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Research Article

Feasibility of Anaerobic Digestion as an Option for Biodegradable Waste Management in the Kingdom of Bahrain

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Abstract

Municipal Solid Waste Management (MSWM) represents a main challenge to the developing countries. Almost all of the MSW in these countries are currently dumped into the landfills, which harms the environment and public health. Dumping of biodegradable waste into the landfill results in methane emission, which is a greenhouse gas 25 times more potent than carbon dioxide. Thus, finding a sustainable solution to manage the biodegradable waste tend to be crucial. Bahrain is a small developing country. It generates about 2 million ton/year of MSW dumped into the landfill, the only MSW landfill in Bahrain. This study aims to explore the feasibility of Anaerobic Digestion (AD) technology to manage the biodegradable waste in the Kingdom of Bahrain. AD is an important waste-to-energy technology that produces biogas, an important and promising renewable energy resource for the country. Cost- Benefit Analysis (CBA) was used in this study that shows the feasibility of the AD project. In addition, the contribution in reduction of the landfill methane emission was estimated. The study may provide sufficient information for future adoption of evidence-based technology selection in order to adopt MSWM technologies in Bahrain, which contributes to the decision and policy-making processes.

Keywords: Municipal Solid Waste Management, Waste-to-Energy, Feasibility, Cost-Benefit Analysis, Anaerobic Digestion Technology, Kingdom of Bahrain.

INTRODUCTION

Municipal Solid Waste (MSW) generation rises steeply with the increase in population growth rate, developmental activities, economic and industrial development and urban growth. It has become a globally addressed issue (UN Environment Annual Report, 2017: Al-Ansari MS, 2012). If it is not managed properly, negative consequences will appear and affect the public health, environment and economy (Zafar S, 2016: Al-Sabbagh MK, et al., 2012). In developing Asian countries, the organic waste represents the majority of municipal solid waste, in which it is disposed in landfills. As a result, it degrades in the anaerobic conditions and generates the landfill methane, the greenhouse gas that is 25 times more potent than CO_2.

Accordingly, biodegradable waste represents a promising resource that can be used to produce bio-energy as well as soil fertilizer. Thus, sustainable management of this waste can significantly contribute to climate change mitigation (Sharp A, 2010: Metson G and Bennett E, 2015: Abbas SY, et al., 2020).

Biomass is the world's fourth-largest energy source, following coal, oil and natural gas. Biomass appears to be an attractive feedstock for three main reasons. First, it is a renewable resource that may be sustainably developed in the future. Second, it appears to have formidable positive environmental properties including reduced GHG emissions, reduced NO_x and SO_x based on the fossil fuels displaced (MWMUPA, 2019).

With regard to GHG, organic household waste has contributed the most to the emissions from various types of waste. In most developing countries where the organic content of waste is high, improper management of waste (e.g., open dumping and landfill of organic waste without gas recovery and open burning of plastic waste) may lead to higher GHG emissions in the future. (MWMUPA, 2019).

Waste Management in the GCC Countries

Waste generating per capita ranked among the highest in the world in the GCC Countries (Al-Sabbagh MK, et al., 2012). The estimated total amount of waste generated in the GCC range from 90 million to 150 million metric tonnes annually, with the UAE being the highest generator at approximately 2.2 kg per capita. The amount of recycled waste is around 5percent of the total, with the rest being accounted for landfills or, even worse, to illegal dump sites. The amount of waste generated is expected to grow rapidly to anywhere between 1.5 and 2 times of the current volume in 2021. Changes in consumption patterns of the Gulf Co-operation Council (GCC) countries, have led to an increase in the MSW dumping. (Al-Ansari MS, 2012: MWMUPA, 2019) has argued that waste management protocols need to be re-evaluated in order to establish methods that contribute to minimizing greenhouse gas emissions, improving the efficiency of resource management, and designing more eco-friendly management plans in GCC states.

The composition of the waste would generally suggest that a large part of it is biodegradable. However, this is not reflected in common waste management practices in the GCC Countries, where most waste goes to landfill. In countries like Bahrain, Qatar, and the UAE, landfill space is running low and this practice is becoming a major problem.

MSW in the Kingdom of Bahrain

The Kingdom of Bahrain is located in the heart of the Arabian Gulf, west of the Asian Continent. It is an archipelago of 33 islands with Bahrain Island being the largest land mass which represents approximately 80% of the total land area of the Kingdom of Bahrain and amounts to 770 km^2. The Kingdom is split into four Governorates namely the Capital, Muharraq, Northern, and Southern Governorates (Figure 1).

