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Feasibility Study on the Utilization of Municipal Solid Wastes Using Energy Conversion Technology in Muntinlupa, Philippines

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Abstract: This feasibility study dealt with the evaluation of various energy conversion technology for the municipal solid wastes in the City of Muntinlupa, Philippines. With the increasing population and economic activity, waste production is also rapidly increasing. A solution being seen into is the conversion of residual wastes for energy generation. The multi-attribute decision-making scheme was utilized for such evaluation of the alternatives, namely: pyrolysis, gasification, and anaerobic digestion. Among the three, pyrolysis was chosen because of its reliability, availability, carbon emission, net present value, sulfur dioxide emission, and nitrogen oxides emission.

Keywords: *Waste-to-energy, pyrolysis, Muntinlupa, Waste Analysis and Characterization (WACS), Multi-attribute Decision Making (MADM), conversion technology*

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I. INTRODUCTION

A. *City of Muntinlupa*

The City of Muntinlupa, simply called Muntinlupa, is the southernmost highly urbanized city of Metro Manila. As of 2015, it has a population of 504,509. It is bordered by Las Pinas in the west, Paranaque in the northwest, Taguig in the North, Bacoor and Dasmarinas in Southwest, and San Pedro and the Laguna de Bay in the east. The vision of the city is for it to be one of the leading investment hubs in the country, with educated, healthy and God-loving people living peacefully and securely in a climate change-adaptive and disaster-resilient community, under the rule of transparent, caring and accountable leadership. Its missions are: to promote a broad-based economic growth and business-friendly environment for sustainable development; to protect every person from natural and man-made hazards by ensuring strict enforcement of necessary safety measures; to provide quality social services that include education, health care, livelihood and employment, socialized housing, and social assistance, among others; and to institutionalize community participation in local governance, environmental protection, and economic development [1].

B. *WACS Study*

WACS is a study composing of waste generation per time, waste composition, waste properties and characteristics. It is necessary to do WACS study to accurately make waste management decisions and evaluate environmental risk [2]. Table 1 shows the projection of the waste

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generation in Muntinlupa City. As shown in the table the waste generation in Muntinlupa will continue to increase and it is predicted to reach around 300,000 tons/day on 2021.

TABLE 1
WASTE GENERATION PROJECTION IN MUNTINLUPA CITY

Year	Waste Generated (kg/day)
2015	273,293
2016	278,157
2017	283,108
2018	288,148
2019	293,277
2020	298,497
2021	303,810
2022	309,218
2023	314,722
2024	320,324

Table 2 shows the composition of the municipal solid waste in Muntinlupa City. As shown in the Table, around 70% of the municipal solid wastes are non-recyclable. Currently, these non-recyclable wastes are only being disposed on a landfill.

TABLE 2
WASTE COMPOSITION IN TERMS OF PERCENTAGE

Parameter	Composition (%)	Heat Content (MJ/kg)
Biodegradable	43.39	4.36
Recyclable	29.17	-
Special Waste	0.15	-
Residuals	27.29	19.85
Total	100	7.30

C. *Waste-to- Energy Conversion Technology*

The continuous growth and development in urbanization and industrialization, together with unstable population growth, results to an exponential increment in the quantity of Municipal Solid Waste (MSW) in the territory concerned. The MSW includes metal, paper, organic waste, cardboard, leather, wood, rubber, plastics, and the like. In the southern part of Asia, about 70 million tons of wastes is generated per year. The value is expected to triple by the year 2025 [3]. Hence, there is a need to mitigate and control municipal solid wastes through proper management systems. However, countries having relatively lower Gross Domestic Product (GDP), such as Sri Lanka, Malaysia, Thailand, and the Philippines, are having trouble in coping up with this problem due to lack of resources and facilities in taking care of the solid wastes [4]. In Muntinlupa City, 283.10 tons/year of MSW is generated, with 56.61% of the MSW are residual wastes [5].

