6,

Table 2. Investment Required for Constructing the Biogas Plant

Total Cost of Household Bins	(Bins per Household) (Number of Household) (*Cost* per Household Bin)
Total Cost of Business Dumpsters	(Number of Commercial Bins) (*Cost* per Commercial Bins)
Cost of Trucks	(Number of Trucks Required) (*Cost* per Truck)
Capital Cost for Setting up the Plant	$((8 \times 10^{-6} \times tpy^2)-(1.3561 \times tpy)+(80678))$(*Annual* Food Waste Recovery)
Cost of Land for Facility	Rs. 30000000

Table 3. Annual Cost to Run the Biogas Plant

Annual Truck Maintenance & Fuel Cost	(Rs. 20/(Ton - Km))(*Annual* Kilometers Travelled) (*Average* Truck Load)
Annual Operation Cost of the Truck	(*Hourly* Wage) (Time/Run) (Runs/Day) (365)
Plant O&M, Overhead and Labor Cost	$((2.2 \times 10^{-7}) \times tpy^2) - (0.0373 \times tpy)+(2276.5))$(Annual Food Waste Recovery)

Table 4. Annual Earnings from the Biogas Plant

Tipping Fees Revenue	(*Annual* Food Waste recovery (in Tons) (Tipping Feeper Ton)
Electricity Sale Revenue	(*Annual* Electricity Production) (Price of Electricity)
Electricity Feed-in-Tariff	(*Annual* Electricity Production) (Feed - In - Tariff Price)
CNG Sale Revenue	(*Annual* CNG Production (in Kg)) (Price of CNG (per Kg))

along with the displayed values for each variable, are taken from the EPA CoEAT model.

$$Annual\ CH_4 Production = (DFWR)(TS\%)\left(\frac{VS}{TS}\right)\left(\frac{BG}{VS}\right)(VSDE)\left(\frac{CH_4}{BG}\right)(365) \quad ..\ (4)$$

Where

DFWR = Daily food waste recovery (Kg)

TS% = Total solids percentage (30%)

$$\left(\frac{VS}{TS}\right) = \frac{Volatile\ Solids}{Total\ Solids} = 89\%$$

$$\left(\frac{BG}{VS}\right) = Biogas\ per\ volatile\ solids = 0.936$$

VSDE = Volatile solids destruction efficiency = 80%.

$$\left(\frac{CH_4}{BG}\right) = Methane\ to\ biogasratio = 60\%$$

Annual Electricity Production

$= (Annual\ CH_4\ Production)\ (HVM)(HVM)(EHR)(\eta)$ .. (5)

Where

HVM = Heat value of Methane =37668.8kJ/m^3

HER=Energy to Heat ratio = 0.000277kWh/kJ

η = Generator Efficiency = 25%

To increase the profits, it will be required, as shown in the next section, to convert some of the Methane produced to CNG. While calculating the revenue, the percentage of conversion will be taken into account. Equation 6 below provides the procedure to determine the annual CNG production for a 100% conversion of methane.

$$Annual\ CNG\ Production = (Annual\ CH_4 Production)(CE)\left(\frac{HVM}{HVG}\right) \quad ..\ (6)$$

Where

CE = Conversion Efficiency = 80%

HVG = Heating value of Gasoline=44000kJ/Kg

Biogas revenue is the sum of electricity revenue and CNG revenue. The equation to calculate the Biogas revenue is provided by Equation 7.

Biogas revenue

=Annual Electricity revenue (1–CNG%)

+(Annual CNG revenue (CNG%) .. (7)

Where

CNG% = Percentage of Biogas used to produce CNG

In the present analysis, MSW generated from Household and Commercial establishments is considered. Table 6 shows the commercial establishments and their waste generation per day. Considering 74134 households, the total waste generated from both household and commercial establishments per day in the city of Madanapalle is 68.32 metric Tons. This amounts to approximately 25000 Tons per Year (tpy). All the calculations are based upon the 25000 tpy capacity.

