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Assessment of refuse-derived fuel production from a thin-layer landfill

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Abstract: This study evaluates the refuse-derived fuel (RDF) production potential from a thin-layer landfill in Thailand. Unmanned aerial vehicle (UAV) photogrammetry was used to estimate the waste volume. Electrical resistivity tomography (ERT) measurements were performed to estimate the proportion of RDF in the waste pile using the relationship between resistivity and waste composition. Then, an economic cost–benefit analysis was performed. Disposal zones C and D at Chanthaburi landfill were used as the study site. The results showed that zones C and D's total waste volume and weight were 219,163 m³ and 170,947 tons, respectively. ERT results imply that the potential of RDF production from plastic waste in zone C was between 27.01% and 35.57%, and between 29.96% and 55.64% in zone D. Thus, the spatial average of RDF production potential from both zones was approximately 30.97%. As a result, the RDF produced during this study was approximately 55,666 tons. The economic cost–benefit analysis observed that the total financial cost of construction and operation was 97,642,554 THB, while the benefits from selling RDF, soil-like material for waste covering, and regaining the landfill volume was a totally 131,734,704 THB. The net present value was 50,754,800 THB, indicating that the project was worthwhile.

Keywords: Electrical resistivity topography, landfill mining, refuse-derived fuel, thin-layer landfill.

1. Introduction

Over the past ten years, municipal solid waste (MSW) produced in Thailand was 26.41 million tons per year. However, only 6.65 million tons per year of waste was recycled. The remaining waste is disposed of in landfills that are operated improperly. In 2020, 1891 sites were operated improperly, while only 355 were correctly operated [1]. These solid waste disposal sites impact the environment by both leachate contaminating water resources and methane released into the atmosphere [2]. The circular economy concept would address waste in landfills by recycling it as fuel [3-4]. In the refuse-derived fuel (RDF) production process, waste can be produced from new waste and landfilled waste. The waste was sorted according to composition using various methods, such as manual or mechanical separation. Then, the waste may be shredded into a smaller size and compacted [5]. However, the problem with RDF production from landfills is the fuel quality in terms of their low heating values. In addition, the amount of waste that can be recycled as fuel is not economical [6]. Therefore, depending on the quality and quantity of RDF, producing RDF from old landfills in Thailand would not be appropriate for all landfills.

Aerial photogrammetry has been applied to landfill surveys. Incekara et al. [7] used an unmanned aerial vehicle (UAV) to evaluate the waste capacity of a landfill. Kaamin et al. [8] applied aerial photogrammetry to evaluate the waste volume in the landfill. Therefore, UAV photogrammetry is a method that can be used to estimate the amount of waste in a landfill accurately and quickly.

In addition, geophysical techniques were used to pre-scan and characterize the waste within the landfill. Boonsakul et al. [9] applied electrical resistivity tomography (ERT) to characterize the waste operating with open dumping at Nonthaburi, Thailand. The study found that the electrical resistivity of the waste layer was greater than 50 ohm-m. In the same year, Chungam et al. [10] applied resistivity measurement technology to assess the characteristics of the waste operating in the thin-layer landfill in Chanthaburi, Thailand. The thin-layer landfill can reduce the stabilization time by promoting aerobic decomposition of the waste [11]. Chungam et al. [10] revealed that the resistivity of the waste layers averaged 42 ohm-m in low plastic material areas. In comparison, the resistivity was higher than 100 ohm-m in a very high plastic material area. This is because plastic is a resistance material that causes high resistivity in the waste body. In addition, the correlation between the resistivity and the waste that can be used to produce RDF (plastic bag) was significant. The correlation coefficient is 0.90, indicating that the resistivity measurement technique can accurately analyze waste composition to determine its potential to produce RDF. Chungam et al. [10] revealed that the resistivity of waste to produce RDF should be 40 to 80 ohm-m and 100 to 180 ohm-m to produce RDF in moderate potential (30-40%RDF) and high potential (>40%RDF), respectively.

As mentioned previously, UAV photogrammetry and ERT measurements can be used to assess the potential for RDF production in terms of quantity and quality. The UAV photogrammetry technique can assess the volume of waste above the ground level. The proportion of RDF in the waste pile can be evaluated by the relationship between resistivity value and the amount of plastic material. However, project developers must consider the project's economic potential. Therefore, this research assessed the potential of RDF production from waste treated in a thin-layer landfill using UAV photogrammetry, ERT, and economic cost-benefit analysis.

