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Original Research

Feasibility Study for Mining Waste Materials as Sustainable Compost Raw Material Toward Enhanced Landfill Mining

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Abstract

Semarang, the capital of Central Java, had a population of 1,814,100 in 2019. City's Jatibarang landfill waste dump was expected to close in 2021. This dump can be rehabilitated by mining the backfill and utilizing mining materials. Herein, a mining feasibility study was conducted to examine the environmental, technical, and financial aspects to determine the condition of the waste dump zone. The environmental feasibility was evaluated using the integrated risk basic approach (IRBA); the technical feasibility was analyzed by conducting laboratory tests and determining the appropriate technology for processing fine materials; and the net present values (NPV), payback period (PP), and internal rate of return (IRR) were calculated for financial feasibility analysis. The total waste heap in zones 1 and 2 was 2,444,700 m^3, with a fine material composition of 56% and density of 738.05 kg/m^3. IRBA analysis results indicated a moderately hazardous dump. Thus, this dump can be rehabilitated via landfill mining. The fine material can be converted to granular organic fertilizer for use in the petrochemical industry. Overall, landfill mining is financially feasible, with a NPV value of IDR 11,126,547,566>0, IRR 33%>9.86%, and PP of seven years<planning year.

Keywords: feasibility study, granule organic fertilizer, Jatibarang landfill, landfill mining

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Introduction

Owing to continued population growth, the amount of waste and the demand for resources, such as fuel, are increasing. In many industrialized countries, European Union countries, and the United States, landfills are an integral part of the waste management infrastructure [1]. In Indonesia, the waste management system has not been optimally implemented, resulting in the generation of waste mountains. Therefore, this study focuses on waste utilization in landfills. For example, at the Jatibarang landfill in Semarang, approximately 850 tons/day of waste is stockpiled in zones 1 and 2, which are scheduled to be closed. Since 2019, these landfills have been utilized as waste power plants due to high proportions of methane gas, which is expected to decrease after 2021 [2]. This has been reinforced by research conducted by Budihardjo et al. [3], who examined the potential of refuse-derived fuels (RDFs) as alternative renewable energy sources from the Jatibarang Landfill. During a trial with electricity buyers, the plant failed to meet the requirements owing to a decrease in gas volume. The concentration of methane gas dropped below 40% after 4 h of operation, resulting in a reduced economic impact. The use of methane gas in passive zone one and passive zone two will be discontinued in landfills; methane has instead been used as a mining material.

Prior to mining, landfills must be subjected to a feasibility assessment. According to Danthurebandara et al. [4], who assessed the feasibility of landfill mining in Belgium, both environmental and economic aspects must be considered before mining. Meanwhile, Winterstetter et al. [5] reported that the technical, socio-economic, and project plans must be considered before landfill mining. Based on the results of the study in Belgium, landfill mining is feasible in terms of its environmental and economic aspects as it applies thermally added material processing. Winterstetter et al. [5] examined several landfills, including the Bornem landfill, which had a negative net present values (NPV) value, and the Turnhout landfill, which was identified to be economically viable, with a NPV value of €361,000. Several researchers have assessed the mining potential of landfills in Indonesia. For example, in a study conducted at the Cikundul landfill in Sukabumi City, fine materials (soil cover and organic waste) utilized in the active zone and sold as landfill soil for construction accounted for 56.36% of the mining materials. In contrast, rough materials, such as plastic, glass, and metal, which are sold by scavengers, accounted for 37.68%, and other waste was stockpiled in the spoil heap [6]. A study conducted at the Blondo landfill in Semarang District using mining material for granule organic fertilizer revealed a NPV>0 value of IDR 12,079,813,538. Therefore, landfill mining can be performed at this site [7].

Landfill mining is a profitable landfill rehabilitation method that utilizes mining products. For example, Hutabarat et al. [8] examined the potential of combustible waste in the passive zones of the Jatibarang Semarang Landfill as a raw material for RDFs. In this study, the waste was retrieved from depths of 0-1 m, 1-2 m, and 2-3 m, and the low calorific value varied for each waste depth, ranging from 3.5 to 4.25 kcal/tons. These results indicate that the passive zone waste at the Jatibarang landfill can become an RDF raw material because it exceeds the minimum necessary calorific value limit of 2-2.5 kcal/ton. Rotheut and Quicker [9] evaluated the energetic utilization of RDFs from landfill mining, with mining waste as an RDF, and concluded that decomposed manure could be used as an RDF. However, as mining waste is dominated by noncombustible waste, mixing with new waste at a ratio of 1:10 is required.

Few feasibility studies have been conducted on the utilization of organic materials from landfill mining, especially in Indonesia [6, 7, 9]. Several feasibility aspects, including environmental, technical, and financial matters, can be analyzed to determine whether landfill mining using organic materials is feasible as landfills in Indonesia contain a higher percentage of organic than inorganic material [6]. This organic material can be used as granular organic fertilizer (GOF), cover soil, and construction fill soil [6, 7]. Notably, the feasibility assessment performed in this study was expected to overcome the problem of waste in the Jatibarang landfill, thereby reducing waste accumulation, extending the landfill's life, and increasing the economic value of waste [10]. This study aimed to determine the existing conditions of the landfill zone at the Jatibarang landfill to derive the environmental, technical, and financial feasibility of landfill mining.

