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Environmental Economy Investigation on Using Anaerobic Digestion Method in Municipal Solid Waste Management in Tehran, Iran

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ABSTRACT

Tehran generates 7000 tons of municipal solid waste (MSW) daily with 70% of organic component which causes leachate and greenhouse gases generation. Anaerobic digestion (AD), as a natural process, can be a solution. On this basis, the aim of this research is to compare AD and sanitary landfilling as two scenarios environmentally and economically. So, capital cost, operational cost, environmental costs of greenhouse gases GHG emission, Benefits from GHG reduction and selling outputs has been considered and their time value has been calculated for the life span of 20 years. Although landfilling has much lower cost, AD has been selected as the best scenario due to engineering economy parameters. The benefit cost ratio and economical balance of landfilling and AD has been calculated 1.2 and 73.28 respectively. While, these figure are obtained -19.25 and 0.08 for landfilling, respectively. Finally, SWOT analysis has been done for the selected scenario.

1. Introduction

Global warming is of the most environmental concern through more greenhouse gases (GHG) emission by human. Methane and Carbone Dioxide are two major GHG. In this regard, municipal solid waste (MSW) collection, dumping and landfilling emit these two GHGs. Waste Management is quite important role in global warming because among all methane sources landfills, as a part of MSW management chain, are the largest human-related source of methane which is being accounted for 34% of all methane emissions. It is important to know that methane has 21 times the global warming potential of carbon dioxide by mass (EPA, 2016). As an international concern, atmospheric methane concentrations have doubled over the last 200 years and continue to rise, although the rate of increase is slowing (Malinauskaite et al., 2017., 2015; Jouhara *et al.*, 2017).

Tehran, the capital of Iran, generates more than 7000tons of MSW daily with about 70% of organic component (Abduli et al., 2007). Table 1 shows the physical analysis of Tehran MSW at a glance.

On this basis, it is quite important to prepare an alternative method to utilize such kind of MSW instead of landfilling. Anaerobic Digestion (AD) is a good alternative because this method allows for a drastic reduction in pollution stemming from organic part of MSW as it produces a valuable energy carrier. So this research is currently aimed at examining the advantages and disadvantages of the application of anaerobic digestion in Tehran waste management. The economic costs, benefits, and influence of AD on environmental pollution are considerations at the center of their studies, experiments, and observations. Scientists are concentrating on the basic scenario related to hygiene disposal and the first scenario of anaerobic digestion. Each method is evaluated in relation to their environmental and economic impact in the hopes of to be considered in waste management strategy by authorities of Tehran.

AD includes a multi-step process that occurs through the concerted action of several types of bacteria. The first step relates to the biological hydrolysis of the degradable waste solids into smaller, soluble molecules. The second step involves the creation of acid forming bacteria. The final step uses the soluble intermediates as substrates for energy and growth. This results in the formation of fermentation products such as Volatile Fatty Acids (VFAs). VFA-consuming bacteria or methanogens are created, producing methane and carbon dioxide (Harper & Poland, 1987).These three steps are officially known as hydrolysis, acid genesis, and methanogens. The complete process takes place in the large anaerobic digesters holding a temperature range of 30ºC to 65ºC (Kayode & Jude, 2015)

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***Table 1**: Tehran MSW characteristics (OWRC, 2004)*

Component	%	Component	%
Organic	68.8	Ironic metals	1.6
Soft plastic	2.2	Non-ironic metals	0.2
Hard plastic	0.6	Textile	3.4
Pet	0.7	Glass	2.4
Adhesive plaster	6.2	Wood	1.7
Paper	4.4	Leather	0.6
Cardboard	3.7	Rubber	0.7
Dust	1.3	Hazardous	1.6

There are four stages in an anaerobic digestion plant management including pre-treatment, waste digestion, gas recovery, and residue treatment. The pre-treatment stage includes the separation of non-digestible components that include glass metals, and stones from the digestible waste. The result of this process is composed of purified digestible waste. This is found in the last stage and is shredded prior to placing the waste in a digester within a designated retention time. A heat exchanger is used in order to control the digesting vessel temperature. The whole AD process creates a biogas that contains 50-70% methane, 30-45 % carbon dioxide, and hydrogen sulphide (200-400 ppm) (Verma, 2002). De-watering the digester residue and treating the waste results in usable compost. 90 anaerobic digestion plants have existed worldwide since 1996 with 90% of the plants located in Europe (Verma, 2002).

