Ranking of Technologies for Energy Recovery from Municipal Solid Waste in Bangladesh Using the Analytic Hierarchical Process (AHP): A Case Study

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Abstract

Energy recovery by appropriate management of solid waste from municipal can be the solution to sustainable waste management as well as providing energy security in Bangladesh. However, the choice of appropriate waste to energy technology is a complex and challenging issue as a widespread variety of environmental, economic and social controlling criteria need to be identified and investigated. In this paper an Analytic Hierarchical Process is used to find the most preferable waste to energy technology by evaluating environmental, economic and technical criteria. The technologies considered were anaerobic digestion, gas recovery from landfill and incineration. Conducting a qualitative and quantitative assessment a preference ranking is produced which concluded that anaerobic digestion is the preferred technology for Bangladesh based on cost, benefit and environmental risk. We believe this study will provide a guideline for waste to energy decision makers in Bangladesh alongside with other similar developing countries.

Keywords: Municipal solid waste (MSW) management, Waste treatment alternatives, Analytic Hierarchical Process (AHP)

1. Introduction

In the developing economy of Bangladesh, the energy consumption, mainly in the form of electricity, has experienced a rapid and significant increase over the last few decades (w to e report). Energy generation is mostly based on conventional energy sources for instance natural gas (75%), fuel (18%) and coal (2%) (Bangladesh power development board, 2011). Although the country is still disposing of natural reserves, mainly in term of natural gas, the dependence to importation is high and the energy sector is subjected to market volatility. Moreover, the energy sector of Bangladesh is a matter of great concern because of its generous contribution to greenhouse effect and global warming. Through this observation, it is obvious for Bangladesh to diversify the energy sector with the implementation of alternative solutions based on unconventional energy source.

In parallel of that, the increasing urbanization coupled with the change in consumption patterns thousands of tons of waste is generated every day throughout the country. Waste generation rate of Bangladesh varies from 0.25 to 0.56 kg per person per day (BBS,2013). Sometimes those are dumped in landfills, but mostly illegally dumped in law land besides streets, riversides and households. Management of solid waste is becoming a major concern for Bangladesh and represents a social, environmental and technical challenge. Based on these different considerations, generation of energy by treating these wastes with appropriate technology is an alternative solution for both energy and appropriate management of solid waste.

But the selection of technology to convert waste into energy is a complex problem as physiochemical parameters of solid waste from municipal is different in each area. Waste management should include environmental and economic criteria (Berger et al., 1999). Different researchers have investigated impact of environment from different waste to energy technology as well as economic criteria. (Antopoulos et al. 2014, Finnveden et al. 1995, 2005). Researchers have reviewed previous studies regarding waste to energy technology and found that MCDA can be an effective analyzing tool to access quantitative data and qualitative data regarding waste management. In MCDA experts selects important criteria (such as environmental, economic, social) then weights these by importance score. At last weighted score for each options (technology) are computed and compared to find the best options (Hanan et al., 2012). Multi-criteria analysis is a flexible tool which efficiently support decision making process. Though different decision tools have been developed, AHP is appropriate for proper management of waste.

In this paper analytic hierarchal process is used to find a suitable municipal solid waste to energy technology for Keranigonj area of Dhaka city. Keranigonj is characterized by a high population growth rate (2.8% per year) and rapid urbanization due to easy accessibility with Dhaka city (Vitti, 2018). In near future this area will also help to support Dhaka to carry the extra crowd and population. It has become an unprecedented challenge for appropriate management of solid waste because of these situations. Currently the household and commercial waste amounts can be estimated to 410,000 mt per year. On the other hand, currently electricity, generated by heavy-oil-based centralized power generation facilities (capacity 100 MW) powers the city. Due to oil dependency, electricity tariffs for the end consumer are relatively high and will continue to increase. Thus producing energy can be the sustainable solution.

2. Literature Review

Conversion of energy from waste refers to generate electricity, heat and gas from waste. This study is focused on energy conversion technology for appropriate management of solid waste from municipal in context of Bangladesh. There are two conversion option – (1) thermal conversion (Incineration) and (2) Non-thermal (Anaerobic Digestion and Landfill Gas Recovery). In thermal process waste is converted into gas, liquid and solid; leading to volume reduction and recovery of energy (Tchobanoglous et al. 1993, Bosmans, 2013). Non-thermal or biochemical conversion is the recovery of energy by biochemical decomposition to produce energy rich fuel (Stehlik, 2009, Waste to energy Council, 2013). AHP is a MCDA tool for ranking when factors are intangible and is used effectively in several study in conversion of energy from waste sector (Saaty, 2005, Antonopoulos et al. 2013, Hanan et al. 2013, Vego, 2008).