In 2017, the entire Luzon Island of the Philippines had an average annual growth rate (AAGR) of 12.62%, between the 9,726 MW system peak demand in 2016 and the 10,054 MW of 2017. The peak demand for electricity is having a rising trend, not only in Luzon but also in the National demand [6]. In August 2018, the Manila Electric Co. (MERALCO) faced its customers with an increase from PHP 10.1925 per KWH in July to PHP 10.219 per KWH in August. Despite a decrease of PHP 0.0966 in September 2018, electricity price in the Philippines is second highest in Asia [7].

Waste-to-energy technologies are viable solutions for the treatment of residual wastes for the disposal of municipal solid wastes and power generation [3]. The relatively high calorific value of the pyrolysis gaseous product from MSW has potential use to provide process fuel for energy generation [8].

1) Pyrolysis: The thermal decomposition of biomass in a no-oxygen environment is called pyrolysis. Originally, pyrolysis was used as a method in producing charcoal, mainly in the Middle East and Southern Europe for useful day-to-day necessities. Through the years, the application of pyrolysis became varied in the chemical production field such as obtaining coke and charcoal. Since the heat from burning charcoal was the working temperature for melting copper and tin to produce bronze, pyrolysis was also needed for metallurgical processes [9]. Moreover, pyrolysis is particularly challenging and difficult because it involves a great deal of physical and chemical transformations and produces a large number of product species. The main goal of studies involving pyrolysis is to totally eradicate the dependence on non-renewable fossil fuels for climate change mitigation. The use of pyrolysis in various fields as a biomass thermal conversion technology has been growing internationally. This is because of its high efficiency rate and eco-friendliness. It is able to convert agricultural residues, crap tires, non-recyclable plastic, and most especially, municipal solid wastes for clean energy generation. Products include chemicals, heat, and electricity [9, 10].

2) Gasification: The process of converting organic and fossil fuel matter into hydrogen, carbon monoxide, and carbon dioxide. The feedstock is entered at an operating temperature of greater than 700 degree Celsius. The reaction is only done at partial combustion through controlled oxygen and steam. The output gas is called synthesis gas, syngas, or producer gas. The gas product can be used as feed through a power plant. The generated electricity is considered as renewable, especially if the feed is biomass [11].

3) Anaerobic digestion: The chemical decomposition of organic matter into products such as carbon dioxide, methane and water, by two groups of microorganisms, bacteria and archaea with the absence of oxygen is referred to as anarerobic digestion. It has 4 major processes: namely, hydrolysis, acidogenesis, acetogenesis, and methanogenesis. In the final step of anaerobic digestion, the products of the acetogenesis are converted into methane gas by two groups of microbes known as acetoclastic and hydrogen-utilizing methanogens. The acetoclastic methanogens convert acetate into carbon dioxide and methane. Hydrogen-utilizing methanogens reduce hydrogen and carbon dioxide into methane [12].

II. PROBLEM STRUCTURE AND DECISION MODELING

A. *Decision Problem*

The Muntinlupa City produces a high number of residential wastes with 0.5417 kg/day/capita or 288,147.56 kg of residential wastes per day. From the WACS by the Muntinlupa City Environmental Sanitation Center (ESC), it was found that 24.21% of those wastes can be used for waste-to-energy utilization. Diverging a portion for energy generation is viable for the benefit of government or public sector such as the city school, library, or hospital. The decision would be to select the most feasible waste-to-energy technology for the utilization of the municipal solid waste of Muntinlupa City.

B. *Objectives*

1) Hierarchy of Objectives 1. The fundamental objectives of the project are to:

- Maximize economic gains on the part of the Muntinlupa LGU in putting up a waste-to-energy facility;
- Minimize detrimental environmental impacts of non-recyclable residual wastes thrown in the landfills; and
- Minimize negative social impacts on the citizens of Muntinlupa City.

