Proceedings of IOE Graduate Conference, 2016
pp. 163–169

Estimation of Biogas Potential and Sizing of Anaerobic Digester for Malangwa Municipality, Sarlahi, Nepal

Ram Bali Mahato [1], Ajay Kumar Jha [2]

[1, 2] *Department of Mechanical Engineering, Pulchowk Campus, Institute of Engineering, Tribhuvan University, Nepal*
Corresponding Emails: [1] maitorambali.ioe@gmail.com, [2] ajaykumar_521@yahoo.com

Abstract

Nepal is undergoing a population explosion in its urban areas in recent times especially due to the rural migrants seeking employment, business and other opportunities. Malangwa is a town and municipality and the headquarters of Sarlahi district in the Janakpur zone of Nepal. This research was analyzed by data analysis from biogas calculation tool V3.1 and EASEWASTE of collected data from site survey. This research has objective to evaluate biogas potential from municipal solid waste and emissions reduction with use of biogas digester in Malangwa municipality, Sarlahi, Nepal. Average composition of MSW is as follows: organic waste 65%, plastics 7%, paper and paper products 11%, glass 3%, metals 2%, textiles 3%, rubber and leather 4%, and others 5 %. The site survey results show more than 80% of municipal solid waste has domestic waste category. Avg. per capita Household (HH) waste of Malangwa Municipality was 0.266 Kg/day. Biogas potential in each ward is found in which lowest in ward no. 1 is 11.3 m^3 and highest in ward no. 4 is 42.8 m^3. The recommended standard size of biogas plant size in each ward is minimum 40 m^3 and maximum 100 m^3. These all biogas plant is financially feasible with subsidies having payback period and internal rate return (IRR) are 3 to 5 years and 21 to 25 % respectively. This biogas plant investment is not feasible without subsidies due to having negative net present value. There are comparisons of scenarios between existing waste management (open dumping) and an aerobic digestion technology by using LCIA model. Human toxicity via water and global warming impacts saving is 513.53 m^3 water and 6074.76 Kg CO^{2eq} Reduced quantity of Human toxicity via air and Ecotoxicity in water (chronic) are 445749076 m^3 water and 19597.12 m^3 water respectively.

Keywords

organic solid waste – anaerobic digestion – Biogas – large size biogas plant – EASEWASTE – Biogas calculation tool V 3.1

1. Introduction

The environmentally acceptable management of municipal solid waste has become a global challenge due to limited resources, ever increasing population, rapid urbanization and industrialization worldwide. Urbanization is occurring rapidly in many less developed countries. It is expected that 70 percent of the world population will be urban by 2050, and that most urban growth will occur in less developed countries [1]. Nepal, a least developing nation located in Asia, lies in the central part of the Himalayan Belt in 26 ° 22’ and 30° 27’ north latitude and 80° 41’ and 88° 12’ east longitude. Nepal is characterized by a rugged topography, high relief and variable climate. Nepal is undergoing a population explosion in its urban areas in recent times especially due to the rural migrants seeking employment, business and other opportunities in the cities. Nepal is undergoing a population explosion in its urban areas in recent times especially due to the rural migrants seeking employment, business and other opportunities in the cities. Presently there are 217 Municipalities in Nepal of which only 58 existed until 2014, 72 were established in May 2014, 61 in December 2014 and another 26 in September 2015. Malangwa is a town and municipality and the headquarters of Sarlahi District in the Janakpur Zone of Nepal. It is located at 26 ° 52’0N 85° 34’0E with an altitude of 79 metres (262 feet) near the border with India at Sonbarsa. For better administration purpose Malangwa has been divided into many wards, from ward no. 1 to ward no. 13.

Malangwa municipality has 30,292 populations residing in 5267 households having total coverage area 13.7 Sq. Km [2]. There is not segregation of household waste and material recoveries facilities. There is not door to door waste collection and disposal management technology insertion[3]. The organic fraction like food scraps is used to cattle, pig, goats etc. food who has involved in farming. The inorganic fraction (non compostable) material are burned or disposed at open places outside the home and roads. This type of pattern of waste composition and disposed scenarios are most challenging for Malangwa municipality. This haphazardly disposed and burning has different environmental and social impacts. This unmanaged waste disposal has damaged beauty and attraction of this city.

