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From Waste to Resource: An Economic Analysis of Landfill Mining for Refuse-Derived Fuel Production in Five Thai Landfills

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Abstract

Using the data from a prior investigation into the amount and quality of refuse-derived fuel extracted from five landfills, this study aimed to assess the economic viability of landfill mining across all landfills. The cost-benefit analysis involves the assessment of net present value, benefit-cost ratio, and economic internal rate of return to identify cost-effectiveness. The cost-benefit analysis results were related to the amount of refuse-derived fuel fractions in scenarios of processing both new and old waste. Nonthaburi active landfill site has the highest net present value (NPV) and benefit cost ratio (B/C ratio) which are 379,174,807.37 THB and 2.04, respectively. Followed by Nakhon Sawan active site which has NPV and B/C ratio of 187,649,865.46 THB and 2.12, respectively. In contrast, in the combined scenario (new and old waste), we found that, in addition to refuse-derived fuel quantity, refuse-derived fuel quality (in terms of calorific value) has an important effect on net present value; for example, soil cover and land recovery were essential benefits. The vital cost factors for old and new waste were refuse-derived fuel transportation and operating costs. Moreover, the refuse-derived fuel fraction was the primary factor influencing investment decisions. refuse-derived fuel price and transportation costs were the next-most significant factors in the absence of government support. The waste-separation process for mined waste should be improved in Thai landfills to increase refuse-derived fuel quantity. In addition, government policies are needed to secure landfill mining funding for projects that require additional support.

Keywords : Cost-Benefit Analysis; Waste Management; Refuse-Derived Fuel (RDF); Waste to Energy; Alternative Fuel

Introduction

Population and economic expansion in low-middle-income countries influence poverty and energy demand and increase waste generation [1]. The concept of the circular economy has been implemented in various nations to promote the efficient utilization of resources, safeguard the environment, boost economic growth, and shape policy [2, 3]. Two persistent issues are the escalation of waste generation and the application of waste reduction, reuse, recycling, and recovery strategies per the waste hierarchy [1, 3, 4]. Another aspect that aligns with the circular economy concept is the practice of energy recovery from waste through landfill mining. This approach complements other waste management strategies such as waste-to-energy, waste-to-land, and waste-to-materials approaches [5-8].

Thailand uses three main waste disposal methods: composting, combustion, and disposal on land. Waste disposal on land is the primary practice in Thailand and includes open dumping and landfill disposal [9]. Organic waste is degraded with aerobic degradation for open dumping and anaerobic degradation for landfilling. These two reactions influence the spatial variation of biodegradation at disposal sites. In addition, combustible and incombustible waste is mixed in disposal sites, making it difficult to correctly specify where landfill mining should take place. However, mined waste will be separated using machines. The quantity of combustible waste that is available for use as refuse-derived fuel (RDF) is impacted by the efficiency of the machinery and the amount of rejected materials, including soil-like materials unsuitable for RDF [10]. In addition to waste quantity, the heating value and moisture content of waste play a crucial role in determining the price of RDF. These factors are affected by the amount of time since the waste was disposed of since the share of RDF derived and its heating value increase with time. Biodegradation of organic waste produces leachate and influences organic fraction reduction. Over time, the leachate collection system decreases the amount of leachate, resulting in increased fractions of RDF, reduced moisture content, and increased heating value [11-14]. As a result, in the past, businesses in landfill mining usually processed waste in closed landfills with old waste [15, 16]. More recently, geophysical technologies and invasive methods have been applied to investigate disposed waste to evaluate the potential of RDF production in final disposal sites [17-20].

Because of the high investment required and the low price of RDF, landfill mining has not been economically viable, making it an unpopular business in developing countries [21]. The main investment costs for RDF production are related to the mining process, separation machinery, and transportation [22]. In addition to assessing the feasibility of landfill mining businesses, numerous studies have utilized cost-benefit analysis (CBA) to determine the investment required for landfill mining businesses. This analysis often incorporates metrics such as net present value (NPV), benefit-to-cost (B/C) ratio, and the economic internal rate of return (EIRR), all of which are contingent on the project period [21, 23, 8, 24]. In Thailand, landfill mining has been an unpopular option for some projects due to high investment costs, occasional low RDF prices, and high transportation expenses – this is especially the case if the project is located far from cement plants [25]. Previous studies have analyzed the quantity and quality of RDF in Thailand [17, 19, 20, 26]. However, there has, to date, been no CBA analysis of Thai landfill mining. This study's objective is to assess the economic value of the landfill mining business using geophysical and photogrammetry technologies to ascertain the quantity and quality of RDF at each study site. Additionally, the study offers practical guidelines for the landfill mining business based on realistic analysis.