Experimental Procedures

Scope and Boundaries

This study was conducted in passive zones one and two at the Jatibarang Landfill, Semarang, Central Java. To determine the state of the landfill zone, the environmental, technical, and financial aspects were analyzed before landfill mining.

Laboratory Procedure for Environmental Analysis

The sample parameters for the analysis were pH, moisture, organic carbon, total nitrogen, and heavy metals (Pb and Cd). In this study, only Cd and Pb were used to represent heavy metals because they can drastically affect human health. Further, regulations regarding compost provide limits only for Cd and Pb. Prior to conducting the laboratory tests, the organic material was enriched according to SNI 19-7030-2004 on compost specification from domestic organic waste. Sampling was then performed for the laboratory tests using the coning and quartering method based on SNI 19-0428-1998.

pH

The acidic and alkaline properties of organic waste can be determined by its pH value. pH was determined according to SNI 7763:2018 on a solid organic fertilizer. An analytical balance sheet with a precision of 0.1 mg, a pH meter, and a 50 mL erlenmeyer were use for this test. The pH was determined by weighing 5 g of the smoothed sample (≤0.5 mm), inserting the model, and adding 20 mL of ion-free water to the erlenmeyer flask. The whipped bottle was then shaken until a homogeneous solution was achieved. Finally, the sample suspension was analyzed using a calibrated pH meter.

Moisture Content

The moisture content in the waste heap sample from the Jatibarang landfill was measured by vaporizing the water in the waste sample at an oven temperature of 105ºC for 16 h. This test was performed according to SNI 7763-2018 following careful weighing of 10 g of sample. The sample was subsequently inserted into a watch glass with a known mass. To determine the mass of the watch glass, the watch glass was warmed for 30 min at an oven temperature of 105ºC, and cooled in a desiccator for 10 min. Thereafter, the watch glass was weighed, and the mass recorded. Subsequently, the sample was placed on a watch glass, transferred to an oven and dried for 16 h at 105ºC, cooled in a desiccator for 10 min, and weighed. The moisture content was calculated using the following formula:

$$\text{Moisture Content (\%)} = \frac{\text{mass before the oven} - \text{mass after the oven}}{\text{mass before the oven} - \text{mass of the watch glasses}}\ x\ 100\% \quad (1)$$

Organic Carbon with UV-VIS Spectrophotometer

Organic carbon testing of solid organic fertilizer was performed according to the Technical Guidelines for Chemical Analysis of Soil, Plants, Water, and Fertilizer [11]. Thus, 0.5 g of the sample was weighed and transferred to a 100 mL measuring flask. Thereafter, 5 mL of KCr_2O_7 was added to the flask using a pipette, and the mixture was shaken. Following the addition of 7.5 mL of H_2SO_4, the flask was shaken in a horizontal motion, rotated, and left undisturbed for 30 min until the solution cooled. The mixture was diluted using distilled water and stored for 24 h. Thereafter, an explicit solution absorbance measurement was performed using a UV-VIS spectrophotometer at a wavelength of 561 nm.

Total Nitrogen with UV-VIS Spectrofotomoter

Soil, plants, water, and fertilizer were analyzed by weighing 0.5 g of the samples, and inserting them into a porcelain cup [11]. Subsequently, 1 g of selen mixture and 3 mL of concentrated sulfuric acid (H_2SO_4) were added to the cup, which was heated at 350ºC for 3-4 h. The final destruction was confirmed by a white steam discharge and a clear extract (after approximately 4 h). The tube was lifted, and the solution was cooled, diluted with up to 50 mL of aqueous solution, shaken until homogeneous, and left overnight for particle settling. The sample was then strained, and 1 g of the clear extract was retrieved. Two mL of tartrate sangga solution and 2 mL of Na-Fenat were added to the mixture, which was then shaken for 10 min. Two mL of 5% NaOCl was subsequently added and the mixture was shaken for 10 min. The sample had a turquoise color, and its intensity was measured using a spectrophotometer at 636 mm.

Cadmium Heavy Metals (Cd)

According to SNI 7763-2018, Cd in solid organic fertilizers must be extracted first for testing. In the open destructive system, fertilizer samples (0.5 g) that have been smoothed were carefully weighed and transferred into an Erlenmeyer flask. Subsequently, 3 mL of HNO_3 and 9 mL of HCl were added to the sample, which was then shaken and left for 30 min. A hot plate was heated from a starting temperature of 100ºC. After emission of a yellow steam, the temperature was raised to 150ºC for emission of a white steam. The sample was cooled, diluted with H_2O to 50 mL, shaken to ensure homogeneity, and filtered with a filter paper to obtain a clear extract. The last section of the clear samples and standard working solutions was measured using atomic absorption spectroscopy, and their absorbance values were recorded.