In general there are three classes of AD including single stage, multi stage, or batch methods and be categorized based upon total solids (TS). These are the contents of the digester reactor slurry with slurries consisting of <10%TS, 15-20% TS and 22 - 40 TS classified as low solids, medium solids, and high solids respectively. It is possible to combine any two of the treatment systems, classifying the procedure as either a single stage low solid (SS LS), single stage high solids (SSHS), multi stage low solids (MSLS) and multi stage high solids (MSHS) (Valorga,2017)

The multi-stage process involved in AD occurs in separate reactors with the increased flexibility of each system contributing to the optimization of each reaction. Two reactors are normally used in this process; one for hydrolysis / liquefaction -acetogenesis and the other for methanogens (Lissens *et al*., 2001).

Batch reactors work by first loading the feedstock, allowing the raw materials to undergo reactions before the product is discharged and a new batch is loaded. These bath systems are similar to in-vessel landfills with the exception of a much higher reaction rate (i.e. 50 - 100 % higher biogas production). This higher reaction rate it attributed to the continuous re-circulation of the leachate and higher operating temperatures (Lissens *et al*., 2001).

2. Methodology

Two scenarios have been considered to compare Business as Usual and utilizing AD. So, scenario 1 is defined as landfilling. For real calculation sanitary landfilling with landfill gas collection system equipped with flare is considered. Scenario 2 takes advantages of AD. Since Tehran has a high content of TS in one hand and have non-organic fraction of about 30% in another hand, the best method of AD would be AD dry single stage which is the basis of calculations for scenario 2.

Capital cost (CAPEX), operational cost (OPEX), benefit from selling the out puts (if applicable) have been considered as engineering economic parameters. Environmental cost of GHG emission which is the losses to the nature, people and environment through CO_2 and CH_4 emissions has been considered as environmental economy parameter. Also, income through Clean Development Mechanism due to avoiding CH_4 emission to the atmosphere by utilizing flare in scenario 1 and utilizing AD and electricity generation in scenario 2 have been calculated as other environmental economy parameters.

Since the life span of both scenarios has been considered to be 20 years, time value of money should be considered for OPEX and benefits. Thus, Net Present Value (NPV) has been calculated utilizing equation 1 as follow (Oskounejad, 2015):

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} \quad (1)$$

Where Ct is cost in year t, r is discount rate, and t is desired year number. All costs and benefits in different years should be assessed as their present value. After calculation of NPV of costs and benefits, method of cost-benefit would be applied to choose the better scenario using equation 2 (Oskounejad, 2015).

$$B/C = NPV(B) / NPV(C) \quad (2)$$

Scenario with higher amount of *B/C* is more economical. After choosing the best scenario, a Strength, Weakness, Opportunities, Threats (SWOT) would be applied to provide a clear view for being considered by decision makers. At the end, defensive and aggressive scenarios would be established by combining and analyzing the SWOT matrix (DISNA, 2017).

3. Results and Discussion

In the scenario 1, the most important concern regarding sanitary landfills is the landfill gas (LFG) which can cause explosion and fire risks, hygiene risks, destruction of food products such as vegetables, underground water pollution, odor from the site, as well as GHG emission to the atmosphere (Sharifah & Latifah, 2013). Basic parameters to calculate the sanitary landfill costs are described as follows:

- Landfill gas is generally composed by 50% of methane and 50% of CO_2 (EPA, 2016)

- Potential of Methane and CO_2 generation in landfills are 130 and 100 m3 per tons of MSW in Tehran, respectively (Kamalan, 2009).
- The efficiency of LFG collection and Flare are 70 and 30%, respectively (Gupta et al., 2015).
- Density of Methane and CO_2 are 0.66 and 1.98 Kg/M^3, respectively.
- The global warming potential of methane is 21 times of CO_2 (IPCC, 2001).
- Environmental cost of CO_2 is 210$/ton (Majidi & Kamalan, 2017).
- CAPEX is 10$/ton of MSW (OWRC, 2004).
- OPEX is 2 $/ton of MSW annually (OWRC, 2004).