2. Method

2.1 Site description

The study site was the Chanthaburi Landfill in the Chanthaburi province of Eastern Thailand (Lat: 102.183, Long: 12.652). The site locates in a tropical monsoon climate zone. The landfill has operated since 1995; the waste disposal rate is 150 tons per day. The dumping area is divided into four zones, as shown in Figure 1. The waste disposal used a thin-layer landfill technique in which waste was spread with low compaction using a bulldozer. The height of the waste layer is 0.5–1 m. After the waste was partially stabilized for 12-18 months, the waste was excavated to extract the RDF by trommel screen with a 10x10 cm sieve size [11]. This study examined waste in zones C and D aged 4-10 years, which is considered old waste.

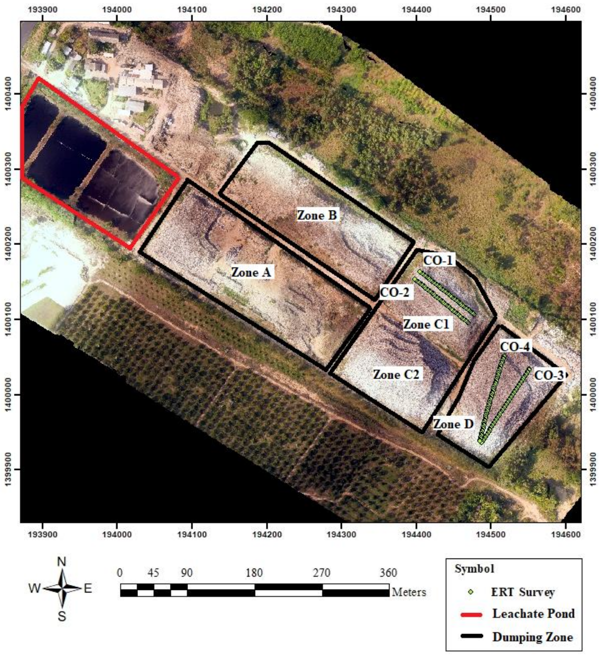

Figure 1. Orthophoto map of the test site.

2.2 Waste quantity evaluation

The waste quantity above ground was evaluated using unmanned aerial vehicle (UAV) photogrammetry. A UAV, DJI Phantom 3 Professional (DJI, China), captured the aerial images. The Pix4Dcapture (Pix4D, Switzerland) application determined the flight configuration and controlled the UAV. Aerial images were processed using Agisoft Photoscan V.1.4.4 (Agisoft, Russia). The Agisoft Photoscan program aligned the aerial images and merged each image to create a dense cloud and produce an orthophoto. The orthophoto was used to determine the ERT lines, and a digital surface model (DSM) was used to estimate the waste volume.

2.3 Waste quality survey

ERT was used to classify waste components by different resistivity values at the landfill site. The resistance waste, such as plastic, rubber, leather etc., was determined as a high resistivity material, while conductive waste, such as food waste and yard waste etc., was determined as low resistivity material. This technique is based on Ohm's law, given by Equation (1). For the basic principle of ERT, the current is injected into the ground through the resistivity meter. Then, the current flows through the wire and transferred to the ground through an electrode clip.

$$\rho = \frac{VA}{IL} \tag{1}$$

where ρ is resistivity value in ohm-m, V is voltage in volts, L is the material's length in m, I is the current in amperes, and A is the area in m² [12].

The data acquisition used GD-10 SUPREME 2D multi-electrode resistivity imaging system (Geomative, China). There were four ERT survey lines, as shown in Figure 1, consisting of CO-1 and CO-2 of 118 m in length as well as CO-3 and CO-4 of 94 m in length. The electrode configuration was designed as Schlumberger with an electrode spacing of 2 m.

The RES2DINV V.4.03 software (GeoMetrics Inc., USA) was used to determine the resistivity from the measurement. First, the program calculated the observed resistivity and converted it into inversion models. Next, the appearance resistivity values were used to evaluate the RDF fractions using Equation (2), which was derived from Chungam et al. [10] with a standard error of ±7.5%. Then, the RDF fraction data were used to produce a model for the RDF fraction using Surfer version 23 software (Goldensoftware, USA) with the kriging method.

$$y = 0.084x \times 26.263 \tag{2}$$

where y is the RDF fraction in percentage and x is appearance resistivity in ohm-m.

2.4 Economic cost-benefit analysis

The data used in the economic cost-benefit analysis was comprised of the RDF production potential, investment cost, operating expenses, and revenue from selling RDF. The net present value (NPV) and payback period (PB) were determined using Equations (3) and (4):

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

$$Payback = \frac{Project\ \ Investment\ \ Cost}{Annual\ \ net\ \ benefit} \tag{4}$$

where B_t is benefit value at year t, C_t is the cost value at year t, r is the discount rate return, and t is the number of project time periods (year).