Table 6. Commercial Establishment Food Waste Generation

Establishments	No of Units	Average Waste Generation Factor In Kg	Total Waste Generated (TPD)
Commercial Shops	1523	3.2	4.87
Hotels/Lodges	9	5.6	0.05
Restaurants	3	48	0.14
Schools	5	17.5	0.09
Colleges	2	12.66	0.03
Offices	20	15	0.3
Hospitals/Nursing Homes/Diagnostics	56	30.5	1.71
Vegetable Market/Fish Market	4	600	2.4
Celebration House (Banquet)	3	400	1.2
			10.78

Results and Discussion

Investment and cost analysis for biogas plant

Table 7 provides a summary of the total investment, Annual cost for running the biogas plant and basic annual earnings from the sale of electricity and tipping fees. The formulae used for calculating the initial investment, annual costs and annual earnings are shown in Tables 2, 3 and 4 respectively. The value of Capital Cost per Ton, determined using the equation shown in Table 2 is Rs. 52121.50. Similarly, the value of Plant O and M, Overhead and Labour Cost per Ton calculated using the appropriate equation provided in Table 3 is Rs. 1483.74. Tipping fee per ton is Rs. 2520. The truck driver wages is assumed to be Rs. 72 per hour which is common in India. Cost of household bin and commercial dumpster are taken as Rs. 304 and Rs. 2429 respectively. Although the CNG benefits and Feed-in Tariff are shown in Table 7, they are not included while calculating the basic annual benefits. CNG price of Rs 58 per Kg is used in the entire NPV calculations. Price of electrical energy is taken as Rs. 5.6 per kWh while calculating the annual electricity sale revenue. The total biogas plant is estimated to be spread across a 22 acre facility and the cost of the land is taken as Rs. 30000000.

Simulation of NPV for varying Tipping fee and Feed-in-Tariff

A sample NPV calculation process is shown in Table 8. Although a 15 year period is considered for the calculation, due to space constraint, only 5 year data is shown in Table 8. Inflation rate of 2% is taken while calculating the Net Cash Inflow for each year. Similarly, a discount rate of 8% is taken for all the NPV calculations.

The effect of simultaneously varying the tipping fee and feed-in-tariff on NPV is shown in Figures 2 and 3. Tipping fee is varied from Rs. 2520 to Rs. 6480. Similarly, the feed-in-tariff is varied from Rs. 0 to Rs. 14.4 per kWh. The pink values in Figure 2 are negative and yield a net loss. For the 25000 tpy being considered, it is advised to remain in the blue zone which will yield a net profit.

Although the feed-in-tariff from the government

X →

Y ↓ / Z ↘	2520	2880	3240	3600	3960	4320	4680	5040	5400	5760	6120	6480
0	-762660867	-676500579	-590340290	-504180001	-418019712	-331859424	-2.46E+08	-1.6E+08	-7.3E+07	12781732	98942020	185102309
1.44	-654816604	-568656315	-482496027	-396335738	-310175449	-224015160	-1.38E+08	-5.2E+07	34465706	120625995	206786283	292946572
2.88	-546972341	-460812052	-374651763	-288491475	-202331186	-116170897	-30010608	56149680	1.42E+08	228470258	314630547	400790835
4.32	-439128078	-352967789	-266807500	-180647211	-94486923	-8326634	77833655	1.64E+08	2.5E+08	336314521	422474810	508635099
5.76	-331283815	-245123526	-158963237	-72802948	13357340.5	99517629.2	185677918	2.72E+08	3.58E+08	444158784	530319073	616479362
7.2	-223439551	-137279263	-51118974	35041314.9	121201604	207361892	293522181	3.8E+08	4.66E+08	552003047	638163336	724323625
8.64	-115595288	-29434999	56725289.3	142885578	229045867	315206156	401366444	4.88E+08	5.74E+08	659847311	746007599	832167888
10.08	-7751025	78409263.8	164569553	250729841	336890130	423050419	509210708	5.95E+08	6.82E+08	767691574	853851863	940012151
11.52	100093238	186253527	272413816	358574104	444734393	530894682	617054971	7.03E+08	7.89E+08	875535837	961696126	1.048E+09
12.96	207937501	294097790	380258079	466418368	552578656	638738945	724899234	8.11E+08	8.97E+08	983380100	1.07E+09	1.156E+09
14.4	315781765	401942053	488102342	574262631	660422920	746583208	832743497	9.19E+08	1.01E+09	1.091E+09	1.177E+09	1.264E+09

Fig. 2. NPV values for varying Tipping fee and Feed-in-Tariff

Table 7. Summary of Investment, Annual Cost and Annual Earnings

Investment (Rs.)		Annual Cost (Rs.)		Annual Earnings (Rs.)	
Cost of Household bins	20283062.4	Annual Truck Maintenance and Fuel Cost	5814497.97	Tipping Fees Revenue	62855091.78
Cost of Dumpsters	3947125	Operation Cost of Truck	990413.6437	Electricity Sale Revenue	43707690.75
Cost of Trucks	10500000	Plant O&M, Overhead and Labor Cost	37008268.71	Electricity Feed-in-Tariff Revenue	112391204.8
Capital Cost	1300040483			CNG Revenue	118854426.5
Cost of Land for Facility	30000000				
Total Initial Investment	1364770670	Total Annual Costs	43813180.32	Total Annual Benefits	106562782.5