Environmental Analysis

The integrated risk-based approach (IRBA) method was used for the environmental feasibility analysis. The IRBA is a decision-making method for closing or rehabilitating open landfills through environmental risk assessment. In the IRBA, the technical, environmental, and social aspects, which significantly impacts society, are examined. The parameters considered in the IRBA analysis were divided into three categories: location criteria (20 parameters), waste characteristics (four parameters), and leachate characteristics (three parameters). The parameters were assigned a weight and sensitivity index, and whether the landfill should be closed or rehabilitated was determined based on these parameters. A value between 601 and 1000 implies that the landfills should be closed immediately owing to environmental pollution or social problems. Values between 300 and 600, indicate that the landfills should gradually be rehabilitated into controlled landfills. Finally, if a value of <300 was obtained, the landfill can be established as a spoil heap land for a long time. Landfill mining can thus be performed if the environmental risk index assessment results range from 300-600.

Technical Feasibility Analysis

The technical feasibility analysis was performed to determine the correct technology and materials for mining. The proper mining method by the Regulation of the Minister of Public Works and Public Housing No. 3 of 2013 was used to determine the appropriate technology for processing Granule Organic Fertilizer (GOF); this method is recommended for the analysis of GOF quality based on petrochemical industry standards. Notably, the appropriate technology determines whether the composition and density of landfills are known. SNI 19-3964-1994 on sampling and measurement of examples of urban waste, and EPA 1995 on testing of waste compaction density in landfills were the methods used for sampling landfill composition and thickness, respectively. Laboratory tests were performed to determine GOF quality. The tested parameters were pH, moisture content, organic carbon, total nitrogen, and heavy metals (Pb and Cd). The SNI 7763-2018 method for solid organic fertilizers was used to determine the pH, moisture content, organic carbon, Pb, and Cd parameters. Total nitrogen was assessed according to the Technical Guidelines for Analysis of Soil, Plant, Water, and Fertilizer Chemistry.

Economic Analysis

The economic analysis was performed to determine the financial feasibility of mining the Jatibarang Landfill. For the financial feasibility analysis, the payback period method, NPV, and internal rate of return (IRR) formula were employed, and the investment and operational costs, income, profit and loss, cash flow, and economic feasibility were calculated.

$$\text{Present Value} = \frac{\text{Net cash flow}}{\text{Faktor PV}} \qquad (2)$$

Payback Period = Cash flow of the previous year + cash flow for the current year

Sensitivity Analysis

Sensitivity analysis was performed to analyze the potential changes that occurred during the investment time. The sensitivity analysis was conducted by changing the variables to determine the durability of the project. In this study, loan changes and changes in the price of cow dung were analyzed.

Result and Discussion

Existing Condition of the Waste Zone

The Jatibarang landfill, the largest landfill in Central Java, is located 12 km southwest of Semarang City. This landfill has been operating since 1992 for 46 ha. Waste is transported to this landfill at a rate of 850 tons/day [12]. A controlled landfill was used as the waste management system. The land used by the Jatibarang landfill is divided into six zones: active zone 3, active zone 4, ex-narpati zone, WtE power plant zone, passive zones 1 and 2, and Waste to Energy (WtE) plan zone. Mining planning was carried out in passive zones 1 and 2. Based on a prior study, the density of the active waste entering the Jatibarang landfill is 154 kg/m^3 [13]. For comparison, the density of passive waste was obtained by sampling conducted at three points. At point one, 20 measurements were conducted to determine the weight of the entire sample retrieved using an excavator. Points two and three were examined four times owing to weather constraints. To determine the volume of waste, 20 sacks of rice husks were required to fill a hole 1 m deep; the volume of rice husks is known based on the cardboard size. Based on the sampling results, the density values of passive zones 1 and 2 were altogether 738.05 kg/m^3 as presented in Table 1. The landfill composition is listed in Table 2.

Table 1. Density of landfill waste at Jatibarang.

Description	Point 1	Point 2	Point 3
Mass (kg)	736	727	729
Volume (m^3)	0.99 (20 sacks of rice husks)		
Density (kg/m^3)	743.6	734.35	736.19
Average density (kg/m^3)	738.05		
Lowest Estimated Density (kg/m^3)	733.15		
Highest Estimated Density (kg/m^3)	742.94		
Standard Deviation (kg/m^3)	4.90		

Table 2. Jatibarang landfill composition.

