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Appropriate Technology for Municipal Solid Waste Management Based on Wastepreneurship Implementation

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Abstract. Piyungan landfill is the biggest landfill in the Special Region of Yogyakarta, Indonesia, which receives municipal solid waste (MSW) from two districts and a city, while its designed service time has been over and faces operational obstacles. Meanwhile, the volume of the MSW grows rapidly and exceeds the reduction rate in their sources. The difficulty in finding a new landfill area is the reason why appropriate technological alternatives in the MSW management are strongly needed. Therefore, the study aimed to evaluate the social and economic aspects and formulate appropriate technology based on the waste entrepreneurship (wastepreneurship) concept. The methods of this study were conducting calculation of waste characteristics and composition, social evaluation, and economic evaluation of the combination of composting, incinerator, and sanitary landfill. Waste characteristics and composition were taken using direct field measurement following Indonesia's National Standard Guideline about retrieving and measuring examples of urban waste emergence and composition. Characteristics of waste are used for the calculation of calorific value and energy. The social evaluation was conducted using an in-depth interview with the rag pickers. The economic evaluation was conducted using net present value, internal rate of return, and payback period. The result of the study shows that Piyungan Landfill with total combustion waste reach 82.22% has the potential of incinerator implementation. In social evaluation, the implementation of composting and incinerator technologies would open employment for the surrounding community and rag pickers. The economic evaluation shows the combination of composting and incinerator technologies was economically feasible with an average profit margin of 12.97% in the operational period of 18 years. In conclusion, the concept of wastepreneurship is relevant in Piyungan Landfill by adjusting the MSW management paradigm from previously cost-center into business-center.

Keywords: Economic evaluation, Landfill, Social evaluation, Solid waste management, Waste entrepreneurship

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INTRODUCTION

Piyungan Landfill, located in Bantul, Yogyakarta, Indonesia, receives solid wastes from two districts and a city in the Special Region of Yogyakarta, including Sleman District, Bantul District, and Yogyakarta City since 1995 (Putra et al. 2018). Municipal Solid Waste (MSW) disposal to the landfill in 2020 was 639.4 tons/day with an annual growth rate of 8% and lead to increasing demand for landfill area of almost 447 hectares in 2030 (Sudibyo et al. 2017).

The reduction of MSW at sources has not been optimal since the existing waste banks in the Special Region of Yogyakarta could only reduce 34.3 tons per day or 6.25% of the total MSW disposed to the Piyungan Landfill (Putra et al. 2018; Sudibyo et al. 2017). Although there has been a reduction of MSW in their sources, the remaining waste should be disposed to the landfill that required final processing. Therefore, thermal or biological MSW processing technologies should be implemented in the landfill (Sudibyo et al. 2017). Thermal technology has economic feasibility with optimal waste reduction (Sudibyo et al. 2016). Proper waste management requires the capacities to implement modern tools (Łęgowik-Świącik 2019). There is also potential for a new paradigm to be implemented in the social, economic, technical, and environmental aspects of the landfill (Prihandoko et al. 2020).

Waste entrepreneurship (waste-preneurship) is a proposed concept of the MSW management model, which is based on the idea that MSW still holds a value that can be recovered into income sources. Wastepreneurship model implementation can change MSW management practices that are costly (cost-center) into a source of income (business-center). The waste-preneurship implementation may be simply as sorting waste processing methods based on the categories of waste recycling, worth selling organic waste composting, to the utilization of MSW into energy sources (waste-to-energy) (Prihandoko et al. 2020). Recycling has the potential to produce income, advance ecosystem services, create a cleaner environment while supporting human prosperity in the process (Gwada et al. 2019).

Various technological alternatives in MSW management are implemented in the landfill, including sanitary landfill, biological processing, and thermal processing. Landfill still becomes the predominant MSW disposal method in Indonesia, with a landfill disposal rate of 79% (Kaza et al. 2018). National Regulation of Republic Indonesia Act, Number 18 of 2008 About Waste Management, dictates that every landfill use controlled-landfill or sanitary-landfill method in their waste management. However, the fact is that most of the landfills in Indonesia have not maximally implemented the sanitary-landfill system (Ministry of Energy and Mineral Resources 2015; Rahim et al. 2012). MSW characterization is a significant advance in establishing a waste management system (Demiraslan and Çelik 2018). The waste generation of the Piyungan Landfill reached 521.5 tons/day in 2018. At the annual waste growth rate of the landfill of 8% (Sudibyo et al. 2017), it was predicted that the waste generation of the landfill would be 2,625.14 tons/day in 20 years or 958,178 tons/year, meaning that it would increase five times.