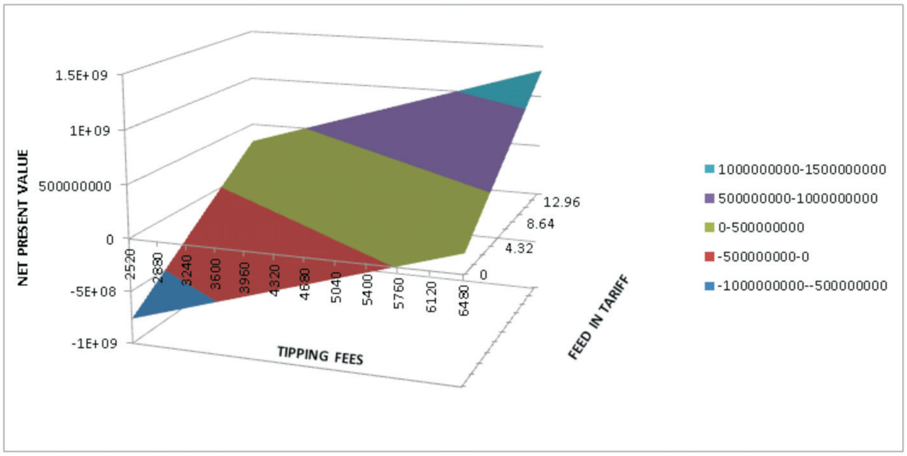

Fig. 3. Effect on NPV with Varying Tipping fee and Feed-in-Tariff

is highly encouraging for the start-up biogas plant operators, it is less likely to receive such huge funds from a developing country like India.

Simulation of NPV for varying Tipping fee and percentage of CNG conversion

Figures 4 and 5 shows the variation of NPV with varying tipping fees and CNG conversion percentage simultaneously. In Figure 4, negative NPV values are shown in pink and positive values are shown in blue. Both tipping fees and CNG conversion percentage are in the control of the plant operator. A minimal increase in the tipping fees with high CNG conversion percentage will yield high benefits. As can be seen from Figure 4, 100% CNG conversion with a tipping fee of Rs. 2880 will yield an NPV of Rs. 4.4 Crores. For this very same combination of 100% CNG conversion and a tipping fee of Rs. 2880, the IRR is calculated to be 8.504%. Payback period for this combination is calculated to be 8.6 years and the discounted payback period is 14.3 years. It can be concluded that the municipal solid waste conversion to biogas would be profitable business even without generous government subsidies. Private investors can increase their profit margin by using higher efficient generators, employing co-genera-

Tipping Fee →

CNG % ↓ / NPV ↘	2520	2880	3240	3600	3960	4320	4680	5040	5400	5760	6120	6480
0	-762660867	-676500579	-590340290	-504180001	-418019712	-331859424	-2.46E+08	-1.6E+08	-7.3E+07	12781732	98942020	185102309
10	-690554297	-604394008	-518233719	-432073430	-345913142	-259752853	-1.74E+08	-8.7E+07	-1271987	84888302	171048591	257208880
20	-618447726	-532287437	-446127148	-359966860	-273806571	-187646282	-1.01E+08	-1.5E+07	70834584	156994873	243155162	329315450
30	-546341155	-460180867	-374020578	-287860289	-201700000	-115539711	-29379423	56780866	1.43E+08	229101444	315261732	401422021
40	-474234585	-388074296	-301914007	-215753718	-129593430	-43433141	42727148	1.29E+08	2.15E+08	301208014	387368303	473528592
50	-402128014	-315967725	-229807436	-143647148	-57486859	28673429.9	114833719	2.01E+08	2.87E+08	373314585	459474874	545635162
60	-330021443	-243861154	-157700866	-71540577	14619711.8	100780001	186940289	2.73E+08	3.59E+08	445421156	531581444	617741733
70	-257914873	-171754584	-85594295	565993.705	86726282.5	172886571	259046860	3.45E+08	4.31E+08	517527726	603688015	689848304
80	-185808302	-99648013	-13487724	72672564.4	158832853	244993142	331153431	4.17E+08	5.03E+08	589634297	675794586	761954874
90	-113701731	-27541442	58618846.3	144779135	230939424	317099713	403260001	4.89E+08	5.76E+08	661740868	747901156	834061445
100	-41595161	44565128.2	130725417	216885706	303045994	389206283	475366572	5.62E+08	6.48E+08	733847438	820007727	906168016