This research has objective to find Biogas Potential from Municipal Solid Waste and emissions reduction with use of biogas digester in Malangwa Munacipality, Sarlahi, Nepal. This study shows waste composition and fraction of waste of MSW. This study shows potentiality of fraction of organic waste fitted for an aerobic digestion which leads to availability of Biogas plant potential, sizing and financial parameters using Biogas Calculation tool V3.1 prepared by Alternative Energy Promotion Center (AEPC), Khumltar, Nepal[4]. The EASEWASTE model is also used to compare different waste management strategies, waste treatment methods and waste treatment technologies by quantitatively evaluating environmental impacts and resource consumptions . This study was done by using life cycle impact assessment (LCIA) method from EDIP 1997[5] was applied to translate the emissions into environmental impacts[6].

2. Methods and Materials

2.1 Sample Size Calculation

The formula used for these calculations was:

$$Sample\,Size(n) = \frac{z^2.N.p.(1-p)}{ME^2.(N-1)+z^2.p.(1-p)}$$

Where,
n= required sample size
z^2= Normal distribution for the specified confidence level
N= Population size (Household)
ME = Desired Marginal error [7]

Total Households of Malangwa Municipality was 5267 that was population size. Assuming population was normally distributed having desired marginal error 5% at 95% confidence level. We got sample size 374 which covered from each wards considered as stratum based on stratified sampling principle. The sample size for each stratum (ward) was determined by probability proportional to size sampling technique (i.e., the greater the stratum size; the greater the sample size). However, the minimum sample size for each stratum was set at 15 households. Households were selected from each ward depending on its economic level.

2.2 Questionnaire Development

Structured questionnaires were used to gather data on generation, sorting, recycle, transportation, disposal about the municipal solid waste. Basically the weight of the various wastes would be taken like organic, plastics, paper, glass, rubber and leather, textile, metal, construction, demolition waste and dust, other[8]. This will help to identify fraction of organic and inorganic materials which help for identifying percentage of waste fit for Biogas Calculation tool V3.1. The questionnaires would be designed based on requirements for analysis of data through EASEWASTE.

2.3 Field Survey and Data Collection

Since there was some comprehensive studies about the solid waste management in Malangwa municipality this study will assets municipal authority in Malangwa to effectively manage solid waste management problem in future. The no systematic collection of waste carried out by municipality of the Malangwa municipality. Primary waste generators in Malangwa municipality were households, hotels and shops out of which households were more responsible. Therefore households selected as waste generation centers. Interviews with respective peoples were conducted according as sample size calculations.

2.4 Data Analysis

From site we calculated data. In the part of data analysis used EASEWASTE-12 for cording, cleaning and presentation of the primary data collected from the field. By using Biogas calculation tool V3.1, biogas potential and sizing were done.

3. Results and Discussions

3.1 Existing waste management system in Malangwa Munacipality

Figure 1 shows the average composition of MSW is as follows: organic waste 65%, plastics 7%, paper and paper products 11%, glass 3%, metals 2%, textiles 3%, rubber and leather 4%, and others 5 %.