Materials and Methods

This research evaluates the economic feasibility of the landfill mining business using data on RDF quantity obtained from the National Research Council of Thailand (2021). The five sites studied are the Nonthaburi, Nakhon Sawan, Chanthaburi, Buriram, and Yasothon landfills. A previous study collected aerial image data using unmanned aerial vehicles and produced photogrammetric maps using the Agisoft

PhotoScan Ver 1.4.4 (Agisoft, Russia), including a digital elevation model (DEM). The DEM was used to evaluate waste volume. Electrical resistivity tomography (ERT) was applied to estimate the quantity of RDF in the landfill by correlating the resistivity values with the RDF fractions. The ERT data was collected by conducting two to four ERT survey lines per area, with an electrode spacing of 2–3 meters, and employing the Schlumberger array [17, 18]. The correlation between RDF fractions and resistivity values using linear regression analysis with soil-cover criteria are shown in equations (1) for Nakhon Sawan old waste, Buriram old and new waste, and Yasothon old waste and (2) for Nonthaburi, Nakhon Sawan new waste, Chanthaburi, and Yasothon new waste [27]. Based on the waste density of 1.19 ton per m^3.

$$\% RDF = 0.0631RS + 48.866 \quad (1)$$
$$\% RDF = 0.1917RS + 41.753, \quad (2)$$

where %RDF is the percentage of RDF in landfill obtained from the resistivity survey, consisting of plastic bags, high-density plastics, foam, leather, rubber, and textiles, and RS is the resistivity value in ohm-m.

Based on the above equation, the weight percentage of RDF fractions ranges from approximately 52.42% to 64.70% for old waste and 46.75% to 53.62% for new waste. As already noted, the waste extracted through mining was blended with incombustible waste and soil-like materials. Muttarid et al. [10] estimate the efficiency of the separation machine used to sort RDF fractions as ranging from 51.66% to 56.89% by weight. Therefore, this study assumed a conservative estimate of 50% by weight for RDF fractions following the separation process. Table 1 displays the quantity of extracted waste, the RDF fractions, and their corresponding percentages.

CBA analysis was conducted to assess the potential for RDF production from landfills under three different scenarios: closed (i.e., old waste which waste age more than five years), still operating (i.e., new waste which waste age less than five years), and combined (i.e., old and new waste); the analysis included the costs of investment, operations, and maintenance. The direct and indirect benefits of RDF production were measured through NPV, B/C ratio, and EIRR, using a discount rate of 10% per year. It was also necessary to take into account the transportation of RDF from landfills to a cement kiln located in the Kaeng Khoi district of Saraburi province. The CBA is presented below.

Table 1 The amount of mined waste, RDF fractions, and percentage of RDF fractions

Landfill (nomenclature)	The amount of mined waste (ton)	RDF fractions (ton)	Percentage of RDF fractions (%by weight)
Nanthaburi inactive (NI)	204,164	53,511	26.21%
Nonthaburi active (NA)	1,451,491	367,590	25.33%
Nakhon Sawan inactive (NSI)	81,408	21,838	26.83%
Nakhon Sawan active (NSA)	618,123	144,486	23.38%
Chanthaburi inactive (CI)	531,899	157,123	29.54%
Chanthaburi active (CA)	142,453	34,730	24.38%
Burirum inactive (BI)	225,835	59,214	26.22%
Burirum active (BA)	320,234	85,855	26.81%
Yasothon inactive (YI)	180,767	58,478	32.35%
Yasothon active (YA)	110,190	28,462	25.83%

Cost-benefit analysis

1. Cost analysis

The financial costs of RDF production consist of investment, RDF transportation, electricity, and maintenance costs. The cost of equipment, construction, transportation, and electricity is adjusted to economic cost using conversion factors of 0.84, 0.88, 0.87, and 0.90, respectively [28].

2. Benefit analysis

The direct benefit of mining old waste is the proceeds of the sale of RDF, which amounts to 99,200 tons per year. This estimate is based on a productivity rate of 40 tons per hour, 8 hours of work per day, and 310 working days per year. The price of RDF is determined by its heating value, estimated at 0.2 THB per mega-calorie. The heating value used in this study was obtained from the National Research Council of Thailand (2021). Table 2 sets out the costs of transportation from the landfill to the cement kiln. The indirect benefits consist of a reduction of approximately 30% in the volume of soil-cover material, which has a density of 300 kg per m^3 and a value of 280 THB per m^3 [17, 29-31]. Additionally, land recovery is expected to reach 99,200 tons per year, with a disposal fee of 250 THB per ton. In the case of new waste, the direct benefits are derived from the sale of RDF and the disposal fee. The indirect benefit comes from the reduction of soil-cover materials.