2. The means objects of the project are to:

- Reduce the cost of municipal solid waste management;
- Generate savings from municipal solid waste;
- Reduce greenhouse gas emissions;
- Reduce the generation of particulate matter;
- Create job opportunities for career, skilled, and semi-skilled personnel in construction, operating, and maintaining the facility
- Minimize health hazards from criteria air pollutants

C. *Means-Objectives Network*

The means objective network (Fig. 1) shows the relationship among the objectives. The reduction in the operating and maintenance costs will result to an increase in savings. Furthermore, both the increase in savings and the reduction in the operating and maintenance costs contribute to economic gains and the reduction in the emissions of criteria air pollutants will minimize the its health hazards.

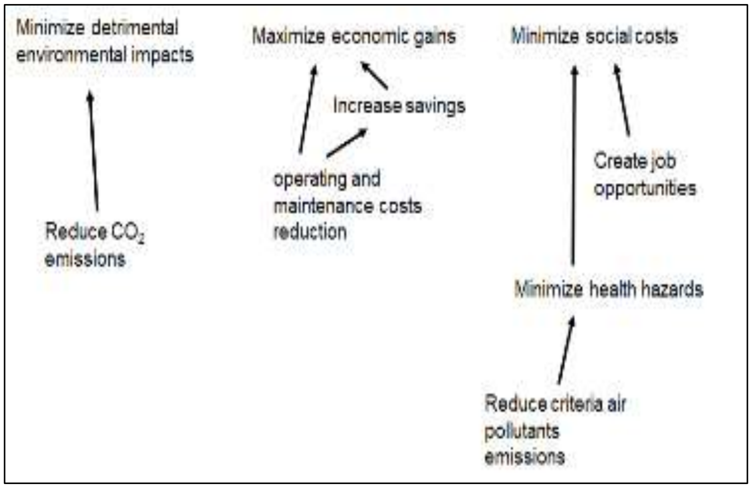

Fig. 1. Means-objectives network

D. Valuation of Objectives

The weights for each fundamental objectives are presented in Table 3. These are the environmental, economic, and social aspects to be considered in the decision-making process.

TABLE 3
WEIGHTS OF FUNDAMENTAL OBJECTIVES

Fundamental Objectives	Weight, %
Economic	50
Environmental	30
Social	20

E. Alternatives

The alternatives that were considered in the study are the energy conversion technologies to be considered in using the municipal solid wastes as source of energy. These include pyrolysis, gasification, and anaerobic digestion. Incineration of municipal solid wastes was not included since it is still illegal in the Philippines. Fig. 2 shows the waste-to-energy conversion flowchart. It starts with the household and passes through the collection and segregation facilities. From there, the sorted wastes will either proceed to the Material Recovery Facility (MRF) or go to the landfill. The ones that will be thrown to the landfill will be the feedstock for energy generation.