The assumptions for the financial cost are shown in Table 1. In this study, the investment cost consists of construction and equipment, while the operational cost consists of operational, maintenance, and RDF transportation costs. The benefits were separated into two schemes: direct benefits from RDF selling and indirect benefits from gaining soil-likes material for waste covering and landfill volume. In order to convert the financial costs into economic costs, this study used the conversion factors of 0.84, 0.88, 0.87, 0.92, 0.90, and 0.92 for the equipment, construction, transportation, labor, electricity fee, and other costs, respectively. After obtaining the economic cost, the present value was evaluated by converting the economic cost with a discount rate of 10%.

Table 1. Assumption of financial cost [13-14].

Data	Assumption
Cost	
Construction and equipment	50,000,000 THB
Maintenance cost	60 THB per 1 ton of waste
Operational cost	120 THB per 1 ton of waste
Transportation of RDF	400 THB per ton
Benefit	
RDF	650 THB per ton
Soil-likes material	930 THB per ton
Regaining the landfill volume for receiving the new landfilled waste	400 THB per ton of waste

3. Results and discussion

3.1 Waste volume evaluation

The results from UAV photogrammetry are the DSM map (with the horizontal error less than ±5 cm. and vertical error less than ±5 cm.), shown in Figure 2, and a waste volume estimate. The results showed that the volume of old waste above the ground in Zone C and D were 80,548 m³ and 138,615 m³, respectively. Based on the waste density of 0.78 ton/m^3 [15], the waste weight of zone C and D were 62,827 and 108,120 tons, respectively. Thus, the total waste weight was 170,947 tons.

3.2 Potential of RDF production (%RDF)

The resistivity inversion models are shown in Figure 3 and 4. The results show the cross-section model's depth as observed 25–30 m from the waste surface. The observed waste layer of CO-1 and CO-2 was located at an elevation between +5 and +18 m. The waste layer above ground is approximately 10 m with five thin layers of waste. While CO-3 and CO-4 were at an elevation between +15.5 and +21 m, the waste layer above ground is approximately 6 m with three thin layers of waste. The average resistivity of zone C1 consisting of CO-1 and CO-2 ERT survey lines, was between 4.39 and 249.77 ohm-m. (33.01±26.16 ohm-m), lower than the average resistivity of zone D, consisting of CO-3 and CO-4 ERT survey lines, which were between 19.12 and 733.26 ohm-m (126.20±92.69 ohm-m). Comparing the results of this study to the results from Georgaki et al. [16] revealed that the resistivity values between 20-50 ohm-m refer to the waste with low organic content and above 50 ohm-m refer to completely inorganic waste.

On the contrary, Georgaki et al. [16] revealed that the resistivity values between 4-20 ohm-m, 20-50 ohm-m, and above 50 ohm-m represent the organic waste, low organic waste, and completely inorganic waste, respectively. Thus, the waste composition, CO-3 and CO-4 would consist of low organic content or completely inorganic waste, while CO-1 and CO-2 would consist of organic waste [16]. In addition, the resistivity of CO-3 was higher than CO-4 because CO-3 is closer to the side slope so that leachate can flow out more easily than CO-4 located in the middle of the waste pile. Then the moisture content from the leachate of CO-3 is lower than CO-4. As the moisture content influenced the resistivity inversely, waste with low moisture content therefore has a high resistivity [17-18]. Consistent with biodegradation, waste exposed to air was stabilized faster than waste inside the waste body [19].

Figure 2. Digital surface model of the landfill.