The Kingdom of Bahrain is one of the Co-operation Council (GCC) countries. Oil and natural gas are the primary natural resources in Bahrain. The population growth rate is 7.4 percent on average. According to the (Mutz D, et al. 2017), the municipal solid waste composition in the Kingdom of Bahrain includes: 1- food waste; 2-garden (yard) and park waste. 3- paper and cardboard; 4-wood; 5- textiles 6- nappies (disposable diapers); 7- rubber leather; 8- plastics; 9- metal; 10- glass (and pottery and china); others (e.g. ash, dirt, dust, soil, electronic waste). Since organic waste is considered as the most harmful portion of the MSW content due to its hazardous environmental impact, organic waste management becomes a concern in many of the developing countries with the highest organic portion within their MSW content. Waste composition is considered to be one of the main factors influencing emissions from solid waste treatment, as different types are known to contain varying amounts of degradable organic carbon (DOC), and fossil carbon. Organic waste in landfills undergo degradation process, mainly anaerobic digestion, resulting in methane gas production, which is considered to be the most harmful greenhouse gas (GHG) that causes global warming and as a consequence, climate change.

The biodegradable waste (consisting of garden and green waste, papers and cardboards, food waste) represents the highest composition percentage in Bahraini domestic waste, according to MWMUP. It was above 60 percent in 2017, while it continues the average of 63% for 2018 and 2019, which shows that biodegradable waste continues to be one of the biggest components (percentage wise) of Bahrain's MSW.

Anaerobic Digestion (AD)

AD is a complex biochemical process for the treatment of organic waste, which occurs in a vessel in the absence of oxygen. In this process, breaking down of the organic material occurs by micro-organisms in the absence of oxygen, which leads to the formation of mixture of carbon dioxide and methane gas known as "Biogas", which is typically used to provide electrical power generation, heat, and a solid and liquid digestate. The digestate quality is dependent on availability of source- segregated organic waste stream (Cioabla A, et al. 2014: MWMUPA, 2019). The relevance of biogas technology lies in the fact that it makes the best possible utilization of organic waste as a renewable clean energy source (MWMUPA, 2019).

The biogas produced by anaerobic digestion primarily comprises of (CH_4 ≈ 60percent by volume), carbon dioxide

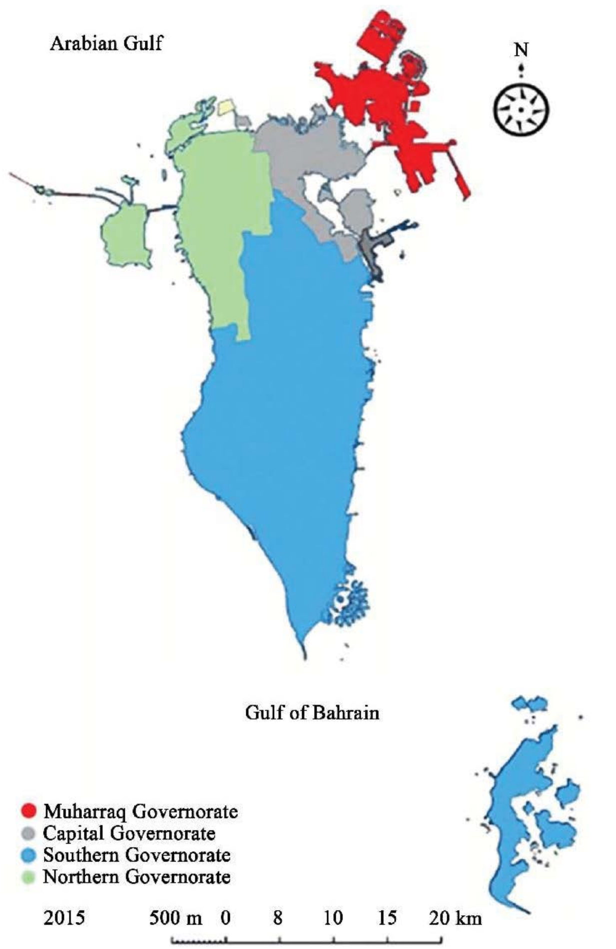

Figure 1: Bahrain map with the main governorates.