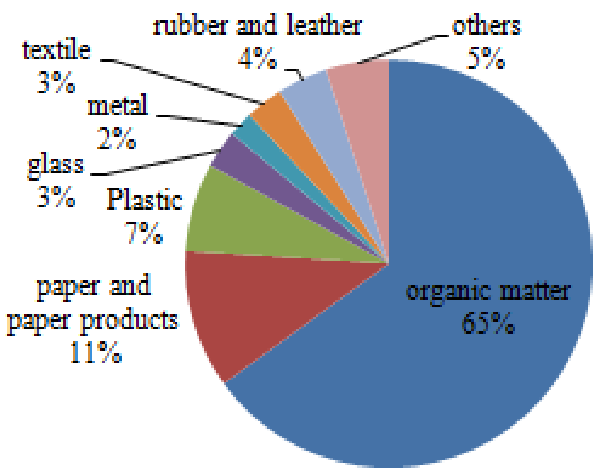

Figure 1: Composition of overall Municipal Solid Waste in Malangwa Munacipality

Total Municipal Solid Waste (MSW) generation is 9.49 tons/day out of which 1.5 tons/day MSW gets collected having 15.8 % collection efficiency[9]. Malangwa Municipality has 1 supervisor, 1 permanent and 13 temporary sweeper. The sweepers sweep about 5-8 km of road on daily and 2-5 km once a month using ordinary brooms. The Municipality has 1 tipper, 1 rickshaw and 10 handcarts for waste collection. The mode of waste collection is roadside pickup service. Waste generated by the household is dumped on the street side and other open places in the morning and the sweepers collect the waste every morning. The municipality does not have containers or door-to-door collection system.

3.2 Wardwise Data and information from site survey

Site survey on solid waste was carried out to quantify organic and inorganic fraction of solid waste. Primary individual's questionnaires, Manual segregation and weighing of solid waste were done for field survey. Also for segregation of an-aerobically digestible solid waste, organic waste which could be evenly and smoothly digestible under an-aerobic condition were manually segregated and weighed. Such an- aerobically digestible waste included paper, food, vegetables etc. Primary field observation on household solid waste suggests that in an average around 90 % of household organic fraction is an aerobically digestible waste.

Figure 2 shows wardwise average per capita household (HH) waste in Malangwa municipality. Average per capita HH waste is minimum at ward number 1 which is 0.221 Kg/day and maximum at ward number 10 which is 0.293 Kg/day.

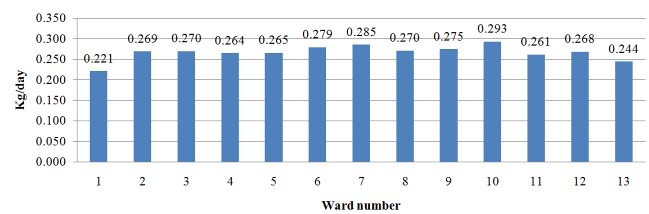

Figure 2: Wardwise Avgerage per capita HH waste

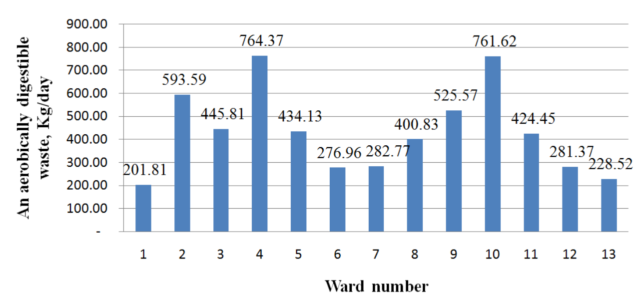

Figure 3: Wardwise Anaerobically digestible waste production

The total daily availability of solid organic waste in the year 2016 was collected, after the segregation the total organic solid waste fit for the anaerobic digestor. 3. Figure 3 shows anaerobically digestible waste production potential wardwise in Malangwa municipality. Minimum aneerobically digestable waste in ward number 1 is 201.81 Kg/day. And maximum anaerobically digestible waste in ward number 4 is 764.37 Kg/day.

3.3 Biogas Potential and sizing of biogas plant

Biogas calculation tool v3.1 of AEPC was used for the calculation of biogas potential, sizing of biogas Plant. There was not used toilet and others waste for feedstock for the an-aerobic digester. Malangwa Munacipality is situated in Terai area of Nepal so Hydaulic retention time (HRT) was taken as 55 for unheated digester. The biogas plant was assumed to be used for cooking purpose only. Type of biogas plant was taken as modified GGC 2047 model.[10]

Figure 4 shows biogas potential wardwise in malangwa municipality. Biogas potential in each wards has been found; which is lowest in ward number 1 with the value of 11.3 m^3 and highest in ward number 4 with the value of 42.8 m^3. Thus, Malangwa municipality has overall biogas potential of 314.8 m^3