Cost-Benefit analysis

In the CBA we compared costs and benefits over the project period to determine its feasibility and era. The future values of costs and benefits were converted into the present value with an annual discount rate of 10%. The feasibility and merit of the project were calculated as set out below.

1. NPV was used to determine the project's profitability at a defined discount rate; an NPV exceeding zero is an indicator of economic feasibility and is calculated using equation (3).

$$NPV = \sum_{t=0}^{n} \left(\frac{B_t - C_t}{\left(1+r\right)^t} \right), \tag{3}$$

where B_t is the benefit at year t, C_t is the cost value at year t, r is the discount rate, and t is project time measured in years from 0 to n.

2. B/C ratio was used to identify the cost management efficiency of the project at a defined discount rate. A B/C ratio greater than 1 indicates that the project is economically feasible and can be calculated using equation (4).

$$B/C = \frac{PVB}{PVC}, \tag{4}$$

where PVB is the present value benefit, and PVC is the present value cost.

3. EIRR is representative of the actual rate of return. If the EIRR is greater than the opportunity cost, the project is economically optimal, as demonstrated in equation (5).

$$NPV = \frac{\sum_{t=0}^{n} \left(B_t - C_t\right)}{\left(1+EIRR\right)^t} = 0 \tag{5}$$

Table 2 Transportation cost, heating value, and RDF price

Landfill	Transportation cost (THB/ton)	Heating value (kcal/kg)		RDF price (THB/ton)	
		New waste	Old waste	New waste	Old waste
Nonthaburi	380.87	2991.00	2628.00	598.20	525.60
Nakhon Sawan	375.65	4154.00	2011.00	830.80	402.20
Buriram	495.65	2845.00	2842.00	569.00	568.40
Yasothon	580.16	2606.00	2850.00	521.20	570.00
Chanthaburi	425.22	2557.00	2730.00	511.40	546.00

4. Sensitivity analysis was conducted to evaluate the impact on the project of unexpected changes. In the first four scenarios, the benefits were reduced by 10%, 20%, 30%, and 40%, and in the remaining four scenarios the costs were increased by 5%, 10%, 15%, and 20% while keeping other factors constant.

Results and Discussion

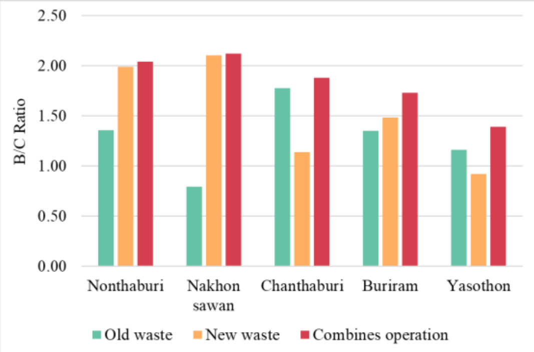
Cost-benefit analysis

The study results indicate that most of the landfills studied are economically suitable for waste mining, except for NSI and YA (see nomenclature in Table 1). This can be attributed to the two areas having the least amount of mined waste. In the case of combined operations, all sites are economically optimum, as shown in Figure 1(a). Of the sites, NA has the highest NPV of 379,174,807.37 THB and a B/C ratio of 2.04, followed by NSA with an NPV of 187,649,865.46 THB and a B/C ratio of 2.12. This is explained by the fact that the two areas have the highest RDF fractions. Additionally, NSA has the highest heating value, resulting in the highest RDF price. Figure 1(b) shows that NSA has a higher B/C ratio than NA due to the higher RDF price. In some cases, the EIRR could not be evaluated, as the net benefit of each year did not meet the criteria of having one negative and one positive value.

Comprehensive analysis of cost and benefit value

The costs and benefits of the most economically impactful factors were assessed. The study found that old waste was sensitive to soil-cover material reduction and land recovery, which were related to RDF fractions, in agreement with Zhou et al. (2015). Greater RDF recovery resulted in the recovery of soil-cover materials (waste-to-material) and land, leading to a higher B/C ratio, as shown in Figure 1(b). Transportation costs were sensitive to investment and operational costs, with the amount of RDF transported having a significant impact. The distance between the landfill and the cement plant was also a relevant factor, as evidenced by the high transportation costs recorded for the Yasothon landfill.