(CO_2 ≈ 40 percent by volume), and small traces of hydrogen sulphide (H_2S), hydrogen (H_2), nitrogen (N_2), carbon monoxide (CO), oxygen (O_2), water vapour (H_2O) or other gases as well as vapors of various organic compounds (Burrows D, 2013).

According to the American biogas council, many different anaerobic digester systems are commercially available based on organic waste stream type (manure, municipal wastewater treatment, industrial wastewater treatment and municipal solid waste). Anaerobic digestion of the organic fraction of MSW provides an engineered and highly controlled process of capturing methane. It is claimed that the current trend is toward anaerobic digestion of source separated from organic waste streams, including food waste, yard trimmings and soiled paper. Therefore, segregation at source is a main enabler to AD adoption in large scale (MWMUPA, 2019) : Abbas, 2019).

The number of plants treating the digestible fraction of household waste in Europe grew from three biogas plants in 1990 to 195 in 2010, with a total capacity of 5.9 million tonnes per year, as well as a predicted expansion of current capacity every five years (Al Seadi T, et al., 2013). In 2010, about 3percent of the organic fraction of municipal solid waste produced in Europe was treated by the AD, representing 20 percent–30 percent of the biological treatment capacity of organic wastes from households (Al Seadi T, et al., 2013). Analogously, (McKendry P, 2002) claimed that AD is a commercially proven technology and is widely used to treat high moisture content organic wastes that may reach 80– 90percent moisture. (Abbas S, 2019) Empirically characterized the organic household waste in Bahrain and found that the moisture reached 73%, which is optimum for the AD process.

Biodegradable Waste in Bahrain

According to (Al-Sabbagh MK, et al., 2012), the organic fraction of the MSW reached (60 percent wt.) and is comparable to that in middle- and low-income cities (50–80 percent wt.), although on the basis of gross domestic product (GDP), Bahrain is classified as a high-income country. Since organic waste is considered as the most harmful portion of the MSW content due to its hazardous environmental impact, organic waste management becomes a concern in many of the developing countries with the highest organic portion within their MSW content. Waste composition is considered to be one of the main factors influencing emissions from solid waste treatment, as different types are known to contain varying amounts of degradable organic carbon (DOC), and fossil carbon. According to the MWMUP, the total waste going to Askar landfill – the only landfill in Bahrain which already reached its limit- is about 2,131,683 ton, the details of waste composition are shown in Table 1 below:

Accordingly, the total biodegradable waste in the landfill comes from:

- Domestic waste (food, papers and cardboard, green), Garden waste, and Dead animals.

- Commercial waste: Food, green, paper and cardboard.

- Industrial waste: Food, green, paper and cardboard.

- Sludge from Waste water treatment plant (WWTP)

Based on the Waste Audit Report (MWMUP, 2018: MWMUPA, 2019), the average of the last two years was considered in this study. Therefore, the percentages of the biodegradable fraction under each of the above categories were calculated and found to be as shown in Table 2 below:

Biodegradable waste in landfills undergo degradation process, mainly anaerobic digestion, resulting in methane gas production, which is considered to be the most harmful greenhouse gas (GHG) that causes global warming and as a consequence, climate change.

Therefore, biodegradable waste represents the highest composition percentage in Bahraini MSW, according to MWMUP. It reached more than 60percent in 2017. The most recent waste audit studies held by MWMUP shows that organic waste continues to be one of the biggest components (percentage wise), as shown in Table 2 below. While Table 3 below represents the total Bahrain's biodegradable waste composition in ton per year in details.

METHODOLOGY: COST-BENEFIT ANALYSIS (CBA)

In order to commence the CBA for the technology, the considered project life time in this research is 15 years. Data in this section is based on the cost estimated from waste management technologies plants in developing countries ($/tonne) in Germany (Mutz D, et al. 2017). Further Investigations done by the researcher through communications with experts of supplier companies in the industrial sector. AD technology has a fixed direct cost (capital cost), which includes the cost of: Consultant Fees, Environmental and Social Impact Assessment (ESIA) and Permits, Equipment, Engineering Design and Building. This cost is paid at the first year of the project. Next, the indirect costs that need monthly payment (Operation and Maintenance cost) include: Land Lease Agreement, Loan Repayments, Electricity, Water, Labour of Maintenance, Insurance, Labour of Operations and Transportation. The benefit of AD technology is realized through two different ways: by sales estimated depending on the type of technology and product market price; and through the savings realized by stopping the dumping in the landfill.