Landfill Entry Waste		Mining Waste	
Types of Trash	Percent (%)	Types of Trash	Percent (%)
Organic Waste	61.34	Fine Material	56.00
Paper	10.31	Paper	0.67
Glass	0.44	Glass	0.10
Plastic	16.34	Plastic	32.00
Metal	0.27	Metal	2.00
Cloth	1.97	Cloth	2.67
Other	9.32	Other	6.56

According to Table 2, organic waste decomposes to a fine material owing to the process of waste degradation. Meanwhile, an increased mass percentage of inorganic waste was recorded because of the decrease in mass of the degraded waste. Notably, rain can increase the water content of buried waste. Further, some of the decomposed organic materials can adhere to plastic waste, leading to heavier plastic waste. The degradation of organic waste decreases the overall volume and mass of waste [14]. Herein, the volume of the passive zone was derived based on the area of the passive zone multiplied by the height of the heap; the area of the passive zone was 84,300 m^2 and the heap height was 29 m. Accordingly, the total volume of the passive zone heap was 2,444,700 m^3. The fine material from the sampling results at the Jatibarang landfill was analyzed via compost quality tests in the laboratories of the Environmental Engineering Department of Diponegoro University. The results were compared to those of SNI 19-7030-2004 on Compost Specifications from Domestic Organic Waste, as shown in Table 3.

Small amounts of organic carbon and total nitrogen reduces the C/N ratio owing to the type of stockpiled organic waste. If the type of organic waste is hard grain bark and wood, plant spread, and prune trees, this waste has a high C/N content. In contrast, watery materials, such as leaves and soft waste, have a low C/N content [15]. Parameters that do not satisfy quality standards must be subjected to technological engineering to meet these standards.

Environmental Feasibility Analysis

The IRBA method was used to analyze the environmental feasibility. The IRBA value was obtained by multiplying the sensitivity index by the weight of each parameter. The greater the weight, the more influential the parameter. The parameters affecting sensitivity include distance to the nearest water source, depth of waste filling, landfill area, content of hazardous and toxic materials, and biodegradable waste fraction. Based on the obtained value of 581.55 for the Jatibarang landfill (Supplementary Table 1), this landfill is categorized as moderately hazardous and can be rehabilitated gradually with landfill mining. Currently, the methane gas content of passive zones one and two is extracted and used to generate electricity. Once extraction is complete, the process of waste

Table 3. Fine material analysis results.

No	Parameters	Unit	Result	Quality Standards		Note
				Minimum	Maximum	
1	Moisture Content	%	26.25	15	50	Accepted
2	pH		7.05	6.8	7.49	Accepted
	Macro elements					
3	Nitrogen	%	0.19	0.4		Not accepted
4	Organic Carbon	%	5.63	9.8	32	Not accepted
5	C/N-ratio		29.55	10	20	Not accepted
	Micro elements					
6	Cadmium (Cd)	mg/kg	<3	*	3	Accepted
7	Lead (Pb)	mg/kg	78.95	*	150	Accepted

decomposition in the landfill stops, enabling mining. Based on several recommendations, the products of passive waste mining should be converted into compost, cover soil for landfill operations, or processed into fuel or RDF. Landfill mining can reduce leachate production, overcome landslide hazards, reuse land, eliminate hazardous and toxic materials, and utilize mining materials.

Technical Feasibility Analysis

Technical feasibility analysis was performed to determine the appropriate technology for landfill mining and utilization of mining materials. The sampling data revealed a higher content of finer material than other compositions. Therefore, the utilization of mining materials focuses on the use of fine materials in organic fertilizer granules to improve compost quality as they can be used as fertilizer for agriculture, landscaping, nurseries, garden soil conditioning, golf courses, and critical land greening. Thus, the potential market demand for compost is remarkable and the mining process is profitable. In addition to the economic potential and environmental quality recovery, landfill mining activities can also lead to job creation [16].

Landfill Mining

The Jatibarang landfill, prone to landslide hazards, is included in the cliff landfill category. Therefore, mining is prioritized to quickly overcome the dangers of landslides [17]. Mining in zones 1 and 2 is planned for 30 years, with approximately 167 tons mined per day based on the capability and capacity of the equipment. Mining time was calculated as the amount of waste in zones 1 and 2 divided by the amount of waste mined per day. According to sampling, the amount of waste in zones 1 and 2 reached 1,804,301.8 tons based on the heap volume multiplied by density. The volume of excavation per day (226.27 m^3 per day) was calculated using the amount of waste mined multiplied by the density.

Currently, mining is carried out by dividing zones 1 and 2 into mining zones. Eleven mining zones were planned, and the excavation time of each zone was 2.66 y. After completing the excavation at each site, the zone was used immediately to accommodate new waste. New waste was deposited in the Jatibarang landfill using a sanitary landfill system, with a minimum density of 1,000 kg/m^3 [18]. In one mining zone, 113,535 tons of new waste could be accommodated. The mining process began with the preparation of the heavy equipment used to mine waste on the heaps in zones 1 and 2. The selected machinery was adapted to the conditions of landfills and the technology of the materials used. Therefore, heavy equipment was used in excavators and dump trucks during the mining process in zones 1 and 2. The amount of heavy equipment needed was calculated according to the Minister of Public Works Regulation No. 28 of 2016. Based on the results, one excavator with a capacity of 0.65 m^3 and one dump truck with a total capacity of 8.25 tons were required.