Composting is simple biological processing that can be easily carried out. Large-scale processing has been carried out in various cities in India with various capacities from 200-1,400 tons of waste/day (Otoo and Drechsel 2018). Meanwhile, incineration is the most popular MSW processing. Up to 2015, there have been 1,179 units of incinerators that operated worldwide (Makarichi et al. 2018). Wastepreneurship model based on waste to energy incinerator in Yogyakarta's Piyungan Landfill was calculated feasible economically. The incinerator was proposed as chosen waste to energy technology which feasible in economic, social, and environmental aspects (Prihandoko et al. 2019; Prihandoko et al. 2020).

The implementation of waste-to-energy-based waste processing technology such as incinerators can provide people with employment (Cucchiella et al. 2014). People's participation could be upgraded by amplifying empowerment and raising the recurrence of people's inclusion in social community activities (Brotosusilo 2020). Also, the implementation of the composting with windrow system requires many unskilled laborers. It will provide the surrounding people of the composting installation with employment (Otoo and Drechsel 2018), advancing financial sustainability by implemented solid waste fees and diminishing costs by an assortment of recyclable materials, improving compost quality and selling rate (Abdoli et al. 2016). Processed food waste could not be composted because it invited vector animals (i.e., rats and cockroaches) and interfered with the composting process. Food waste can be managed using a deliberate measure of reducing, reusing, and recycling (Limon and Villarino 2020). Economically, the development of waste-to-energy technology gives a faster and stable return on investment (Cheng and Hu 2010) while effectively reducing needed space for landfills and pollution (Tsunatu et al. 2015).

Based on the needs of MSW management alternatives, the study aimed to examine the social and economic aspects and the appropriate technology based on the solid waste characteristic from the quality, quantity, and continuity. The case study is focused on Piyungan Landfill, Yogyakarta, Indonesia.

METHODOLOGY

The study was conducted in Piyungan Landfill situated in Ngablak, Sitimulyo Village of Piyungan Subdistrict of Bantul District, Special Province of Yogyakarta, Indonesia. Social data were gathered using interviews and questionnaires for the respondents of rag pickers. The rag pickers respondents were chosen by their knowledge and experience working in the landfill (key informant). The total number of rag pickers operated in the landfill is 200 persons. The questionnaire was applied using in-depth interviews. The questions are including the number of years working at the landfill, the number of used goods that can be obtained in a day, revenue per day, the opinion related to the condition if the collection of used goods is limited in time and amount, and the opinion related to waste processing at the landfill further. The measurement of waste characteristics and composition was conducted following Indonesia National Standard Guideline number 19-3964-1994 About the Method of Retrieval and Measurement of Examples of Urban Waste Emergence and Composition. The composition is measured using Eq. (1).

$$Composition = \frac{Component\ weight\ (kg)}{Total\ trash\ weight\ (kg)} \times 100\% \quad (1)$$

Characteristics of waste are used for the calculation of calorific value and energy. This calculation is done with laboratory analysis to obtain a proximate value. The calorific value of the laboratory analysis results shows the calorific value of waste in a wet state. The value of dry calorific value is calculated by Eq. (2) (Worrel and Vesilind 2012).

$$Dry\ Caloric\ Value = Wet\ caloric\ value\ x\ \frac{100\%}{100\% - moisture\ content}$$

The chosen technological alternatives were composting, incinerator, and sanitary landfill. The composting was chosen considering its simplicity and labor-intensive. The percentage of compostable solid waste is derived from the total composition percentage of vegetable waste, fruit waste, and gardening waste. Incinerator technology was chosen considering the maturity of the technology that has been implemented widely and was useful to overcome the problem of composting and incinerating residues. Sanitary landfill was selected since its relevance with Indonesia's national program for waste management. By implementing composting, incinerator, and sanitary landfill, technological alternatives are conducted under scenarios: organic biowaste processed using composting, organic non-bio waste, and inorganic waste processed using an incinerator, the residual from the incinerator and non-processed waste will be processed using sanitary-landfill. The combination of the alternatives is valuated using parameters as stated in Table 1.

Economic analysis was made to the combination of the three alternatives, which are composting, incinerator, and sanitary landfill. The factors of estimated investment and operational costs were determined using literature studies to estimate the reasonable values of each key parameter, based on the similarity of measurement and waste processing concept conducted by previous studies. The parameters used are shown in Table 2.