LITERATURE REVIEW

(Hochman G, et al., 2015) has evaluated four available waste treatment technologies: direct combustion, landfilling, composting, and anaerobic digestion in New Jersey- USA using the CBA method. Since the economic criterion is a

Table 1. Waste categories by weight in ton in the last two years in Bahrain .

Waste Category	2018	2019	Average
Dead Animals	8031	11971	10001
Building Waste	831609	322472	577041
Commercial Waste	347827	333093	340460
Construction Waste for Recycling		355690	355690
Domestic Waste	563915	566125	565020
Garden Waste	124324	126107	125216
Industrial Waste	81577	81175	81376
Buhair Area Waste	509449		509449
TOTAL	2466733	1796633	2131683

Table 2. Total biodegradable waste under each category in Bahrain.

Biodegradable Waste in Bahrain ton/ year	Commercial	Industrial	Domestic, Garden and Dead Animals	Sludge from WWTP	Total
Total Waste	340,460	81,376	567,542	20,750	1,010,128
Total Biodegradable Waste	136,184	21,158	357,159	20,750	535,251
Percentage of Biodegradable Waste from Total Waste	40	26	57	100	53

Table 3. Total Bahrain's biodegradable waste composition in ton per year.

Description	Ton/year
Total Domestic Biodegradable Waste (food, papers, green)	221,942
Total Garden Waste	125,216
Dead Animals	10,001
Total Commercial Biodegradable Waste	136,184
Total Industrial Biodegradable Waste	21,158
Total WWTP Sludge	20,750
Total Biodegradable Waste in Bahrain	**535,251**

Table 4. Biogas yield and electricity sales estimation for Bahrain.

Total BDW	Biogas m3/ ton	Total biogas yield (m3)	kWh/ton	Total Energy output (KWh)	Total Energy output (GWh)	Electricity cost (USD)	Benefit USD
535,251	450	240,862,950.00	398.5	213,297,523.50	213.30	0.02	4,265,950

priority worldwide among governments, this research took the economic feasibility into consideration as a main criteria for technology selection. Furthermore, (Moutavtchi V, et al., 2008) showed that CBA is useful for decision making in MSW management because it can be utilized as an efficient tool for information support for implementation of waste management technologies. (Khan M and Kaneesamkandi Z 2013) claimed that it is necessary to predict the biogas yield and to perform cost analysis in order to investigate whether the waste conversion into biogas and digestate is financially feasible (Abbas S, 2019).

In a comparable study held in the Kingdom of Saudi Arabia (KSA) by (Khan M and Kaneesamkandi Z 2013), biogas yield of an average value of 450 m3/tonne organic waste was approved based on experimental based literature. For this reason, the approximate biogas yield from organic waste generated in the KSA found to be 3420.50 million m3 per annum from which one tonne OW can generate about 398 KWh. However, the Official Information Portal on Anaerobic Digestion in the UK outlined that digesting 1 tonne of food waste can generate about 300 KWh of energy, considering the electricity cost by EWA of 0.02 USD/KWh. Since the KSA is a Gulf country and shares many similarities with Bahrain in terms of lifestyle, culture, etc., the value considered to estimate the electricity generated from the biogas yield is 398 KWh/tonne biodegradable waste and therefore, was used as a reference in this study, as illustrated in Table 4, which outlines the benefit from electricity sales in USD.

RESULTS

Estimation of Benefit

Table 4 illustrates the benefit from electricity sales in USD.

From Table 4 above, it is obvious that the AD Plant is expected to generate 213.3 GWh/year, with annual revenues of USD 4,265,950 from electricity sales.

Furthermore, according to the MWMUP, the cost of dumping of 1 ton of waste in the landfill is USD 16, so there will be a saving by discontinuing the total biodegradable waste dumping. In addition, from the literature, it was found that each ton of organic waste produces 0.2 ton of fertiliser.

Estimation of Cost

Cost estimates of an anaerobic digestion plant in developing countries was mentioned by (Cioabla A, et al. 2014) who showed that the capital cost of AD is 18$/ton in average. While he stated that the O & M cost is 14.5$/ton. Accordingly, the total Capital cost and the total O & M cost were calculated based on these prices for an AD of 536,000 ton/year capacity for Bahrain and shown in the CBA of an AD plant Table below. Table 5 presents the cost-benefit analysis of an AD plant for the Kingdom of Bahrain.