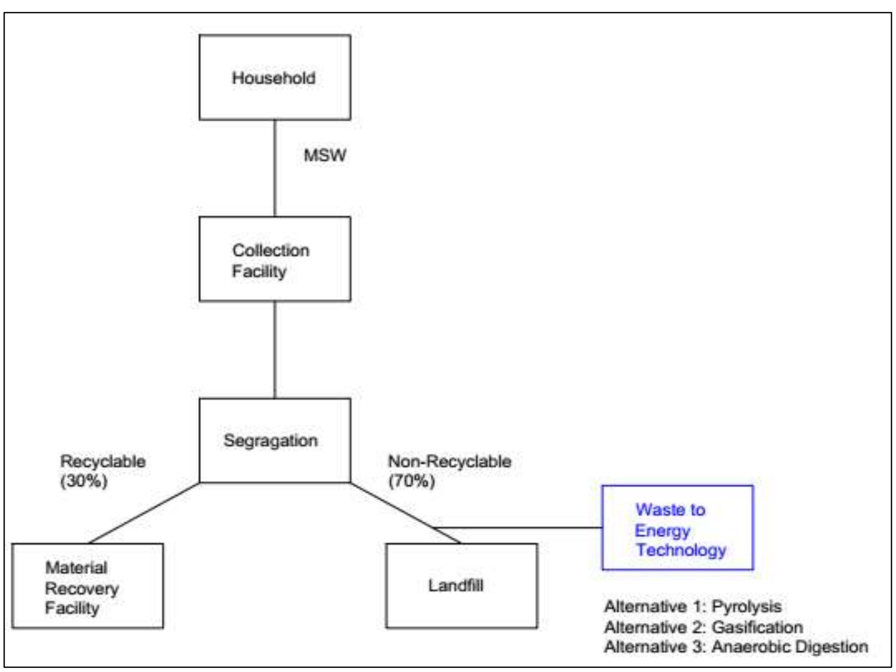

Fig. 2. Waste-to-energy conversion flowchart

F. Influence Diagram

The influence diagram for the decision problem is shown in Fig. 3. As shown in the figure, the choice of waste to energy technology will affect the savings of the LGU, operating and maintenance costs of the facility, the carbon dioxide emissions, criteria air pollutants emissions, and the creation of job opportunities. The savings of the LGU and the operating and maintenance costs of the facility reflect the economic gains while the health hazards from criteria air pollutants and the creation of the job opportunities reflect social impacts. The alternatives will be evaluated in terms of the net value which is the integration of economic gains, environmental impacts, and social impacts.

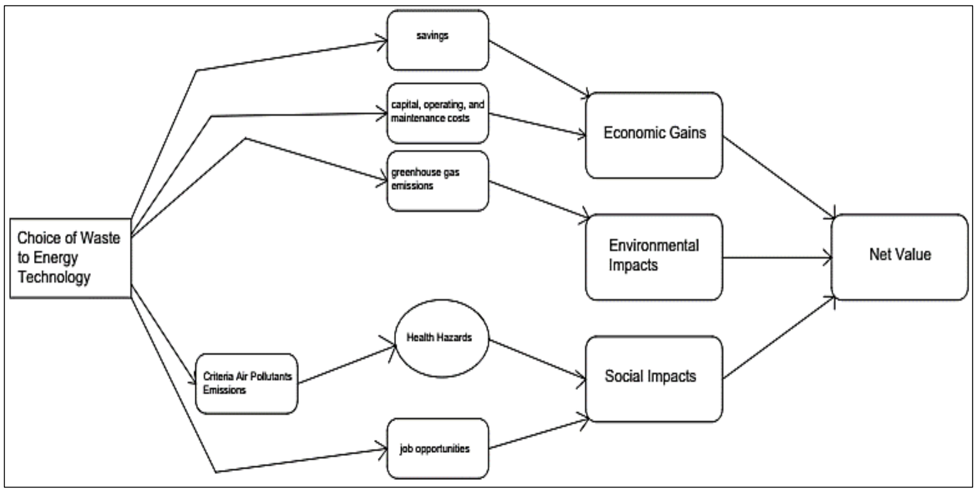

Fig. 3. Influence diagram of the decision problem

G. Decision Tree

The decision tree for the decision problem is hown in Fig. 4. It was constructed based on the format of a decision tree for a decision problem with multiple objectives. Each row of the table represents the alternatives while each column indicates the fundamental objectives. Thus, each waste to energy technology will be evaluated in terms of economic, environmental, and social impacts [13].

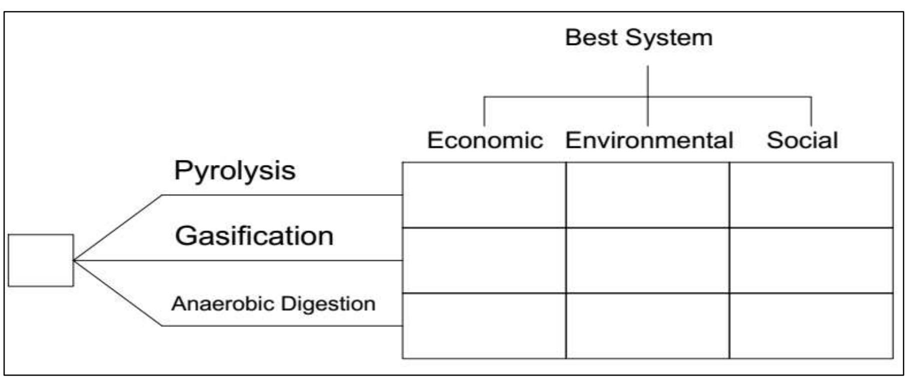

Fig. 4. Decision tree of the decision problem

H. Possible Sources of Uncertainty

The possible sources of uncertainty in this waste-to-energy project are:

- Whether or not there is an actual need to create a waste-to-energy plant;
- Whether or not the product would be economical for the Muntinlupa City Local Government Unit;
- Whether or not the creation of a waste-to-energy plant would lessen the hazardous environmental impacts of the wastes;
- What capacity of the power plant is needed to maximize feedstock usage; and
- Whether or not the city laws will allow the emission levels and waste water generated by the energy conversion technology

III. TECHNICAL ANALYSIS

A. *Pyrolysis*

The process flow diagram for the proposed pyrolysis system is shown in Fig. 5 As shown in the figure, the waste feed will undergo size reduction. Then, It will be subjected to pyrolysis. The syngas and bio-oil produced from pyrolysis will then undergo combustion. Finally, the flue gas from the combustion chamber will pass the gas turbine to generate electricity.

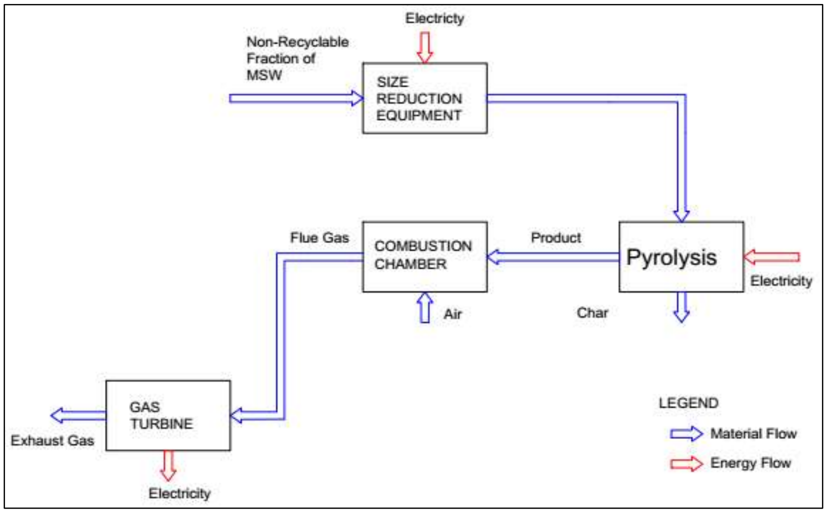

Fig. 5. Pyrolysis of MSW process

For calculation purposes and comparison, the designed waste-to-energy facility will have a capacity of 30 kW. It will be operated 10 hr daily and 208 days in a year. Thus, around 62,400 kWh of energy will be generated in a year. The technical analysis will include the determination of the amount of waste feed to supply the target capacity of the proposed plant. The values obtained from the calculation are shown in Table 4. As shown in the table, around 258 metric tons of waste feed is needed to generate 62,400 kW-h of energy in a year.

TABLE 4
WASTE FEED FOR PYROLYSIS

Parameter	Value
Waste feed requirement, kg/yr	257,651
Volume of waste feed, m^3/yr	1,498

B. *Gasification*

The process flow diagram for the proposed gasification system is shown in Fig. 6. As shown in the figure, the waste feed will undergo size reduction. Then, It will be subjected to gasification. The syngas produced from gasification will then undergo combustion. Finally, the flue gas from the combustion chamber will pass the gas turbine to generate electricity.