Table 1. Valuation Parameters for Combination of the Alternatives

Parameter	Description	References
The wastes are taken by rag pickers	Of the total input to the landfill	Field Survey
Compost production	Of the total compostable organic waste	Komilis and Ham, 2004
Incinerator residue	Of the total mass of the combustible waste	Lu, 1996
Incinerator power production factor	MWh/ton of the burned MSW in the incinerator	Tsai, 2019
Sold power	Of the total incinerator power production	Tsai, 2019
Sold compost	Of the total compost production	Local Price
Composting residue (screen rejects)	Of the total compostable organic waste	Tsai, 2019

Economic analysis is carried out through economic feasibility calculation with Cost-Benefit Analysis (CBA) approach. CBA calculation method used is the benefit-cost ratio (B/C ratio). The calculation of the B/C ratio begins with the identification of all the benefits and costs of the technology to be applied and calculates the benefits and costs in value for money. If the B/C ratio > 1, then the technology is worth continuing, but if the B/C ratio < 1, the technology is not feasible or potentially losing (Boardman 2015). The B/C Ratio is calculated with Eq. (3).

$$B/C\ Ratio = \frac{Total\ Revenue\ (B)}{Total\ Production\ Cost\ (TC)} \quad (3)$$

Table 2. Parameters of Investment and Operational Cost

Parameter	Description	References
Tipping fee	per ton of MSW	ESDM, 2015
Investment cost of the sanitary landfill	per ton of MSW	Chong et al. 2005
The operational cost of the sanitary landfill	per ton of MSW	Chong et al. 2005
The selling price of compost	per kg	Local Price
Investment cost of the composting plant	per input of MSW	Otoo and Drechsel, 2018
Operational cost of the composting plant	per ton of MSW	Otoo and Drechsel, 2018
The selling price of power	per MWh	ESDM, 2015
Investment cost of the incinerator	Capacity 1000 ton/day	Zhao et al. 2016
The operational cost of the incinerator	per ton of burned MSW	Zhao et al. 2016

Other economic evaluation parameters are Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PP). NPV is the difference between the present value of cash inflows and the present value of cash outflows. NPV is a standard measuring instrument in capital planning and investment feasibility evaluation to analyze the profitability of an investment (Eq. (4)).

$$NPV = \frac{Rt}{(1+i)^t} \quad (4)$$

NPV= net present value
Rt = net cash flow at time t
i = discount rate
t = time of the cash flow

IRR is a discount rate when the NPV is equal to zero, meaning that the IRR must always be greater than the discount rate used in NPV calculations to ensure an investment remains viable (Eq. (5)).

$$NPV = \sum_{t=0}^{T} \frac{Ct}{(1+IRR)^t} \quad (5)$$

C = Cash Flow at time t
IRR = discount rate/internal rate of return expressed as a decimal
t = time period

The payback period (PP) is the time needed to return the cost of an investment. The faster the return time, the more desirable the investment will be. The prediction formula of 20 years net profit was calculated considering net cash flow, cumulative cash flow, depreciation, and income taxes. The labor cost was included in the operational cost. Net cash flow was measured using Eq. (6).

$$Net\ Cashflow = Total\ Income - Total\ Expenditure \quad (6)$$

RESULTS AND DISCUSSION

Waste Generation of Piyungan Landfill and Implementation of Technological Alternatives

Field survey in Piyungan Landfill indicates the biggest component of the waste composition in the landfill was food waste (51.21% of weight) followed by plastic (17.96% of weight), paper (11.95% of weight), diaper (8.69% of weight) and the combination of other wastes that reached 10.19% of the weight. There were 12% of the total MSW disposed of in the landfill that was taken by rag pickers. The solid waste percentage that could be composted was 13.67% consisting of vegetable waste, fruit waste, and gardening waste. The compost production calculated 80% of the total processed waste. The predicted compost production in the first year of operation would be 23,075.95 tons/year, with the annual sale of the compost was 50% selling price was IDR 1,000,000/ton of the compost.

The results of the calculation of the value of waste calorific show the highest calorific value owned by organic waste. If done pre-treatment in the form of drying on waste, all categories of waste can be processed thermally with an average calorific value of 19,961 kJ/kg. According to the calculation, Piyungan Landfill with total combustion waste reach 82.22% has high chance of incinerator implementation. The incinerator able to process combustible wastes, plastic, rubber and leather, wood and diapers. Assuming the net salable power was 75%, the incinerator will be able to produce 0.465 MWh/ton of the waste burned. The incinerator's construction takes two years to complete and will be operated in the third year of the construction project. The power production in the first year of the incinerator operation is 85,251.86 MWh, and the sale of the power is 63,938 MWh. The residues of the composting and incinerating were disposed to the landfill with the sanitary-landfill method. The residue of the composting process was 14% of the mass of the processed wastes and in the incinerator was 20% of the mass of the burned wastes, while the remaining wastes that could not be processed in the composting and incinerating processes were 4.13% of the total wastes. The flow of processed waste is shown in Fig. 2.