Utilization of Fine Materials

The fine material from the Jatibarang landfill mining is processed into GOF, which has good quality. Accordingly, the composition of the GOF meets the quality standards. However, according to the results of fine material analysis compared to the quality standard SNI 19-7030-2004, some parameters did not meet the quality standards, including carbon, nitrogen, and C/N ratio. According to the quality standards, cow manure is used as a filler as it can increase the C/N ratio of organic fertilizer granules. Further, its price is relatively low and affordable. The amount of waste planned for mining is 167 tons/day. The amount of waste that will be utilized is 56% of the total content; this waste is a fine material from the sampling of waste composition. Therefore, the estimated amount of waste processed into GOF is 102.87 tons/day; the mass balance of GOF processing is outlined in Fig. 1.

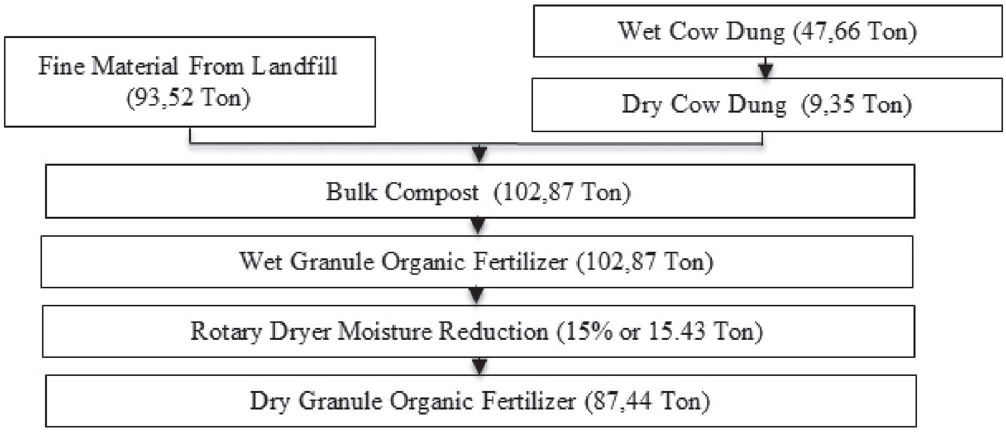

Fig. 1. Mass balance scheme.

Table 4. Quality comparison of GOF Jatibarang landfill with GOF quality standard petrochemical industry.

Parameters	Company Quality Standards	Jatibarang Landfill Compost Laboratory Test	Results After Processing	Information
Organic carbon	Minimum 15%	5.63%	16.345%	Added dry cow manure up to 10% of the total production capacity. C-Organik 27.06% and Total nitrogen 1.65% [19]
Total nitrogen	Minimum 0.5%	0.19%	0.92%	
Ratio C/N	15-20	29.55	17.76	
pH	4-9	7.05	7.05	Accepted
Moisture Content	Maximum 8-20%	26.25%	11.25%	Rotary Dryer can lower water content by 15% [20]
Shape	Granules	Bulk	Granules	Made Granules

In GOF processing, the mining materials are first sorted using a trommel machine. Thereafter, the fine material is mixed with cow manure as a filler using a mixer machine, resulting in 10% of the total fine material. The mixture is then converted into granules using a granulator. The granules are dried in a rotary dryer and cooled in a rotary cooler. Organic fertilizer granules are cooled and packed into sacks weighing 40 kg for the market. The distribution of processing materials in each tool is performed using a belt conveyor, which is more efficient and reduces labor.

The facilities required for this GOF plan include production machine hangars, garages for heavy equipment, production warehouses and stock areas, offices, truck washes, and generator rooms. The land needed for each room was calculated based on its allocation: (1) the size of the hangar for the production machinery was calculated according to the size of each production machine; (2) the size of the garage for heavy equipment was calculated according to the size of the excavator and dump truck; (3) the size of the truck wash was based on the dimensions of the dump truck; (4) the office specifications were calculated according to the number of workers; and (5) the size of the generator room was calculated based on the dimensions of the generator set to be used. Therefore, the total area of land required for the GOF plan was 517,880 m^2. GOF is planned to be marketed to the petrochemical industry, once the company quality standards are met. The quality standard was compared to the laboratory tests and GOF management from the Jatibarang landfill mining, as shown in Table 4. The GOF produced from the planned processing met the quality standards set by the petrochemical industry.

Financial Feasibility Analysis

Several indices were used for the financial feasibility analysis, including the payback period (PP), NPV, and IRR. To evaluate financial feasibility, the investment costs, operating costs, income, investment funding, profit and loss, initial operations, cash flow, and economic feasibility were calculated. Thereafter, a sensitivity analysis was performed to analyze the changes that could occur in investment.