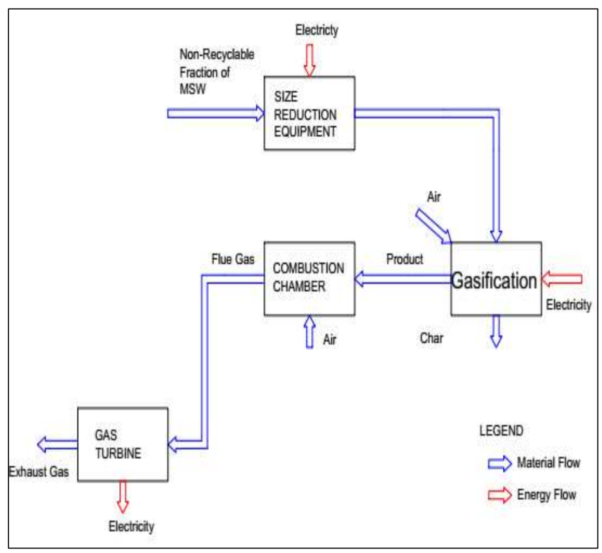

Fig. 6. Function principle of explosion welding

The values obtained from the calculations related to gasification are shown in Table 5. As shown in the Table, around 260 metric tons of waste feed is needed to generate 62,400 kW-h of energy in a year.

TABLE 5
WASTE FEED FOR GASIFICATION

Parameter	Value
Waste feed requirement, kg/yr	259,368
Volume of waste feed, m^3/yr	1508

C. Anaerobic Digestion

The process flow diagram for the proposed anaerobic digestion system is shown in Fig. 7. As shown in the figure, the waste feed will undergo size reduction. Then, it will be subjected to anaerobic digestion. The biogas produced from anaerobic digestion will then undergo combustion. Finally, the flue gas from the combustion chamber will pass the gas turbine to generate electricity.

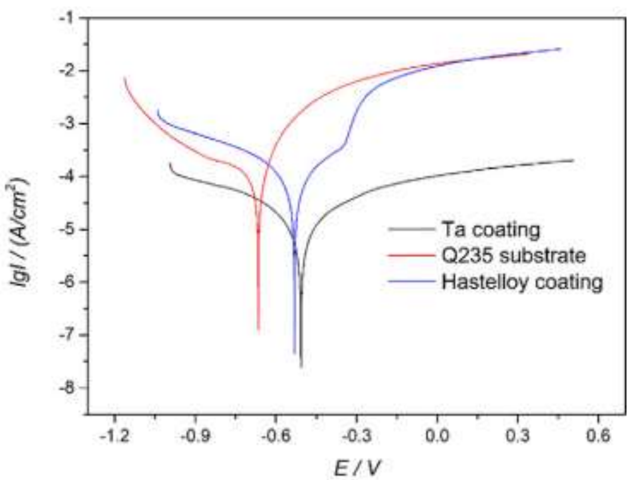

Fig. 7. Anaerobic digestion for MSW process

The proposed anaerobic digestion system will also have a capacity of 30kW. It will be operated 10 hr daily and 208 days in a year. Thus, around 62,400 kWh of energy will be generated in a year. The technical analysis will include the determination of the amount of waste feed to supply the target capacity of the proposed plant. The values obtained from the calculation are shown Table 6. As shown in the Table, around 1,164 metric tons of waste feed is needed to generate 62,400 kWh of energy in a year.

TABLE 6
WASTE FEED FOR ANAEROBIC DIGESTION

Parameter	Value
Waste feed requirement, kg/yr	1,164,623
Volume of waste feed, m^3/yr	6771

IV. ECONOMIC ANALYSIS

A. Time Periods

The base year of the analysis is set in 2018, while the investment year is set the following year. The gestation period will start in 2020 and the operation will start in 2021 till 2040 or 20 years of service life. The period of analysis follows the useful life span of the technology.

B. Financial Aspects

The Net Present Value (NPV) and other economic measures for pyrolysis, gasification, and anaerobic digestion were determined. These include the NPV, ROI, benefit/cost ratio, and payback period. Of the three technologies, pyrolysis has the lowest payback period and gasification has the highest ROI.