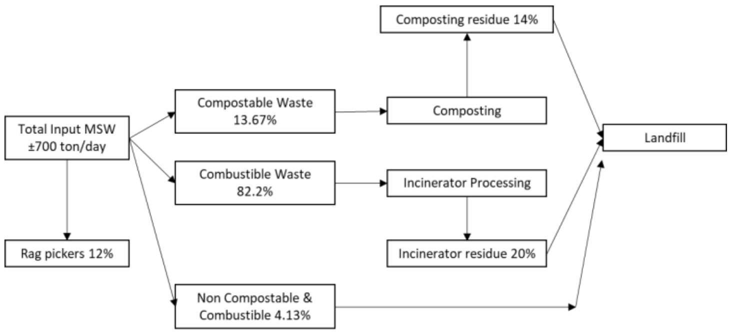

Fig. 1: Flowchart of Processed Waste in the Landfill

The compost and power produced by the incinerator shown in Table 3. The values act as the percentage and number from each parameter derived from literature references.

Social Aspect of the Implementation of the Technological Alternatives in the Piyungan Landfill

Social surveys indicate 93% of the respondents have been rag pickers in the landfill for more than two years. There were 43% of them with a daily income of IDR50,000 - 75,000, 30% with a daily income of IDR25,000 – 50,000, and 10% with the daily income of IDR25,000, and the remaining 13% with a daily income of more than IDR75,000. There were 80% of the respondents agreed on the advanced processing of the waste in the landfill. They also expect that they would still be allowed to do their job through the advanced waste processing technology was implemented in the landfill.

Table 3. The factors in estimating compost production and incinerator power in the combined scenario of composting, incinerator and sanitary-landfill

Parameter	Value	Description
The wastes are taken by rag pickers	12%	Of the total input to the landfill
Compost production	80%	Of the total compostable organic waste
Incinerator residue	20%	Of the total mass of the combustible waste
Incinerator power production factor	0.465	MWh/ton of the burned MSW in the incinerator
Sold power	75%	Of the total incinerator power production
Sold compost	50%	Of the total compost production
Composting residue (screen rejects)	14%	Of the total compostable organic waste

From the 80% respondents who agreed, 13% wants to be involved in the activities of the advanced waste processing in the landfill, and 67% of them made an objection to being involved in the activities of the advanced waste processing in the landfill due to the limitation in the quantity of the junks that they could collect. This result shows that rag pickers are agreed to further improvement of landfill technology. However, they also need to maintain their junk quantity. The solution is to include the rag pickers as one of the components in further waste management.

The social benefit of processing technology implementation in the landfill would be the opening of employment for surrounding people, especially for the rag pickers. Estimated, it took ten unskilled laborers to process a ton of waste input into compost per day. The composting plant of the landfill with a maximum processing capacity of 2,300 tons per day will absorb a maximum of 230 unskilled laborers. Meanwhile, the incinerator installation of the landfill with 750 tons per day would be able to absorb 150 unskilled laborers. Thus, it was estimated that the demand for the unskilled laborers for the incinerator in the landfill of the capacity of 1,000 tons per day would be 200 labors. Meanwhile, the sanitary landfill operation required skilled laborers such as operators of heavy equipment to absorb less unskilled laborers than those absorbed by the composting and incinerator installations.

Economic Aspect of the Implementation of the Technological Alternatives in the Piyungan Landfill

The proposed technological alternatives in Piyungan Landfill were composting, incinerator, and sanitary landfill for the composting and incinerating residues. The composting and incinerating technologies implemented in the landfill would become income sources from the resulting compost and power sale.

Another income source would be the tipping fee, which the government should incur for the party that managed the wastes (ESDM 2015). The cost included investment cost and operational cost for the three technological alternatives (i.e., the composting plant, the incinerator, and the sanitary landfill). The factors in estimating the investment and operational costs could be seen in Table 4.

Table 4. Factors in Estimating the Investment and Operational Costs

Parameter	Value	Description
Tipping fee	IDR300,000	per ton of MSW
Investment cost of the sanitary landfill	IDR11,760	per ton of MSW
The operational cost of the sanitary landfill	IDR100,000	per ton of MSW
The selling price of compost	IDR1,000,000	per ton
Investment cost of the composting plant	IDR52,976,000	per input of MSW
The operational cost of the composting plant	IDR81,760	per ton of MSW
The selling price of power	IDR1,450,000	per MWh
Investment cost of the incinerator	IDR1,026,900,000,000	Capacity 1000 ton/day
The operational cost of the incinerator	IDR273,840	per ton of burned MSW

Economic calculation shows an increase in net profit during 20 years, presented in Billion IDR. The calculation also shows the net profit margin with an increasing trend (Fig. 1). The result shows a potential business-centered model by combining MSW technologies. Economic calculations show profit will be obtained in the third operational year with an average profit margin of 12.97% in the operational period of 18 years, as shown in Fig. 2.