2.1 Incineration

MSW incineration has been very popular over the last decades in developed countries because of volume reduction and energy recovery potential (Knox, 2005). In this process combustible materials with minimum energy value 6 MJ/kg is converted into gas and noncombustible materials remains as residue (Nickolas, 2003, LCA IWM, 2005). Depending on the process developed, different sources of energy can be recovered as well as sometime valuable materials by incineration. In accordance to guideline by ISWA, in law to middle income countries, energy recovery from incineration plants recovers energy about 20 to 25% for power producing plants (ISWA, 2013).

Without recycling and composting opportunity, incineration undermines such development. In general incineration plant has a minimum requirement of 40000 to 100000 t/year (SREDA, 2018). It requires highly qualified personnel, daily operation and complex equipment's.

In Bangladesh municipal solid waste contains mostly law caloric value organic waste with almost 72% moisture (SREDA, 2018). But Incineration technologies are not completely mature and does not perform well with such waste. On the other hand, the environmental regulations are not much strict, thus uncontrolled incineration poses great environmental risk.

2.2 Anaerobic digestion

The Microbial decomposition of organic component in absence of oxygen leading to produce biofuel (CH_4) and compost is Anaerobic digestion. Gas mixture is mainly composed of methane (+/-60%) and CO_2 (+/- 40). Large scale plant capacity is almost 25-50 kt/year (Michel et al. 1981, SREDA, 2018). According to World Bank studies on solid waste management cost, estimated cost is around 20-80$/ton. Anaerobic digestion can be established in wide ranges of scale.

It can only convert organic portion of the waste thus waste with low caloric value and high moisture, thus suitable for countries similar to Bangladesh. But the challenge will be separation of organic portion of solid waste.

2.3 Landfill gas recovery

Sanitary landfill is a step by step construction activity as everyday waste is deposited and when cells are filled these are filled with cover (soil/geotextile), creating an anaerobic atmosphere. The working principal is similar to anaerobic digestion. According to H.C. Willimsen, a normal size plant with gas engine can produce about 300 to 1200 kW power. When no sorting is available, landfill gas recovery will be a better suited option. But it poses risk due to explosion of gaseous fraction and leaching of liquid in groundwater.

Table 2.1 illustrates cost, Benefit and risk data for waste to energy technologies which were taken into consideration for the analysis.

Table 2.1: Waste to Energy Cost-Benefit-Risk (CBR) data

	Criteria's	**Incineration**	**Anaerobic digestion**	**Landfill gas recovery**	**Reference**
Cost	Capital cost ($/t)	850.00	400.00	200.00	Arena et al. 2003;
	Operating cost ($/t)	85.00	16.00	0.80	
	Required land (ha)	0.80	2.00	36.00	US EPA, 1998;
	Energy input (MJ)	0.34	0.08	0.03	
Benefit	Electricity generated (MJ/kg)	2.42	0.40	0.30	Herva and Roca, 2013;
	Material recovered (%)	5.00	70.00	1.00	
	Volume reduction (%)	90.00	49.00	2.00	
	Conversion efficiency (%)	20.00	13.00	10.00	Nixon et al. 2013;
	Compatibility (%)	2.00	70.00	90.00	
Risk	CO_2 emission (kg/kg)	0.95	0.20	0.18	SREDA, 2018
	CO (kg/kg)	0.0001	0.00	0.12	

3. Methodology

This study adopts a combination of both primary and secondary research method. First a structured literature review is carried out to characterize technological options for waste to energy generation in Bangladesh. A technological, environmental and economical assessment was carried out identify controlling criteria. The output of the review is a shortlist of alternatives and evaluation criteria's for AHP analysis. To obtain weighting for criteria academic experts of Bangladesh University of Engineering and Technology are requested to complete a survey to rank the importance criteria using Saaty's recommended 1-9 weighting scale (Saaty, 1977). A AHP analysis is than conducted using office excel. Pair-wise comparisons were performed using literature review and questionnaires survey. As an output a ranking order of preference for waste to energy technology is established.