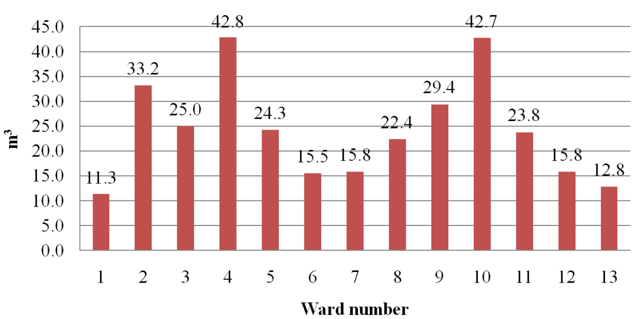

Figure 4: Wardwise biogas potential in Malangwa municipality

The different size of biogas plant that is modified GGC 2047 model approved by AEPC upto 100 m^3 only in 2014. The recommended standard size of biogas plant in GIS map of Malangwa municipality to generate related biogas potential in each ward is shown in figure 5. 40 m^3 of biogas plant size is required in ward number 1 to generate related biogas potential 11.3 m^3. In this way, ward number 2, 4, 10 requires two biogas plant sizes to generate related biogas potential. Because a single biogas plant size exceeds capacity of 100 m^3 which drawing is not approved till now.

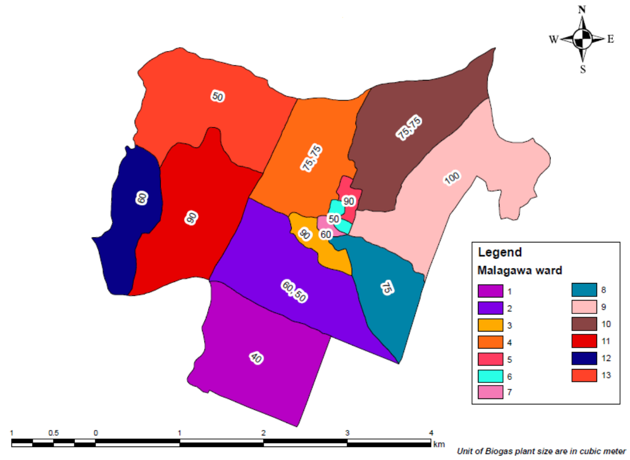

Figure 5: Biogas plant size recommended in GIS map of Malangwa municipality

3.4 Emissions reduction on Anaerobic Digestion (AD) technology

3.4.1 Scenario 1

It is the current waste management system in Malangwa municipality, in which the waste is collected by curbsides technology and it is sent 2 km away from city by using truck (tipper) as transportation. The waste is disposed to land filled mixed waste by using open dumping.

It can be seen that all impacts have positive value means adverse effect on human and environment. There is environmental emissions in fourteen categories however major five emissions potential as shown in 1. The human toxicity via Air 1101 million m^3 of air, Global warming is 6767 kg CO^{2eq}, Human Toxicity via Water is 986.40 m^3 of water, Ecotoxicity via Water (chronic) is 43,377.8 m^3 of water and Ecotoxicity in soil is 394.91 m^3 of soil. The major contribution (direct impact) is due to direct disposal of waste in open places. These all impacts are due to emissions of heavy metals (cadmium, mercury, chromium, nickel, copper, lead, arsenic etc.), emissions of methane, CO_2, CO, aldehydes, chloroflrocarbon,SO_2, H_2S, H_2S etc into air, soil and water.

3.4.2 Scenario 2

The collected waste is sent 4 km away from city by using collection truck. This waste is used as Biotechnology (Biogas and Composting) for treatment, recovery and Disposal where anaerobic digestion takes place.