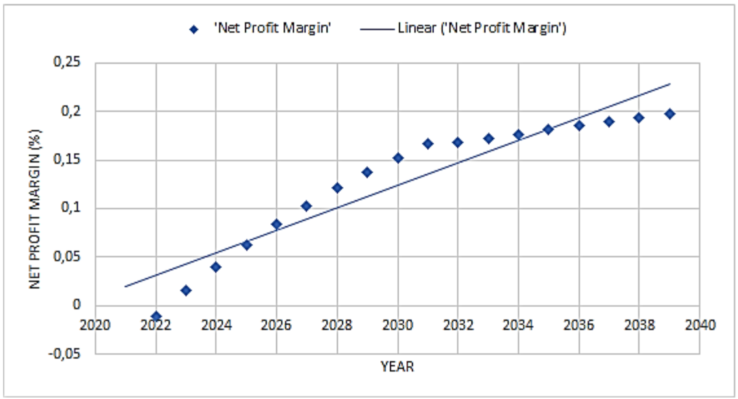

Fig. 2: Net Profit Margin of Incinerator, Composting, and Landfill Implementation

Results of the economic evaluation presented in Table 5 showed that implementing the technological alternatives of the composting, incinerator, and sanitary landfill in the Piyungan Landfill was economically feasible with NPV > 0 and the IRR > NPV.

The concept of wastepreneurship basically combines the implementation of technological alternatives in social and economic aspects and the benefits that follow. The benefits of the social aspect are empowerment and labor chances for surrounding people. Benefits of the economic aspect are bringing additional income, reducing operational costs, and open opportunities for industrial involvement. In other words, the wastepreneurship concept also opens entrepreneurship and business opportunity for involved parties. It also brings a new paradigm to the MSW management practice, which was previously considered costly, most negative impact on society and the environment, to become an industrial potential that provides profit to the community and managing government.

Table 5. Economic Evaluation Results of Incinerator, Composting, and Landfill Combination

Parameter	Economic Evaluation Result
Discount Rate	12%
NPV (billion)	Rp28,55
IRR	12,38%
B/C Ratio	1,017
Payback Period	10 years

The concept of wastepreneurship used for the landfill management model is a management that is carried out capable of realizing circular rotation of technical, environmental, social, and economic aspects and providing benefits from these four aspects. From the technical aspect, wastepreneurship is realized in the form of waste-to-energy, where waste is converted into electrical energy. From the environmental aspect, it is realized in the form of waste reduction that enters the landfill. From the social aspect, wastepreneurship is realized in the form of utilization of waste into compost that can be sold to empower the community and bring in additional income. The involvement of scavengers in waste management is also part of this concept. It can accommodate long-lasting scavenger activities and become an integral part of waste management at the landfill. From the economic aspect, manifested in the form of profits and income obtained from the sale of compost, sales of electrical energy, and the results of recycling waste.

CONCLUSIONS

Wastepreneurship concept in social and economic aspect shows that both are having a promising result. The result of the social aspect shows 80% of the ragpicker respondents agreed on implementing the advanced technology implementation in Piyungan Landfill with the condition that they were allowed to do their routine as rag pickers. It concludes that technology implementation can be done with minimal risk of conflict with the rag pickers. Moreover, the implementation of composting and incinerator technologies would absorb unskilled and skilled laborers in composting and incinerating industry.

The result of the economic aspect shows that based on the NPV and IRR calculation, technological alternatives of the composting, incinerator, and sanitary landfill in Piyungan Landfill were economically feasible. Calculation of net profit margin shows significant rises during the operation years. This condition may bring business opportunities in the waste management industry in the future.

The concept of wastepreneurship is applicable in Piyungan Landfill by altering the MSW management paradigm from cost-centered into business-centered, which able to develop social and economic sustainability for the municipal solid waste management system. Based on the social and economic evaluation, the potential benefits that follow the implementation are in the form of operational cost reduction, increases of economic value for government, increases of social benefit to utilize MSW into additional income, increase the chance of working opportunities for the surrounding society, and to give an opportunity to the industry to take part in MSW management. This condition will also open the investment potential, gaining stakeholders and other parties to take part in MSW management.

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