Steps for AHP –

- Developing a hierarchical layout with an objective at the initial level, the criteria at the secondary level and alternatives are at third level.
- Calculating rational weights values from survey report of selected criteria in respect of the objective.
- The pair-wise comparison framework is demonstrated by taking the levelheaded weight esteem.
- Calculating the row sum and using this row sum values pair-wise comparison framework is normalized.
- Determining the criteria weight by taking the mean value of rows.
- Calculating consistency index.
- Then calculating consistency ratio.
- Finally, using these criteria weights the technologies are compared.

4. Cost, Benefit and Risk assessment

In this study AHP method was applied to compare gas recovery from landfill, incineration and anaerobic digestion technology based on cost, expected benefit and risk criteria evaluation. Cost is addressed through two basic criteria capital cost, operating cost and also two latent cost factor required land and input energy which are responsible for incurring cost. The capital cost and required land addresses the initial cost. The benefit addresses the gain from each technology. The Risk mainly addresses the environmental criteria and their impact. These criteria were analyzed by literature review and then the CBR criteria findings were inserted in AHP tool to obtain best performing technology.

5. The AHP analysis

For AHP analysis some factor is selected by reviewing some literature. Then the factors are categorized into three groups (Table 2.1).

Then a pair-wise comparison is done by assigning weight to the factors. The weights are assigned with the basis of survey report and literature review using the scale proposed by Saaty (Table 5.1)

Table 5.1: Weight Scale ((Saaty, 1977)

1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values
1/3,1/5,1/7,1/9	Values for inverse comparison

Using this scale, the pair-wise matrix is formed. Upper triangular matrix is formed by row weight/ column weight and lower triangular matrix is formed by column weight/ row weight. For diagonal value 1 is assigned as the factors are same, so they are equally important. Table 5.2 illustrates the pair-wise comparison matrix.

For example, how important is capital cost with respect to operating cost is calculated by using the weight of importance scale for capital cost and operating cost. Capital cost is of a very strong importance than operation cost. The diagonal value is 1 because capital cost is equally important with respect to capital cost.

From survey report-
The weight of importance scale for capital cost- 7
The weight of importance scale for operating cost- 5
The value of $X_{ij} = x_i/x_j$ for the matrix.
Here,
x_i = Assigned weight for i^{th} factor
x_j = Assigned weight for j^{th} factor

Table 5.2: Pair-wise Matrix

Factors	Capit al cost	Operati ng cost	Requir ed land	Electri city genera tion	Mater ial recov ered	Volum e reducti on	Conv er sion effi cieny	Compatibi lity	CO_2 emissi on	CO emissi on	ener gy input
Capital cost	1	7/5	6/7	3/4	7/6	6/5	3/4	7/8	7/9	6/7	7/8
Operating cost	5/7	1	5/6	7/8	6/7	6/7	3/4	5/6	4/7	1/2	6/5
Required land	7/6	6/5	1	3/4	5/7	7/8	2/3	5/8	7/9	7/9	6/5
Electricity generation	4/3	8/7	4/3	1	8/9	6/7	3/4	5/8	5/9	4/9	8/5

Material recovered	6/7	7/6	7/5	9/8	1	8/5	9/8	7/6	6/7	5/7	7/4
volume reduction	5/6	7/6	8/7	7/6	5/8	1	6/7	3/4	2/3	2/3	7/4
Conversion efficiency	4/3	4/3	3/2	4/3	8/9	7/6	1	6/7	7/8	3/4	7/4
Compatibility	8/7	6/5	8/5	8/5	6/7	4/3	7/6	1	7/8	4/3	3/2
CO_2 emission	9/7	7/4	9/7	9/5	7/6	3/2	8/7	8/7	1	5/8	7/4
CO emission	7/6	2	9/7	9/4	7/5	3/2	4/3	3/4	8/5	1	8/5
Energy input	8/7	5/6	5/6	5/8	4/7	4/7	4/7	2/3	4/7	5/8	1

After calculating the row sum value, the pair-wise matrix is normalized using this row sum as illustrated in Table 5.3.