TABLE 7
NET PRESENT VALUE AND OTHER ECONOMIC MEASURES FOR PYROLYSIS

Parameter	Value
Net Present Value, PhP	3,835,849
Return of Investment,	% 1.1646
Benefit/Cost Ratio	2.7247
Payback Period, years	5.36

TABLE 8
NET PRESENT VALUE AND OTHER ECONOMIC MEASURES FOR GASIFICATION

Parameter	Value
Net Present Value, PhP	3,964,420
Return of Investment,	% 1.2525
Benefit/Cost Ratio	2.8354
Payback Period, years	6.46

TABLE 9
NET PRESENT VALUE AND OTHER ECONOMIC MEASURES FOR ANAEROBIC DIGESTION

Parameter	Value
Net Present Value, PhP	3,964,420
Return of Investment,	% 1.2525
Benefit/Cost Ratio	2.8354
Payback Period, years	6.46

V. ENVIRONMENTAL ANALYSIS

A. Carbon Dioxide Emissions

The environmental impact of the alternatives was quantified based on their carbon dioxide emissions. The carbon dioxide emissions of the three waste to energy systems are presented in Table 10. As shown in the Table, although anaerobic digestion has a lower kg carbon dioxide emitted per kg of MSW fed, it still has the highest amount of carbon dioxide emissions in a year since it requires the largest amount of waste feed to reach a 30 kW capacity.

TABLE 10
CARBON DIOXIDE EMISSIONS FROM THE ALTERNATIVES

Parameter	Pyrolysis System	Gasific. System	An. Digestion System
Carbon Content, kg CO_2/kg MSW	0.7743	0.7429	0.253
MSW Feed Requirement, kg/yr	257,650.53	259,368.20	1,164,623.32
Carbon Emission, kg CO_2/yr	199,498.81	192,684.64	294,649.7

B. *Criteria Air Pollutant Emissions*

For criteria air pollutants, nitrogen oxides and sulfur dioxide were considered. The nitrogen oxides and sulfur dioxide emissions of the three system are presented in Table 11. These criteria air pollutants are hazardous to human health. Thus, these values will be considered in the social analysis.

TABLE 11
NITROGEN OXIDES AND SULFUR DIOXIDE EMISSIONS FROM THE ALTERNATIVES

Parameter	Pyrolysis System	Gasific. System An.	Digestion System
NO_x Content, g NO_x/kWh	1.22	1.22	0.57
SO2 Content, g SO_2/kWh	0.081	0.081	0.009
Energy Output, kWh/year	62,400	62,400	62,400
NO_x Emission, kg/yr	76.128	76.128	35.57
SO_2 Emission, kg/yr	5.05	5.05	0.5616

VI. SOCIAL ANALYSIS

A. *Public Health*

The operation of the waste to energy plants generation emissions in the form of CO_2, NO_x, and SO_2. Nitrogen oxides (NO_x) are highly reactive, colorless, and odorless gases. The main effect of NO_x on the human body is respiratory inflammation at high enough concentration. Long term exposure can cause weakening of lung capabilities, vulnerability to respiratory related medical conditions, increased sensitivity to allergens, and magnified allergic reactions. NO_x also helps the formation of very fine particulates as well as ground level ozone when it reacts with pollutants in the presence of heat and light. Smog can be carried to long distances by the wind and will also cause damage to plants and is capable of decreasing crop yield [14]. Sulfur dioxide or SO_2 affects the human body mainly by breathing it in. It causes irritation in the respiratory tract starting from the nose all the way to the lungs. It induces coughing, wheezing, shortness of breath, and a compressive feeling in the chest area. These symptoms can be instantaneous and will last up to 15 minutes. Like NO_x, people with asthma and respiratory problems, as well as children and elderly are especially vulnerable to SO_2. For a given amount of energy to be produced, the pyrolysis and gasification processes produced equal amounts of NO_x and SO_2 emissions while anaerobic digestion process produce significantly less [15].