Utilizing abovementioned basis in calculations leads to have the costs of scenario 1 which are presented in table 2.

Table 2: Costs of Scenario 1

Costs	$/ton
Total capital	10
Operational expense	2 –annually
Environmental Cost of Methane emission	0.14 –annually
Environmental Cost of CO_2 emission	0.09 –annually

The only income from scenario 1 is through CDM. Since flare is oxidizing the generated methane to CO_2, the global warming potential of it decreases by 20 times. It means that there are GHG is emitted quite less as CO_2-eq. The un-emitted CO_2-eq can be targeted by CDM as 10$/ CO_2-eqreduction (Majidi & Kamalan, 2017).

In this case the efficiency of gas collection and flare has been considered as well. Finally, benefit of scenario 1 has been calculated 0.33$/ton of MSW.

NPV of costs and Benefit is calculated and summarized in table 3 by having 20% of discount rate.

Table 3: NPV of costs and benefits of Scenario 1

NPV	$/ton
Costs	-20.86
Benefit	1.61

In scenario 1, the economical balance is -19.25$/ton which means that this scenario is not economical. Also Benefit Cost ratio is calculated as 0.08.

In scenario 2, AD generates electricity and fertilizer. So it has 4 different incomes: (1) selling fertilizer, (2) selling electricity, (3) CDM through GHG emission reduction from MSW (4) CDM through GHG emission reduction due to not using fossil fuel. Also, it has CAPEX, OPEX, and Environmental cost of CO_2 and CH_4 emissions.

AD has much higher cost than Landfill in which capital and operational costs are 162.5 and 42.46$/tons of MSW (Valorga, 2017). On the other hand AD produces biogas that includes 7.55 m^3 of CO_2 and 9.23 m^3 of methane per each tons of MSW (Valorga, 2017).

Utilizing above mentioned parameters and basic parameters described in scenario 1 calculation leads to compute costs of scenario 2 as presented in table 4.

Table 4: Costs of Scenario 2

Costs	$/ton
Total capital	162.5$
Operational expense	42.46 – annually
Environmental Cost	0.35 – annually

By calculating the four different income of scenario 2, value tabulated in table 5 is computed.

Table 5: Benefits of Scenario 2

Benefits	$/ton (annually)
Selling Electricity	43.2
Selling fertilizers	9
CDM for electricity not produced by fossil fuels	28.85
CDM for GHG reduction trough waste management	10.18

NPV of costs and Benefit is calculated and summarized in table 6 by having 20% of discount rate exactly similar to scenario 1.

Table 6: NPV of costs and benefits of Scenario 2

NPV	$/ton
Costs	-370.97
Benefit	444.25

In this case the economical balance is calculates as 73.28 and since it is a positive figure this scenario is economically suitable. Benefit Cost ratio is computed 1.2 which is higher than 1 and it is suitable. For selecting the best scenario, Figures 1 and 2 show the economical parameters briefly.

As it is clear from figure 1 and figure 2, scenario 2 is quite better than scenario 1 environmental economically. So, AD would have advantage if is being used as a solution for waste management in Tehran. SWOT method is used to provide a clear view for utilizing this scenario. Table 7 has strength, weakness, opportunities, threats, and strategies established for AD for Tehran.