New waste was found to be sensitive to the soil-cover material reduction price and land recovery; this result is similar to that for old waste. In addition, the benefits attached to mining new waste were sensitive to operational costs since its heating value was lower than that of old waste, resulting in a lower RDF price. However, the operating costs were equivalent. This implies that for RDF production to be feasible in the case of new waste, separation and production processes should be improved to minimize costs, and waste treatment methods advanced to enhance biodegradation.



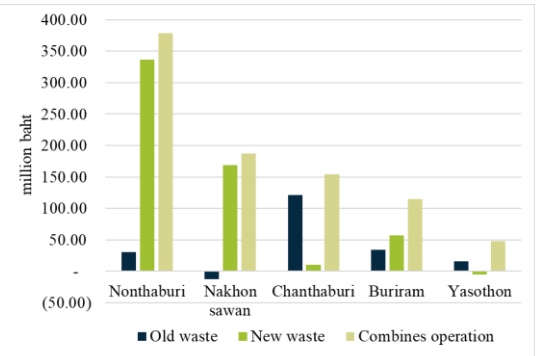
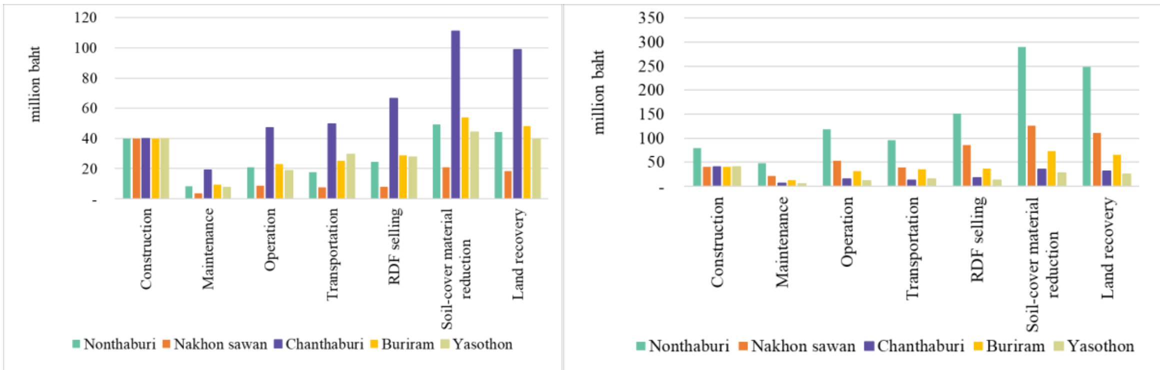


Figure 1 (a) NPV and (b) B/C ratio results for five sites



(a) (b)

Figure 2 Sharing of investment and operating costs (maintenance, operations and transportation) and benefits (RDF selling, soil-cover recovery, and land recovery) of (a) old waste and (b) new waste

Sensitivity analysis

The results of the sensitivity analysis are presented in Table 3. This analysis is an evaluation of the project's cost-benefit position under unexpected conditions. The variables included operations, maintenance, and transportation costs, and the benefits were captured by the RDF selling price, soil-cover reduction, and land recovery. The analysis found that CI was economically feasible with a decrease in benefits, whereas CI and YI were not suitable with a decrease in benefits of more than 10% and 20%, respectively. NSI and CI were not suitable sites when benefits decreased by more than 30%. Regarding new waste, NA and NSA were suitable, while YA, CA, and BA were not suitable when benefits decreased by more than 10%, 20%, and 40%, respectively. When the costs were increased, most of the landfills were suitable, except for NSI and YA. In the case of combined operations, all landfills were suitable. This suggests that the RDF produced negatively correlates with the B/C ratio. Therefore, a decrease in RDF would be more impacted by increased costs and decreased benefits rather than changing transportation cost and RDF price.