Fig. 4. NPV values for varying Tipping fee and % CNG Conversion

Table 8. Simulation on NPV Calculation

Yearà	**1**	**2**	**3**	**4**	**5**
Cost	43813180.3				
Benefit Using Tipping Fees of Rs 2520	106562783				
Net Cash Inflow	62749602.2	64004594	65284686	66590380	67922187
Net Cash Inflow (PV)	58101483.5	54873623	51825089	48945917	46226699
NPV	-762660867				

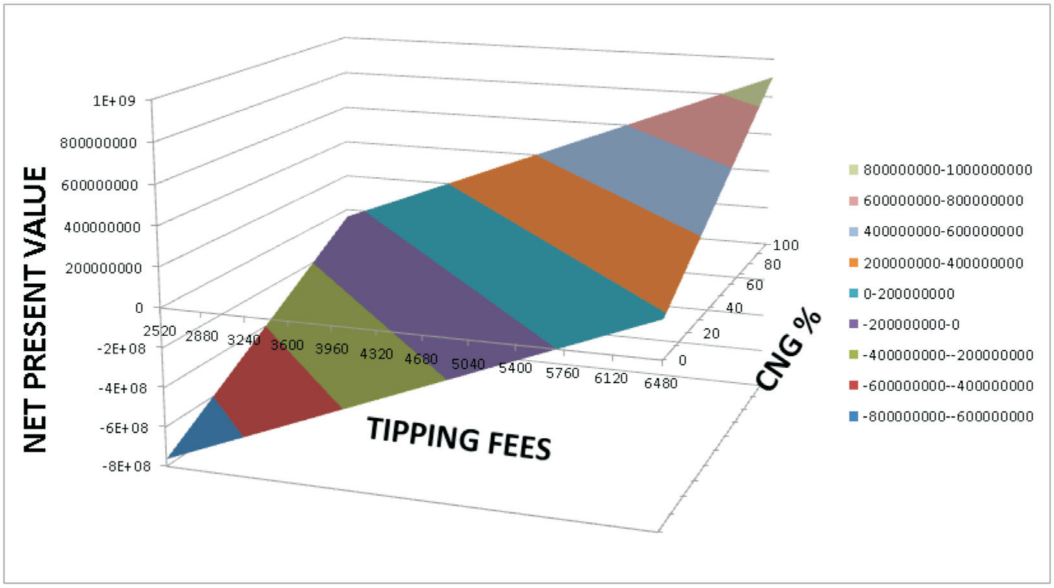

Fig. 5. Effect on NPV with Varying Tipping fee and % CNG Conversion

tion plants to use the thermal energy from the flue gasses and sale of effluent from the digester.

Conclusion

The major goal of this work was to assess the economic feasibility of setting up an anaerobic digestion-based biogas plant using the biodegradable municipal solid waste generated in the city of Madanapalle. A broad perspective was taken so as to include as many variables as possible to assess the economic feasibility of setting up the biogas plant and arrive at a practical solution. A mathematical model was developed which takes in the city population & household details, city waste management data, property tax information, energy data and other government subsidies. The output from the model provides the investment needed, total annual cost for running the plant, annual earnings from the plant, NPV, IRR and payback period for one set of variables. Based on the current data in the city of Madanapalle the economic feasibility of running the biogas plant based on MSW is poor. However, many simulations are run using multi variable analysis to assess the practical and economic feasibility of running the biogas plant in Madanapalle. Some of the factors that greatly increase the economic viability of running the biogas plant in Madanapalle are the increase in Tipping fee, higher utilization conversion percentage of biogas produced to CNG and implementation of feed-in-tariffs. Most of the Indian cities are mandating the use of CNG in public transportation and many vehicles are coming up with new engine designs for using CNG and gasoline interchangeably. Keeping this in mind, the CNG development holds promise as it is a very competitive vehicle fuel. Although the investment costs are higher for handling higher volume of waste, the benefits are proportionally higher. It should be noted that the equations for calculating the capital investment and O&M costs are valid for MSW that are less than 100000 tons per year. Higher benefits are associated with higher volume of waste processing and higher CNG utilization. We conclude that the Municipal Corporation of Madanapalle will yield profit from the biogas plant in Madanapalle operating on MSW by slightly increasing the tipping fee and increase the CNG conversion percentage. Using higher efficient generators and increased volatile solids destruction efficiency is an added benefit.