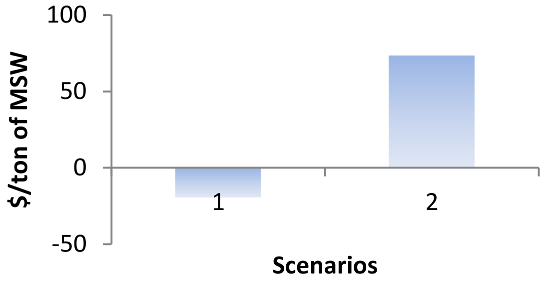

Figure 1: Economical Balance of Scenarios

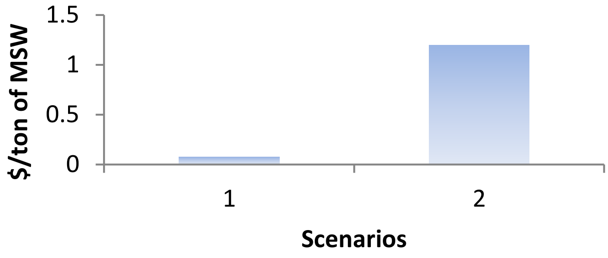

Figure 2: Benefit Cost Ratio of Scenarios

Table 7: SWOT Matrix of AD

	Strength points: S decreasing of need for land to 85%, creating income by production of electricity, heat, and production of organic fertilizers, decreasing GHG emission and sale of Carbone Credit	**Weakness points: W** Relative expensive, lack of serious performance, need for waste separation, lack of public cooperation, potential of unpleasant odors in the factories
Opportunities: O High potentials of destructible environmental resources, possibility of producing energy for decreasing consumption of natural gas, key solution for waste management, decreasing the latent costs of producing energy from fossil fuels	***SO strategies*** SO1- supplying energy by means of heat and electricity and decreasing usage of fossil fuels SO2- application of AD process in the existing landfill site for decreasing of problems by removal of disposal organic wastages	***WO strategies*** WO1-remedy of expenses in the result of applying the process of AD by means of incomes in the result of selling electricity, fertilizers and so on that are produced in this process. WO2- general inform and awakening people from application of separation from the sources and decreasing of costs of using fossil fuels
Threats: T Risk of low public participation in source separation, lack of allocating proper budget	***ST strategies*** ST1-using governmental credits for mechanization process anaerobic digestion for separation and better processing of entering foods. ST2- General informing about decreasing of expenses of using fossil fuels for cooperation in separation of home garbage	***WT strategies*** WT1-using governmental credits for equipping and mechanizing the process of anaerobic digestion and using filtration for removal of unpleasant odors WT2- better and principal application of separating at source

4. Conclusion

Waste Management is by far the most concern of societies. Tehran, a city with 7000 tons of MSW and 5000 tons of organic waste daily, needs a method to manage it. This research has aimed to compare landfilling and AD for Tehran. Results of economical comparison have shown that AD is profitable and landfilling has loss. It is notable that in both methods environmental cost of emissions, revenues through GHG reduction has been considered in addition to economical parameters.

SWOT analysis shows that decreasing of need for land to 85%, creating income by production of electricity, heat, and production of organic fertilizers, decreasing GHG emission and sale of Carbone Credit are AD's strengths. Being relative expensive, lack of serious performance, need for waste separation, lack of public cooperation, potential of unpleasant odors in the factories have been nominated as AD's weakness. Its opportunities can be listed as high potentials of destructible environmental resources, possibility of producing energy for decreasing consumption of natural gas, key solution for waste management, decreasing the latent costs of producing energy from fossil fuels. And AD's threats are appointed as risk of low public participation in source separation and lack of allocating proper budget.

Based on SWOT analysis, here is a list of strategies:

- SO1- supplying energy by means of heat and electricity and decreasing usage of fossil fuels
- SO2- application of AD process in the existing landfill site for decreasing of problems by removal of disposal organic wastages
- ST1-using governmental credits for mechanization process anaerobic digestion for separation and better processing of entering foods.
- ST2- General informing about decreasing of expenses of using fossil fuels for cooperation in separation of home garbage
- WO1-remedy of expenses in the result of applying the process of AD by means of incomes in the result of selling electricity, fertilizers and so on that are produced in this process.
- WO2- general inform and awakening people from application of separation from the sources and decreasing of costs of using fossil fuels
- WT1-using governmental credits for equipping and mechanizing the process of anaerobic digestion and using filtration for removal of unpleasant odors
- WT2- better and principal application of separating at source

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