Investment cost analysis

Figure 3 represents an investment cost in the case of private investment. Six scenarios were identified: without government support (scenario 1), with government support of the RDF price at 50 (scenario 2), 100 (scenario 3), 150 (scenario 4), 200 (scenario 5), and 250 (scenario 6) THB per ton, under the condition of a discount rate of 10%, and only in respect of direct benefits (the RDF selling price). The results show that mining these five landfills was not economically feasible without government support. Three sites, Nakhon Sawan, Nonthaburi, and Chanthaburi, would have been suitable sites with government support for RDF selling prices above 50, 100, and 200 THB per ton, respectively; Buriram and Yasothon landfills required government support of more than 250 THB per ton to be suitable. As noted in Table 1, the amount of waste mined was highest for Nonthaburi, followed by Nakhon Sawan, Chanthaburi, Buriram, and Yasothon, respectively. The RDF fractions of Nonthaburi were the highest, followed by Chanthaburi, Nakhon Sawan, Buriram, and Yasothon, respectively. As shown in Figure 3, the amount of waste at the Nakhon Sawan landfill was relatively high and had the highest RDF price, resulting in a high and increasing NPV. The RDF fraction of the Nakhon 7 landfill was lower than that of Chanthaburi but required less RDF price support because of relatively low transportation cost. In addition, Buriram and Yasothon landfills had very little RDF fraction and had high transportation costs influenced by higher levels of government support. The payback period with only construction costs included was the longest for Buriram, followed by Nonthaburi, Chanthaburi, Yasothon, and Nakhon Sawan. The construction cost of Nonthaburi was twice that of other landfills, and with the highest RDF fractions had a shorter payback period. While the Burirum landfill had very little RDF fraction and a relatively high transportation cost. Moreover, Nakhon Sawan had the lowest payback period due to a relatively high RDF fraction, the highest RDF price, and the lowest transportation cost. The payback period, including construction, investment, and maintenance costs, was positively correlated with the RDF fraction; the exception was the Burirum landfill, which had a lower RDF fraction than Nakhon Sawan but a higher payback period due to lower costs and higher benefit values.

Table 3 Sensitivity analysis

Landfill		Nonthaburi		Nakhon Sawan		Chanthaburi		Buriram		Yasothon	
Sensitivity analysis		NPV (million THB)	B/C ratio	NPV (million THB)	B/C ratio	NPV (million THB)	B/C ratio	NPV (million THB)	B/C ratio	NPV (million THB)	B/C ratio
Decreased benefit											
10%	O	19.10	1.22	−17.28	0.71	93.24	1.60	20.77	1.21	4.44	1.05
	N	268.87	1.79	136.48	1.89	1.79	1.02	39.58	1.33	−21.29	0.71
	O+N	327.42	1.90	162.04	1.97	123.81	1.71	93.33	1.59	8.90	1.07
20%	O	7.31	1.08	−22.00	0.63	65.58	1.42	7.67	1.08	−6.70	0.93
	N	201.05	1.59	104.34	1.68	−6.63	0.91	22.02	1.19	−27.20	0.63
	O+N	275.67	1.75	136.44	1.82	93.24	1.53	71.97	1.46	−4.81	0.96
30%	O	−4.47	0.95	−26.72	0.55	37.92	1.24	−5.43	0.94	−17.84	0.81
	N	133.24	1.39	72.20	1.47	−15.05	0.80	4.47	1.04	−33.12	0.56
	O+N	223.91	1.61	110.83	1.66	62.67	1.36	50.60	1.32	−18.53	0.86
40%	O	−16.26	0.81	−31.44	0.47	10.26	1.07	−18.52	0.81	−28.97	0.70
	N	65.42	1.19	40.06	1.26	−23.47	0.68	−13.09	0.89	−39.03	0.48
	O+N	172.16	1.47	85.22	1.51	32.09	1.18	29.24	1.19	−32.24	0.75
Increased cost											
5%	O	28.54	1.26	−13.55	0.78	115.11	1.71	31.01	1.31	12.78	1.13
	N	323.62	1.91	162.98	2.03	8.51	1.11	53.22	1.43	−17.10	0.78
	O+N	364.92	1.96	181.29	2.04	147.61	1.81	108.85	1.67	18.11	1.13
10%	O	26.19	1.17	−14.53	0.76	109.33	1.65	28.16	1.27	9.99	1.10
	N	310.54	1.84	157.35	1.96	6.81	1.09	49.29	1.39	−18.82	0.76
	O+N	350.66	1.89	174.93	1.97	140.84	1.74	103.00	1.61	13.60	1.10
15%	O	23.84	1.09	−15.52	0.75	103.54	1.60	25.30	1.24	7.20	1.07
	N	297.47	1.78	151.71	1.89	5.11	1.06	45.37	1.35	−20.55	0.74
	O+N	336.40	1.82	168.57	1.90	134.06	1.68	97.15	1.56	9.09	1.06
20%	O	21.49	1.02	−16.51	0.74	97.76	1.55	22.45	1.21	4.42	1.04
	N	284.39	1.72	146.07	1.83	3.41	1.04	41.45	1.31	−22.28	0.73
	O+N	322.15	1.76	162.21	1.84	127.29	1.63	91.30	1.51	4.58	1.03