Investment Costs

Investment costs cover buildings, such as the GOF processing facility and offices, which amount to IDR 1,143,464,800; basic equipment, IDR 3,018,258,100; and supporting equipment, IDR 14,416,600. The total investment cost required was IDR 4,176,139,500 This cost was used as the initial capital required to begin mining and produce mining products, such as GOF. A description of the investment costs is provided in Supplementary Table 2.

Operating Costs

Operational costs consist of fixed costs, such as (1) depreciation costs, IDR 223,907,700 per year; 2) maintenance costs, IDR 1,841,900,00 per month; (3) variable costs, raw material costs, namely filler for the manufacture of organic fertilizer granules as cow dung, IDR 490,980,000 per month; (4) fuel for heavy equipment excavators and dump trucks, IDR 21,162,000 per month; and (5) packing 40 kg sacks, Rupiah (IDR). The cost of the electricity needed to operate the GOF production process and install supporting equipment using the tariff in the Semarang City area is IDR 28,257,900 per month. The semi-variable cost, such as administrative and general cost, is IDR 25,000 per month. The total operational cost required is IDR 9,362,209,400 per year (i.e., IDR 780,005,800 per month and IDR 25,649,900 per day).

Income

Income is derived from the sale of the GOF. Several stages of sales must be carried out to obtain the selling price of the GOF. These stages are used to calculate the prime costs, which cover direct materials and direct labor, and the overhead costs of production, such as indirect material calculations, depreciation of production assets, and indirect labor to obtain the cost of production. Profit is calculated based on the cost of production and the selling price of organic fertilizer granules.

The total prime cost was IDR 17,424,000, with a price per product of IDR 199.26. The total production overhead was IDR 8,887,428, with a total production of 87.441 kg per day, and production cost per product of IDR 101.63. The total cost used to produce the GOF is the sum of the total prime cost and the total production overhead (i.e., IDR 26,324,637 per day and IDR 9,608,671,133 per year). The cost of old goods, which is the total cost required by a business entity to produce granulated organic fertilizer, was calculated by dividing the total cost used to produce GOF by the total production of GOF up to 87,441 kg, which yielded IDR 300.90 per unit of the product. The selling price was obtained from the cost of production plus a profit of 30%. Thus, the selling price of GOF was IDR 400 per unit of product. This price did not exceed the highest permitted retail price of IDR 500, which was determined by the Regulation of the Ministry of Agriculture No. 01 of 2020 concerning the Allocation and Highest Retail Price of Subsidized Fertilizer in the Agriculture Sector for Fiscal Year 2020. Thus, with a selling price of IDR 400 per kg and a price per 40 kg package of IDR 16,000, the gross income per year was IDR 12,591,532,800.

Initial Investment and Operational Funding

The initial capital was borrowed from the Central Java BPD Bank, a loan of private capital from the APBD ("Anggaran Pembelanjaan Biaya Daerah" in local language – Regional Revenue and Expenditure Budget), and the BUMD ("Badan Usaha Milik Daerah" in local language – Regional Owned Enterprises) office of the Central Java Province. Private capital from APBD was IDR 2,707,669,780, and the total borrowed amount was IDR 10,830,679,120, payable over five years. Bank interest rates were stipulated to be the same every year (9.85%), resulting in the same total installments every year. To determine these installments, the loan amount was multiplied by 0.263, according to the interest rate table, which revealed actual installments of IDR 2,846,165,735 every year.

Profit and Loss

Profit and loss were calculated as the total income minus several costs, including operational and investment costs, which revealed the gross profit. The gross profit was subject to a tax of 25% according to Law No. 36 of 2008. However, as the interest payable on loans received tax relief, the tax amount was calculated as the gross profit minus interest on the loan each year, which was then multiplied by 25%. A net profit of IDR 1,620,985,055 was obtained in the first year, the details of which are presented in Table 5.

Cash Flow

Cash flows were calculated over a 30 y period for the annual plans. Cash flow is obtained from net income plus depreciation and minus loan payments. The balance was then calculated at the beginning and end of the year. The cash flow in the 0th year was IDR 0, while that of the 1st to 5th years was negative as the profit was used for bank loan payments; however, from the 6th to the last year, the cash flow was positive, with a final balance of IDR 57,997,356,007.

Table 5. Profit and loss details.

No	Description	Average per month (IDR)	
1	Income		
	Granule Organic Fertilizer Sales	IDR	12,591,532,800
	Total Income	IDR	12,591,532,800
2	Spending		
	Operating expenses including depreciation	IDR	9,362,209,400
	Building Investment Cost	IDR	0
	Basic Equipment Investment Cost	IDR	0
	Investment Cost of Supporting Equipment	IDR	1,188,100
	Total Expenditure	IDR	9,363,397,500
3	Gross profit	IDR	3,228,135,300
4	First Year Loan Interest	IDR	1,066,821,893
5	Tax (25%)	IDR	540,328,352
6	Net profit	IDR	1,620,985,055

Table 6. Recapitulation of financial feasibility analysis.