The impact of the waste is highly reduced at anaerobic digestion. The resulting environmental impacts having negative value indicates that the system in the scenario leads to avoidance of impacts due to replacement of external materials and resource consumption. When the technology is changed, emissions to air, water and soil that would have occurred their open land filling are subtracted from emissions in the waste management system which is anaerobic digestion.[11]

Table 2 others impacts except human toxicity via air and ecotoxicity in water is negative value which are savings to the environmental impacts. Human toxicity via water and global warming impacts saving is 513.53 m^3 water and 692.40 Kg CO_{2-eq}. Human toxicity via air and Ecotoxicity in water (chronic) have still positive value that means still adverse effect to environment. However, reduced quantity of Human toxicity via air aand Ecotoxicity in water (chronic) are 445749076 m^3 water and 19597.12 m^3 water respectively. This results from LCA of the solid waste system in the Malangwa municipality showed the Anaerobic digestion (AD) of the organic waste is better than the current open dumping system in terms of emissions reduction.[12]

3.5 Financial Analysis

3.5.1 Revenue Generation

If only biogas generation plant is to be developed, savings of LPG from the biogas plant is estimated below with reference to biogas calculation tool v3.1 of AEPC. According to practical cooking same quantity paddy rice in LPG and biogas stove, 0.1134 m3 of biogas is equivalent to 0.061 kg of LPG. Then one m^3 of biogas equals to 0.538 kg of LPG. A gas cylinder available in Nepal weighs 14.2 Kg and costs around NRs. 1400 (current market rate /cylinder).then NRs. 98.60 per Kg of LPG is market rate.

Percentage of Digested Slurry (DS) is kept at 50% for the calculation of compost production from an-aerobic digestion process with the waste available in. Biogas calculation tool v3.1 of AEPC is used for the calculation of compost production. Current market rate of compost fertilizer is NRs. 8 per kg[10]. Major revenue is selling of biogas and compost fertilizer production from Biogas Plant. There is varying in revenue according to biogas plant size which is shown in Table 3.

3.5.2 Financial Indicators of Different Size of Biogas Plant

The calculations for plant sizing and costing are made using biogas calculation tool v 3.1 of AEPC. Normal large biogas plants of Modified GGC2047 size biogas plant costs NRs. 20000 per m^3, so it is assumed that the cost of biogas plant with pre-treatment facility is NRs. 30000 per m^3. (Singh et al, 2015) There was taken 40 % subsidy of total cost according to subsidy policy for Renewable energy 2073 B.S, AEPC. There are assumptions which are used in biogas calculation tool v3.1, about operation and maintenance cost generally taken as 8- 10% of total investment cost. All investment cost except subsidy is loan as market interest rate 10 %. Minimum attractive rate of return is as 14 % and service life is 15 years as in AEPC biogas calculation tools. There is Net present value (NPV) of all sizes of biogas plant is positive it means project financially feasible. Internal rate of Return is 21 to 25 % and payback periods are 3 to 5 years which is shown in Table 3. If AEPC subsidies are not provided to this plant then Net present value becomes negative it means financial not feasible.

4. Conclusion

The site survey results show more than 80% of municipal solid waste has domestic waste category. Avg. per capita HH waste of Malangwa Munacipality is 0.266 Kg/day having avg. 76.711 % organic fraction. Biogas potential in each wards is found which is lowest in ward no. 1 is 11.3 m^3 and highest in ward no. 4 is 42.8 m^3. In this way overall Malangwa municipality had biogas potential as 314.8 m^3. The recommended standard size of biogas plant size in each ward is minimum 40 m3and maximum 100 m^3.

These all biogas plant is financially feasible with subsidies having payback period and internal rate return (IRR) are 3 to 5 years and 21 to 25 % respectively. This biogas plant investment is not feasible without AEPC subsidies due to having negative net present value. Human toxicity via water and global warming impacts saving is 513.53 m^3 water and 6074.76 Kg CO^{2-eq}. Reduced quantity of Human toxicity via air and Ecotoxicity in water (chronic) are 445749076 m^3 water and 19597.12 m^3 water respectively. This results from LCA of the solid waste system in the Malangwa municipality showed the Anaerobic digestion (AD) of

Table 1: Environmental emissions potential of the scenarios

S.N.	Impact	Equivalences	Scenario 1	Scenario 2	Reduction
1	Human Toxicity via water	m^3 water	986.4	-472.88	513.52
2	Global Warming	Kg CO_{2-eq}	6,767.16	-692.40	6074.76
3	Ecotoxicity in soil	m^3 Soil	394.91	-23.77	371.14
4	Human Toxicity via air	m^3 air	1,101 million	655 million	445 million
5	Ecotoxicity in water chronic	m^3 water	43,377.8	23,780.68	19,597.12