Table 5.3: Normalized Matrix

Factors	Capital cost	Operating cost	Required land	Electricity generation	Material recovered	Volume reduction	Conversion efficiency	Compatibility	CO_2 emission	CO emission	energy input	Criteria weight
Capital cost	0.08	0.10	0.07	0.06	0.12	0.10	0.07	0.09	0.09	0.10	0.05	0.08
Operating cost	0.06	0.07	0.06	0.07	0.08	0.07	0.07	0.09	0.06	0.06	0.08	0.07
Required land	0.10	0.08	0.08	0.06	0.07	0.07	0.07	0.07	0.09	0.09	0.08	0.08
Electricity generation	0.11	0.08	0.10	0.08	0.09	0.07	0.07	0.07	0.06	0.05	0.10	0.08
Material recovered	0.07	0.08	0.11	0.08	0.10	0.13	0.11	0.13	0.09	0.09	0.11	0.10
volume reduction	0.07	0.08	0.09	0.09	0.06	0.08	0.08	0.08	0.07	0.08	0.11	0.08
Conversion efficiency	0.11	0.09	0.11	0.10	0.09	0.09	0.10	0.09	0.10	0.09	0.11	0.10
Compatibility	0.10	0.08	0.12	0.12	0.08	0.11	0.12	0.11	0.10	0.16	0.09	0.11
CO_2 emission	0.11	0.12	0.10	0.14	0.12	0.12	0.11	0.12	0.11	0.08	0.11	0.11
CO emission	0.10	0.14	0.10	0.17	0.14	0.12	0.13	0.08	0.18	0.12	0.10	0.12
Energy input	0.10	0.06	0.06	0.05	0.06	0.05	0.06	0.07	0.06	0.08	0.06	0.06

By averaging the column values, the criteria weights are calculated as illustrated in table 5.4.

Table 5.4: Criteria Weight Calculation

Factors	Capital cost	Operating cost	Required land	Electricity generation	Material recovered	Volume reduction	Conversion efficiency	Compatibility	CO_2 emission	CO emission	energy input	Criteria weight
Capital cost	0.08	0.10	0.07	0.06	0.12	0.10	0.07	0.09	0.09	0.10	0.05	0.08

Operating cost	0.06	0.07	0.06	0.07	0.08	0.07	0.07	0.09	0.06	0.06	0.08	0.07
Required land	0.10	0.08	0.08	0.06	0.07	0.07	0.07	0.07	0.09	0.09	0.08	0.08
Electricity generation	0.11	0.08	0.10	0.08	0.09	0.07	0.07	0.07	0.06	0.05	0.10	0.08
Material recovered	0.07	0.08	0.11	0.08	0.10	0.13	0.11	0.13	0.09	0.09	0.11	0.10
volume reduction	0.07	0.08	0.09	0.09	0.06	0.08	0.08	0.08	0.07	0.08	0.11	0.08
Conversion efficiency	0.11	0.09	0.11	0.10	0.09	0.09	0.10	0.09	0.10	0.09	0.11	0.10
Compatibility	0.10	0.08	0.12	0.12	0.08	0.11	0.12	0.11	0.10	0.16	0.09	0.11
CO_2 emission	0.11	0.12	0.10	0.14	0.12	0.12	0.11	0.12	0.11	0.08	0.11	0.11
CO emission	0.10	0.14	0.10	0.17	0.14	0.12	0.13	0.08	0.18	0.12	0.10	0.12
Energy input	0.10	0.06	0.06	0.05	0.06	0.05	0.06	0.07	0.06	0.08	0.06	0.06

The validity of the criteria weight is measured by calculating the consistency ratio and consistency index.

Table 5.5: Consistency Ratio Calculation

λ max	C.I= (λ max-n)/(n-1)	C.R = C.I/R.I
11.058	0.006	0.004

Here,
Number of factors, n= 11.
From random index (R.I) table for n= 11, R.I = 1.51
As C.R < 0.10
So, the criteria weight is valid.
Then using these criteria weights, the equivalent value for all factors are calculated as shown in Table 5.6.

Table 5.6: Equivalent Value Calculation

Criteria	Capital cost ($/t)	Operating cost ($/t)	required land (ha)	energy input (MJ)	electricity generated (MJ/kg)	material recovered (%)	volume reduction (%)	Conversion efficiency %	Compatability %	CO_2 emission kg/kg	CO kg/kg
Incineration	71.40	5.95	0.06	0.02	0.19	0.50	7.38	1.98	0.22	0.11	0.00
Anaerobic digestion	33.60	1.12	0.15	0.01	0.03	7.00	4.02	1.29	7.56	0.02	0.00
Landfill gas recovery	16.80	0.06	2.77	0.00	0.02	0.10	0.16	0.99	9.72	0.02	0.015

Finally, the categorized value is calculated and for comparison, the values are converted into percentage value. The question which was considered while comparison was which technology has greater positive factor (benefit) and least negative factor (cost and risk) and the cost-benefit-risk analysis graph, as shown in Figure 5.1 is used to find the answer.