Indicators	Calculation results	Feasibility
NPV	IDR 11,126,547,566	NPV > 0 (Feasible)
PP (Year)	7	< asset life (Accepted)
IRR	22 %	> discounted rate set 9.85% (Feasible)

Financial Eligibility

The investment feasibility indicators used for this feasibility study were NPV, PP, and IRR. The results of the recapitulation of each financial feasibility analysis indicator are outlined in Table 6.

The NPV was obtained by calculating the value of the discount factor, the present value, and adding the current value or cumulative present value until the last year of planning. The NPV value was IDR 11,126,547,566, which was >0. Accordingly, the project is feasible because the cumulative present value, known as the positive value, is the period required for the return on investment. The payback period of the Jatibarang landfill mining was seven years. Overall, this project is feasible because the payback period is shorter than the asset's lifetime. Further, the IRR was 33%, which exceeded the bank interest rate of 9.85%; therefore, the project was feasible to run.

Sensitivity Analysis

A sensitivity analysis was applied to assess the feasibility of a project due to changes that affected the planned project by changing the variables. In this study, analyses of changes in loans and changes in the price of cow dung were carried out, as discussed below.

Loan Change

Changes may occur in loans for the initial capital, as shown in Table 7.

Changes in loans for the initial capital may occur

Table 7. Calculations for the loan change sensitivity analysis.

Description	Initial Condition	Scenario 2	Scenario 3
Percent of BUMD Capital	20%	10%	0%
Percent Loan	80%	90%	100%
Loan Amount	IDR 10,830,679,120	IDR 12,189,287,520	IDR 13,543,625,800
Eligibility Indicators			
NPV	IDR 11,126,547,566	IDR 9,518,991,415	IDR 7,908,428,131
IRR	33%	25%	20%
Payback Periode	7 Years	9 Years	11 Years
Feasibility	Feasible	Feasible	Feasible

Table 8. Sensitivity analysis results for the changes in cow manure prices.

Description	Initial Condition	Scenario 1	Scenario 2	Scenario 3
Operating Costs	IDR 9,362,209,400	IDR 10,209,193,300	IDR 11,050,873,300	IDR 11,050,873,300
Price changes	IDR 350	IDR 400	IDR 450	IDR 450
Selling Price Per Kg	IDR 400	IDR 400	IDR 400	IDR 450
Eligibility Indicators				
NPV	IDR 11,126,547,566	IDR 4,302,729,101	IDR 2,524,096,497	IDR 8,744,726,830
IRR	33%	16%	7%	23%
Payback Periode	7 Years	14 Years	Not Behind Capital	9 Years
Feasibility	Feasible	Feasible	Unfeasible	Feasible

if there is a difference in the value of APBD funds from the Central Java provincial government. Based on the three conditions, the project is financially feasible. Based on Table 7, the greater the capital obtained from BUMD and the smaller the loans, the greater the NPV and IRR. However, the amount of revenue from the regional revenues and expenditure budget cannot be estimated, and if the amount is small, a loan is required.

Changes in the Price of Cow Manure

Another opportunity for change is alterations in the direct material used as cow dung. The full sensitivity analysis results are shown in Table 8.

Based on Table 8, an increase in the direct material affects the operating costs. Based on the analysis, the project was not feasible in Scenario 1 due to an increase in price of IDR 100, which is not matched by the increase in the selling price of organic granular fertilizer. Thus, adjustments are required to result in a feasible project. The project in Scenario 2 can be considered feasible if a price increase of IDR 50 is performed. This increase is considered to be competitive in the market as the market price of granulated organic fertilizer is IDR 500 [21].

Conclusions

Zones 1 and 2 of the Jatibarang landfill comprise 2,444,700 m^3, with a fine material composition of 56% and density of 738.05 kg/m^3. As a value of 581.55 was obtained using IRBA for the environmental aspect, the landfill was categorized as moderately hazardous, and considered feasible for rehabilitation via landfill mining. Analysis using this method can be effectively performed because the IRBA analysis is divided into three categories: location criteria (20 parameters), waste characteristics (4 parameters), and leachate characteristics (3 parameters), which are assigned a weight and sensitivity index to determine the classification of landfills. Robust results were compared with those of previous methods or findings in the literature. The quality of the fine GOF raw material was determined according to SNI 19-7030-2004. Organic carbon and total nitrogen were added to dry cow manure to meet quality standards. The amount of granule organic fertilizer produced was 87.4 tons/day mined with excavators and dump trucks, which was then processed into GOF using a trommel, mixer, rotary dryer, rotary cooler, packing machine, and cow manure dryer. Notably, the generated GOF will be marketed in partnership with the petrochemical industry. Financial feasibility was evaluated by calculating the investment costs, operating costs, income, funding, profit and loss, and cash flow. NPV, IRR, and PP were the indicators used. The NPV values were IDR 11,129,554,699 > 0, IRR 33%>9.86%, and the payback period was 7 years <30 years. Based on these three values, Jatibarang landfill mining is technically, environmentally, and financially feasible.

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Conflict of Interests

The authors declare no conflicts of interest.