References

Abbasi, T., Tauseef, S.M. and Abbasi, S.A. 2012. *Biogas Energy*. New York: Springer.

Appels, L., Lauwers, J., Degreve, J., Helsen, L., Lievens, B., Willems, K. and Dewil, R. 2011. Anaerobic digestion in global bio-energy production: Potential and research challenges. *Renewable and Sustainable Energy Reviews.* 15 : 4295-4301.

Buendia, I.M., Fernandez, F.J., Villasenor, J. and Rodriguez, L. 2009. Feasibility of anaerobic co-digestion as a treatment option of meat industry wastes. *Bioresource Technology.* 100 : 1903-1909.

California Integrated Waste Management Board, 2006. Current anaerobic digestion technologies used for treatment of municipal organic solid waste.

Cherubini, F., Bargigli, S. and Ulgiati, S. 2009. Life cycle assessment (LCA) of waste management strategies: Landfilling, sorting plant and incineration. *Energy*. 34 : 2116-2123.

Eastman, J.A. and Ferguson, J.F. 1981. Solubilization of particulate organic carbon during the acid phase of anaerobic digestion. *Journal of Water Pollution Control Federation*. 53 : 352-366.

Elbeshbishy, E. and Nakhla, G. 2011. Comparative study of the effect of ultrasonication on the anaerobic biodegradability of food waste in single and two-stage systems. *Bioresource Technology.* 102 : 6449-6457.

El-Mashad, H.M. and Zhang, R. 2010. Biogas production from co-digestion of dairy manure and food waste. *Bioresource Technology.* 101 (11) : 4021-4028.

Foley, J.M., Rozendal, R.A., Hertle, C.K., Lant, P.A. and Rabaey, K. 2010. Life cycle assessment of high-rate anaerobic treatment, microbial fuel cells, and microbial electrolysis cells. *Environmental Science & Technology.* 44 (9) : 3629-3637.

Franchetti, M.J. 2009. *Solid Waste Analysis and Minimization: A Systems Approach.* New York: McGraw-Hill Professional.

FAO, 2016. Food and Agriculture Organization Save Food: Global Initiative on Food Loss and Waste Reduction, FAO, Rome.

Ghosh, D., Ray, A.K. and Biswas, C. 2015. Linking small and marginal farmers with the growth of India. *International Journal of Advanced Research.* 3 (4) : 1191-1193.

Haq, Z. 2016. Food India wastes can feed all of Bihar for a year, shows govt. study. Hindustan Times. September 15.

Hall, K.D., Guo, J., Dore, M. and Chow, C.C. 2009. The progressive increase of food waste in America and its environmental impact. *PLoS ONE*. 4 (11) : e7940.

Intergovernmental Panel on Climate Change (IPCC), 2007. IPCC fourth assessment report: Climate Change.

Kim, S., Han, S. and Shin, H. 2004. Feasibility of biohydrogen production by anaerobic co-digestion of food waste and sewage sludge. *International Journal of Hydrogen Energy*. 29 (15) : 1607-1616.

Khanna, K. 2016. Thought for food: using participatory theatre with Indian youth to curb food wastage. *Journal of Content, Community & Communication*. 3 (2) : 60-66.

Li, A. 2010. The sustainable aspects of house hold waste and food crops. *Biofuel*. 1 (5) : 657–661.

Levis, J.W. and Barlaz, M.A. 2011. What is the most environmentally beneficial way to treat commercial food waste? *Environmental Science & Technology.* 45 : 7438-7444.

Massachusetts Department of Environmental Protection (MDEP), 2013. Patrick Administration announces plan to ban disposal of commercial food waste.

Natural Resources Defense Council (NRDC), 2012.Wasted: How America is losing up to 40 percent of its food from farm to fork to landfill.

Spencer, R. 2010. High solids anaerobic digestion of source separated organics. *Bio Cycle.* 51 (8) : 46-54.

U.S. Environmental Protection Agency (EPA).Municipal Solid Waste generation, recycling, and disposal in the United States. 2011.

Viswanadham, N. 2012. Can India be the food basket for the world? Institute of South Asian Studies. Government of Singapore.

Whyte, R. and Perry, G. A. 2001. Rough guide to anaerobic digestion costs and MSW diversion. *Bio Cycle*.

Zhang, L., Lee, Y. and Jahng, D. 2011. Anaerobic co-digestion of food waste and piggery wastewater: Focusing on the role of trace elements. *Bioresource Technology*. 102 (8) : 5048-5059.