Table 2: Revenue generation from different size of biogas plants

Description	Standard biogas plant size					
	40 m^3	50 m^3	60 m^3	75 m^3	90 m^3	100 m^3
Revenue from Biogas Production						
Biogas Production, m^3/day	12	14	17	22	27	31
Annual biogas production, m^3	4,380	5,110	6,205	8,030	9,855	11,315
Annual Revenue, NRs.	232,345	271,069	329,155	425,966	522,776	600,224
Revenue from Compost fertilizer						
Compost Production, Kg/day	42	52	60	83	100	116
Annual Compost Production, Kg	15,330	18,980	21,900	30,295	36,500	42,340
Annual revenue from Compost, NRs.	122,640	151,840	175,200	242,360	292,000	338,720
Total Annual Revenue	354,985	422,909	504,355	668,326	814,776	938,944

Table 3: Financial indicators of different size of biogas plant

Details	Ward No.1	Ward No.2,6,13	Ward No.2,7,12	Ward No.4,8,10	Ward No.3,5,11	Ward No.9
Standard biogas plant size	40 m^3	50 m^3	60 m^3	75 m^3	90 m^3	100 m^3
40% subsidy	584	724.8	857.2	1,091.6	1,300.8	1,458.4
Net Investment('000) NRs.	876	1,087.2	1,285.9	1,637.4	1,951.2	2,187.6
Annual Operating expenses, NRs.	1,46,000	1,81,200	214,300	272,090	325,200	364,600
Annual Revenue	354,985	422,909	504,355	668,326	814,776	938,944
Financial Indicators						
Net Present Value(NPV), NR.s	407,621 (+ve)	3,97,417	495,767	791,373	1,055,858	1,340,117
Internal Rate of Return(IRR), %	23	21	21	23	24	25
Payback Period	4.19	4.5	4.43	4.14	3.99	3.81

the organic waste is better than the current open dumping system in terms of emissions from anaerobic digestion and open dumping.

Acknowledgments

The authors are thankful to Ramesh Ranabhat for his valuable suggestions in emission analysis part of this research. The authors also would like to thank Bikal Adhikari for his help during the preparation of LaTeX code of this paper.

References

[1] UNPF. Urban population at least developing countries. Technical report, United nation population fund, 2007.

[2] Central bureau of statistics. *Environment stastistics of Nepal*. Goverment of Nepal, 2011.

[3] Baseline survey report. Environment friendly local governance program, malangwa municipality, sarlahi. Technical report, 2015.

[4] AEPC. Biogas calculation guide v 3.0. Technical report, ALternative Energy Promotion Center, 2016.

[5] Wenzel et. al. *Environmentr assessment of products, Methodology, tools and case studies in product development , Institute of Product development*. Kluwar academic publishers, 1997.

[6] Kirkeby J.T et.al. Modeling of environmental impacts of solid waste landfilling within the life cycle analysis program. 2006.

[7] C R Kothari and Gorav Garg. *Research methodology methods and techniques*. Khana publishers, 2014.

[8] Ramesh Ranabhat. Life cycle assessment of municipal solid waste management system at vyas municipality , tanhun nepal. Master's thesis, 2012.

[9] ADB. Solid waste management in nepal, current status and policy recommendation. Technical report, Asian Development Bank, 2012.

[10] Singh Riddibir et al. Feasibility study for waste to energy potential in biratnagar sub-metropoliton city. Technical report, Alternative Energy Promotion Ceter, 2014.

[11] Joanna Kuczycka et. al. Life cycle assessment of municipal solid waste management - comparision of results using different lca models. 2014.

[12] Hong-Tao Wang et. al. Life cycle assessment of municipal solid waste management system in hangzhou, china. 2009.

[13] Cristensen et. al. Experience with the use of lca modeling (easewaste) in waste management. Technical report, 2007.