Based on Table 5 below, the capital cost is a fixed cost which is paid during the first year of the project, whereas the operation and maintenance cost (O&M cost) represents the cash out flow, which is the annual cost considered in calculating the net profit. The benefit is expressed as sales revenues from the digestate that can then be used as fertilizer to enhance the soil in agriculture. Since the net profit number is positive and is high, it can be inferred that the AD project itself is primarily considered to be a viable solution to manage the Biodegradable waste in the Kingdom of Bahrain, after calculating the Net Present Value (NPV) that must also be positive. The NPV is the difference between the present value of cash inflows and the present value of cash outflows. NPV is used in capital budgeting to analyse the profitability of an investment or project. It measures the excess or shortfall of cash flows, in present value terms, once financing charges are met (ElQuliti S, 2016). In addition, the Internal Rate of Return (IRR) is defined as the interest rate at which the net present value of costs (negative cash flows) equals the net present value of the benefits (positive cash flows). An investment is considered acceptable if its IRR is greater than an established minimum acceptable rate of return or cost of capital (ElQuliti S, 2016). Furthermore, the Payback Period (PBP) indicates the amount of time it takes for a Capital Budgeting project to recover its initial cost. In capital budgeting, payback period denotes the period of time required for the return on an investment to "repay" the sum of the original investment. To calculate it, the Payback period = Investment required / Net annual cash inflow (ElQuliti S, 2016).

Considering the discount rate 10percent, the Net Present Value (NPV), the Internal Rate of Return (IRR) and the Payback Period (PBP) were calculated in this study for the AD Plant project based on the CBA shown in Table 6.

The cash flow suggests that the AD is a viable project, since the NPV is positive and worth around USD 33.5 M, with an internal rate of return (IRR) that reached 59%, and a payback period of 1.7 year, which indicated the viability of the project.

Environmental Benefit

According to (Mutz D, et al. 2017) and (Lee U, et al., 2017), the conversion of organic waste to biogas is associated with a number of environmental benefits. Biogas from organic waste reduces the emission of greenhouse gases into the atmosphere (Mutz D, et al. 2017) resulting from organic waste dumping (Lee U, et al., 2017).

Each tonne of organic waste dumped in the landfill releases about one tonne of carbon dioxide equivalents (CO_2-e) in the form of methane (Government of Western Australia, 2018).

Consequently, dumping of 535,251 tonne/year of biodegradable waste in the landfill results in 21410 ton CH4/ year (1 ton biodegradable waste results in 0.04 ton CH4), which is equivalent to 535,251 tonne CO_2-e per year. Therefore, the AD project contribute to GHG emission reduction since the landfill methane has a global warming potential of approximately 25 times higher than that of CO_2 (Mutz D, et al. 2017).

Table 5. Cost-Benefit Analysis of AD Plant for the Kingdom of Bahrain.

Description	USD
Capital cost /ton	18
O&M cost/ton	14.4
Total Capital Cost	9,634,518
Total O&M Cost	7,707,614
Benefits/ Year	
Electricity	4,265,950
Fertiliser	642301
Direct saving by discontinuing waste dumping	8,473,705
Total Benefit/year	13,381,957
Net Profit	5,674,342

Table 6. Cash Flow with NPV, IRR and PBP of the AD Plant Project for Bahrain.

PERIOD	CASH FLOW
0	(9,634,518)
1	5,674,342
2	5,674,342
3	5,674,342
4	5,674,342
5	5,674,342
6	5,674,342
7	5,674,342
8	5,674,342
9	5,674,342
10	5,674,342
11	5,674,342
12	5,674,342
13	5,674,342
14	5,674,342
15	5,674,342
DISCOUNT RATE	**10%**
NPV	33,524,979
IRR	59%
PBP	1.7

DISCUSSION AND CONCLUSION

Accordingly, the Cost-benefit analysis in this study gives an economic evidence to recommend AD to the decision makers as a feasible option to manage the biodegradable waste in the Kingdom of Bahrain, which can then be embedded into the national legal and policy frameworks. However, AD is receiving increasing attention as a possible option of energy recovery from waste in the urban context. However, the operation of biogas plants from heterogeneous MSW poses a major challenge in terms of operational, safety and financial requirements. As a consequence, there are very few successful examples of biogas from MSW in developing countries, due to the absence of segregation at source and mixed waste (Abbas SY, et al., 2020). Moreover, 535,251 tonne/year of CO_2-e can be reduced by discontinuing biodegradable waste dumping into the landfill after implementing the AD plant project, assuming the existing biodegradable generation rate in the Kingdom of Bahrain.

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