Table 5.7: Cost-Benefit-Risk value

Criteria	Cost	Cost (%)	Benefit	Benefit (%)	Risk	Risk (%)
Incineration	77.43	58.69	10.27	24.95	0.11	66.72
Anaerobic digestion	34.88	26.44	19.90	48.34	0.02	14.00
Landfill gas recovery	19.63	14.88	11.00	26.72	0.04	21.98

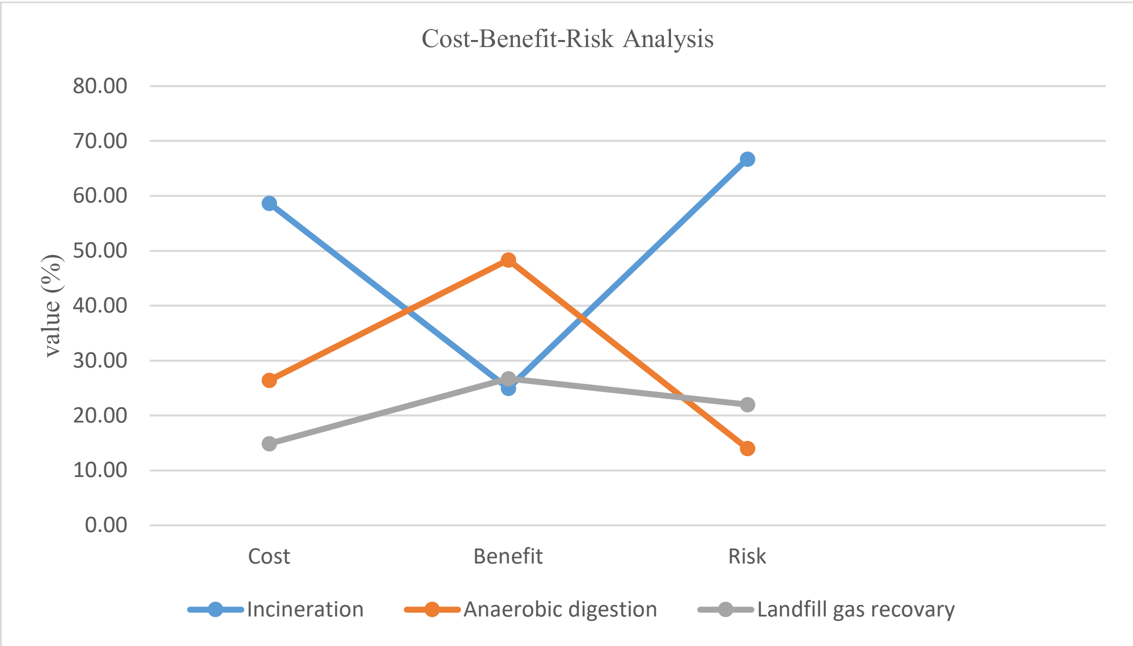

Figure 5.1: Cost-Benefit-Risk Analysis

6. Conclusion

Success and sustainability of a waste to energy conversion technology largely depend on the communities economic and social status. This study evaluates and compares three technologies for waste conversion from MSW in Bangladesh. Based on the analysis it can be said, incineration produces similar benefit as landfill gas recovery. But the cost and risk is much higher than anaerobic digestion and landfill gas recovery. This is due to the unsuitability of the waste stream and increase of capital cost and operation cost due to unsuitable socio-economical condition as skilled labor needed to be imported for lacking in Bangladesh. The risk factor is highest due to the lack of environmental regulation. On the other hand, landfill gas recovery requires the least cost but the benefit is fairly low from anaerobic digestion. The risk factor difference between these two bio-thermal method is fairly close because of similar mechanism, but as Bangladesh falls in the tropical region with high precipitation and high water table, landfill poses some threat of water pollution from leaching. Considering all three factor of CBR, anaerobic digestion is the most preferable for Bangladesh with highest benefit and lowest risk. The cost factor is slightly high due to pretreatment requirement of waste segregation. This cost can be reduced by incorporating at source separation of biodegradable and non-bio degradable waste. Thus it can be concluded that anaerobic digestion with source separation will be the best solution for Bangladesh municipal waste management and energy generation from MSW.

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