B. *Economic Opportunity*

Landfills and collection sites are usually eyed by informal settlers as source of income and goods despite the poor environmental conditions in those areas. The construction and operation of waste to energy conversion plants will provide job opportunities, particularly for project managers, engineers, and operators. Segregation is also an avenue of opportunity for menial work, which is necessary for raw material preparation. This step is more important for the aerobic digestion process since it has a lesser variety of materials that it can process.

VII. INTEGRATION BY MULTI-ATTRIBUTE DECISION-MAKING

The summary of the results of the economic, environmental, and social analyses is presented in Table 12. As shown in the table, gasification has the highest net present value and lowest carbon dioxide emission while anaerobic digestion has the lowest NO_x and SO_2 emissions.

In order to select the best alternative based on the objectives, MADM will be employed. Simple Additive Weighting (SAW) method is the simplest and most widely used MADM method. In this method, each attribute will be assigned with a weight. The sum of assigned weights must be equal to one. Then, the alternatives will be assessed based on the attributes. The overall performance of an alternative can be calculated using Equation 1.

$$P_i = \sum_{M}^{j=1} w_j m_{ij} \quad (1)$$

TABLE 12
RESULTS OF ECONOMIC, SOCIAL, AND ENVIRONMENTAL ANALYSES

Energy Conv. Tech.	Pyrolysis	Gasification	Anaerobic Digestion
Economic (NPV, PhP)	3,835,849	3,964,420	3,386,240
Environment (Carbon Emission, $kgCO_2$/yr)	199,498.81	192,684.64	294,649.7
Social (Health Hazard, $kgNO_x$/yr)	76.128	76.128	35.57
Social (Health Hazard, $kgSO_2$/yr)	5.05	5.05	0.5616

The w_j values are the weights of each attribute, while m_{ij} are the values of the attributes for an alternative. Since the units of the attributes in this decision problem are different from each other, the values of m_{ij} must be normalized by dividing them with the highest m_{ij}.

The calculated normalized values are presented in Table 13. The normalized values for the environmental and social attributes were negated since the goal was to minimize the values for these attributes. The assigned weights of the attributes are based on the valuation of the objectives from section 2. The 20% weight for social impacts is further disaggregated to: (1) 10% for health hazards from NO_x, and (2) 10% for health hazards from SO_2.

TABLE 13
NORMALIZED VALUES OF THE ATTRIBUTES FOR EACH ALTERNATIVE

Energy Conv. Tech.	Pyrolysis	Gasification	Anaerobic Digestion
Economic (NPV), 0.5	0.9676	1	0.8542
Environment (Carbon Emission), 0.3	-0.6771	-0.6539	-1
Social (Health Hazard, NO_x), 0.1	-1	-1	-0.4672
Social (Health Hazard, SO_2), 0.1	-1	-1	-0.1112

The obtained overall performance for each alternative is presented in Table 14. As shown in the table, the alternative with the highest overall performance score is gasification. Thus, gasification is the best alternative for this decision problem.

TABLE 14
NORMALIZED VALUES OF THE ATTRIBUTES FOR EACH ALTERNATIVE

Alternatives	Overall Performance Score
Pyrolysis	0.08067
Gasification	0.10383
Anaerobic Digestion	0.06926

VIII. SUMMARY AND CONCLUSION

The primary goal of the study was determine the feasibility of utilizing waste to energy conversion technology to reduce the amount of municipal solid waste being sent to the landfills. The results of the MADM analysis show that gasification process is the best alternative to be used as waste to energy using the current designs and parameters. The pyrolysis process also showed good results, with a closer overall score to that of the gasification process. Both technologies showed quick payback periods, with the gasification process achieving a payback period of 6.46 years while the pyrolysis process is at 5.36 years. Despite the difference in payback period in favor of the pyrolysis process, the gasification process is still more profitable and has less CO_2 emission than the pyrolysis processes, which made it the better alternative.

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