Note: N: New waste, O: Old waste, and O+N: Old and new waste

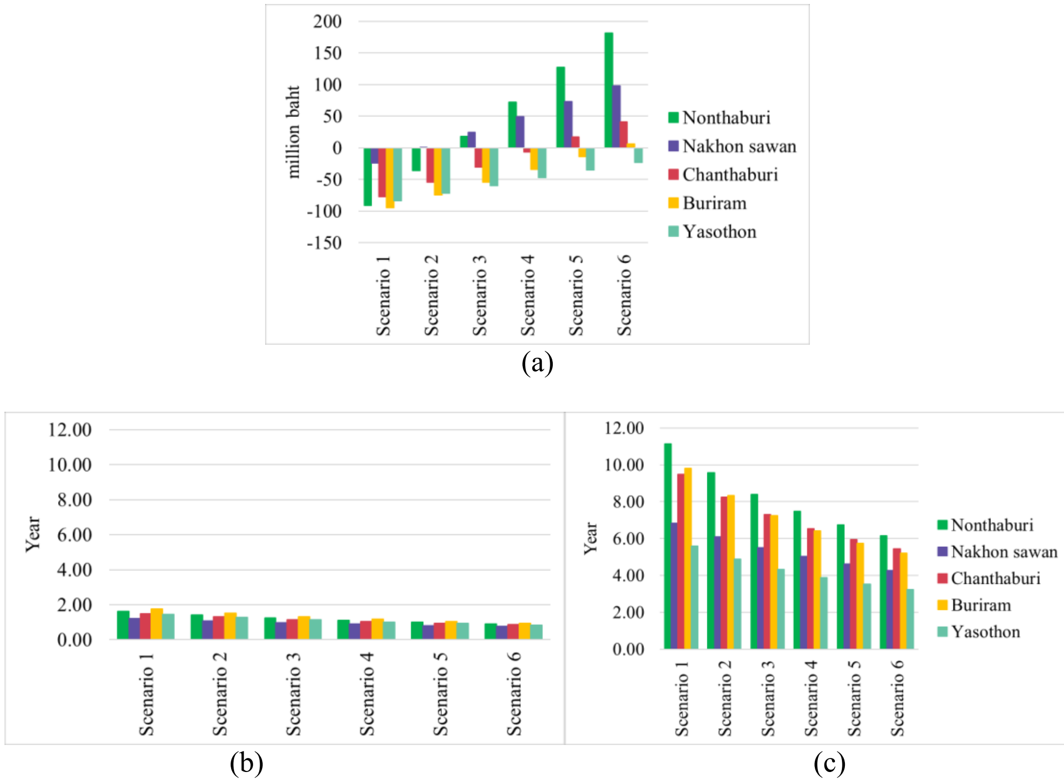


Figure 3 Private sector investment cost by (a) NPV, (b) payback period with only construction costs, (c) payback period with operations and maintenance costs

Conclusion

The CBA of the landfill mining business, based on the old and new waste criteria, revealed that the results of the CBA for the landfill mining business for old and new waste were based on the amount of RDF fractions. When the amount of RDF fraction is very low, as observed in NSI and YA, it results in a lack of economic viability. In cases where there is a combined operation, the quality of RDF in terms of heating value and the quantity of RDF fraction impacts economic value. The analysis of factors impacting NPV showed that it was affected by the amount of waste mined and the RDF fraction. The benefits related to soil cover and land recovery, while the costs were RDF transportation and operating costs for old and new waste, respectively. This is because the RDF quality is better for old waste than for new waste, resulting in a higher RDF price, while the operating costs are the same. The analysis of investing in the landfill mining business shows that the amount of RDF fraction is the primary factor in the decision to invest in the business, followed by RDF price and transportation cost, in the absence of government support. This suggests that the development of landfill mining businesses in Thailand should focus on improving the waste treatment process to enhance RDF from new waste to match that of old waste, for example, by using biodry processes or thin-layer landfills. Additionally, policies should encourage the use of RDF in the energy sector to reduce transportation costs by sending RDF to closed RDF power plants or cement plants. Furthermore, RDF production processes should be developed to improve mining and separation efficiency and reduce government support in cases of minimal waste.

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