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Supplementary Material

Table S1. Jatibarang Landfill Environmental Risk Assessment Index.

No	Parameter	Score	Landfill Data	Sensitivity Index Value	Score
I - Landfill criteria					
1	Distance to the nearest water source	69	120	1	69
2	Waste filling depth (m)	64	29	0,75	48
3	Landfill Area (Ha)	61	46,018	0,75	45,75
4	Groundwater depth (m)	54	>20	0,1	5,4
5	Soil permeability (1 x 10^{-6} cm/sec)	54	6,161 x 10-6	0,25	13,5
6	Ground water quality	50	Can be drunk if there is no alternative	0,6	30
7	Distance to habitat (wetland / conservation forest (km)	46	8,3	0,65	29,9
8	Distance to nearest airport (km)	46	11,6	0,55	25,3
9	Distance to surface water (m)	41	120	0,85	34,85
10	Type of subgrade (% clay)	41	73	0,1	4,1
11	Age of location for future use (years)	36	<5	0,1	3,6
12	Type of waste (urban / residential waste)	30	50/50	0,75	22,5
13	Total amount of waste disposed (tons)	30	292.554,642	0,5	15

Table S1. Continued.

14	Amount of waste disposed per day (tonnes/day)	24	850	0,65	15,6
15	Distance to nearest settlement in dominant wind direction (m)	21	400	0,6	12,6
16	Flood return period (years)	16	25	0,65	10,4
17	Annual rainfall (cm/year)	11	208,7	0,6	6,6
18	Distance to city (km)	7	12,7	0,3	2,1
19	Community acceptance	7	Doesn't get people's attention	0,1	0,7
20	CH4 ambient air quality (%)	3	0.1	0,75	2,25
II. Characteristics of waste in landfill					
21	The content of hazardous and toxic materials in the waste	71	2,00%	0,1	7,1
22	Fraction of biodegradable waste (%)	66	71,65%	1	66
23	Waste filling life (years)	58	10 - 20	0,5	29
24	Humidity of waste in landfill (%)	26	66,63	1	26
III. Karakteristik Lindi					
25	BOD of leachate (mg/L)	36	468,1	1	36
26	COD of leachate (mg/L)	19	2390	1	19
27	TDS of leachate (mg/L)	13	774	0,1	1,3
JATIBARANG LANDFILL RISK INDEX					581,55

Table. S2. Details of Investment Costs.

No	Description	Amount	Unit	Unit price	Total
I	Building				
1	Plan	1	Unit	IDR1.143.464.800	IDR 1.143.464.800
SUBTOTAL A					IDR 1.143.464.800
II	Basic Equipment				
1	Exavator	2	Unit	IDR 935.000.000	IDR 1.870.000.000
2	Dump Truck	1	Unit	IDR 317.000.000	IDR 317.000.000
3	Trommel	1	Unit	IDR 121.109.200	IDR 121.109.200
4	Belt Conveyor	6	Unit	IDR 2.520.000	IDR 15.120.000
5	Hopper	9	Unit	IDR 7.080.900	IDR 63.728.100
6	Mixer	1	Unit	IDR 28.040.300	IDR 28.040.300
7	Granulator	1	Unit	IDR 88.511.000	IDR 88.511.000
8	Rotary Dryer	1	Unit	IDR 157.379.600	IDR 157.379.600
9	Rotary Cooler	1	Unit	IDR 175.407.600	IDR 175.407.600
10	Packing Machine	1	Unit	IDR 35.404.400	IDR 35.404.400
11	Animal waste dryer	1	Unit	IDR 21.525.900	IDR 21.525.900
12	Trafo 150 KVA	1	Unit	IDR 29.100.000	IDR 29.100.000
13	Generator	1	Unit	IDR 95.932.000	IDR 95.932.000
SUBTOTAL B					IDR 3.018.258.100

Table S2. Continued.

III	Ancillary equipment						
1	Table	2	Unit	IDR	250.000	IDR	500.000
2	Laptop	2	Unit	IDR	3.399.000	IDR	6.798.000
3	Printer	1	Unit	IDR	610.000	IDR	610.000
4	Hand Pallet 5 ton	1	Unit	IDR	3.300.000	IDR	3.300.000
5	Wood pallete	2	Unit	IDR	99.000	IDR	198.000
6	Chair	2	Unit	IDR	275.000	IDR	550.000
7	Office Uniform	2	Unit	IDR	75.000	IDR	150.000
8	WeaIDRack	8	Unit	IDR	109.000	IDR	872.000
9	Security Uniform	1	Unit	IDR	150.000	IDR	150.000
10	Helmet	7	Unit	IDR	27.500	IDR	192.500
11	Gloves	7	Unit	IDR	2.300	IDR	16.100
12	Safety shoes	8	Unit	IDR	135.000	IDR	1.080.000
SUBTOTAL C						IDR	14.416.600
SUBTOTAL A+B+C						IDR	4.176.139.500