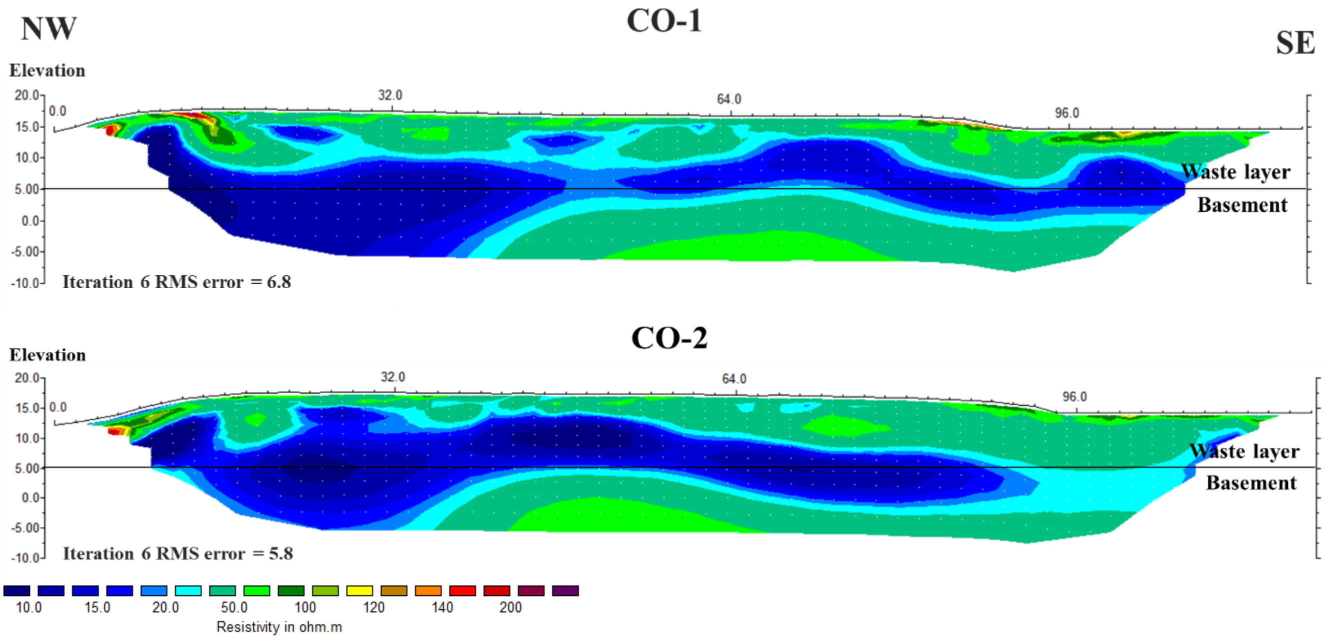

Figure 3. Inversion resistivity model of zone C (CO-1 and CO-2)

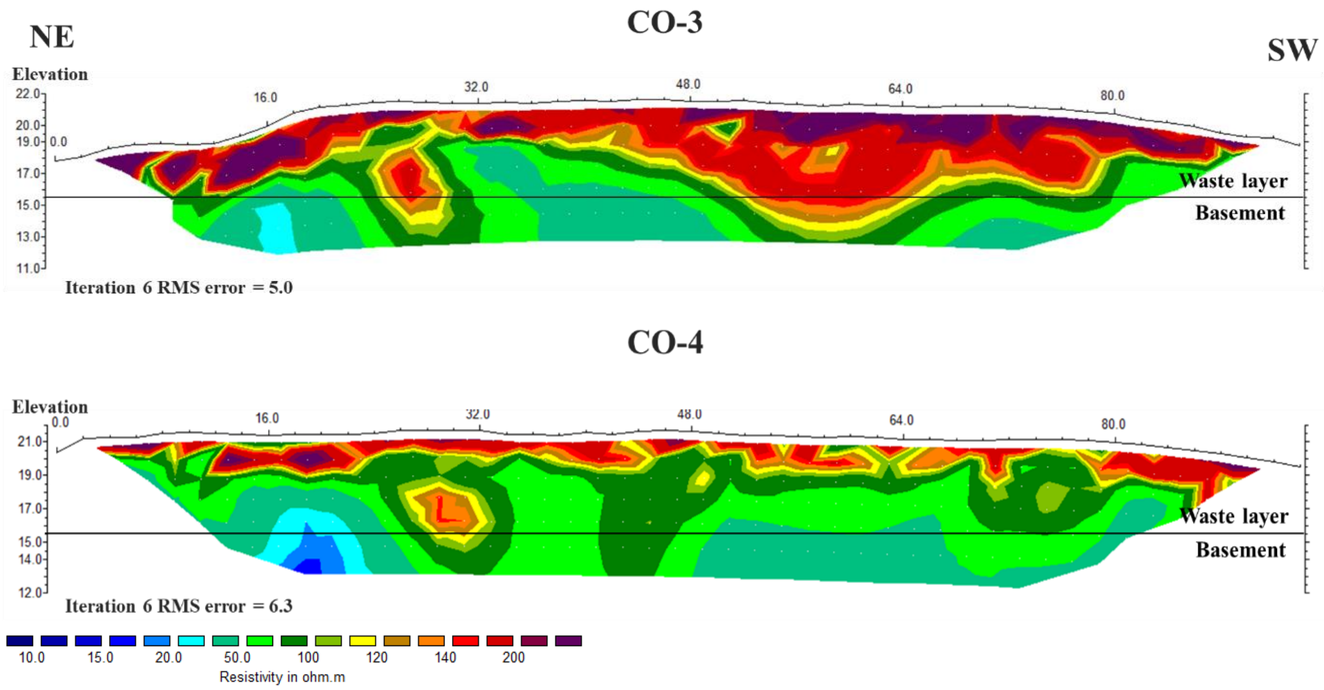

Figure 4. Inversion resistivity model of zone D (CO-3 and CO-4).

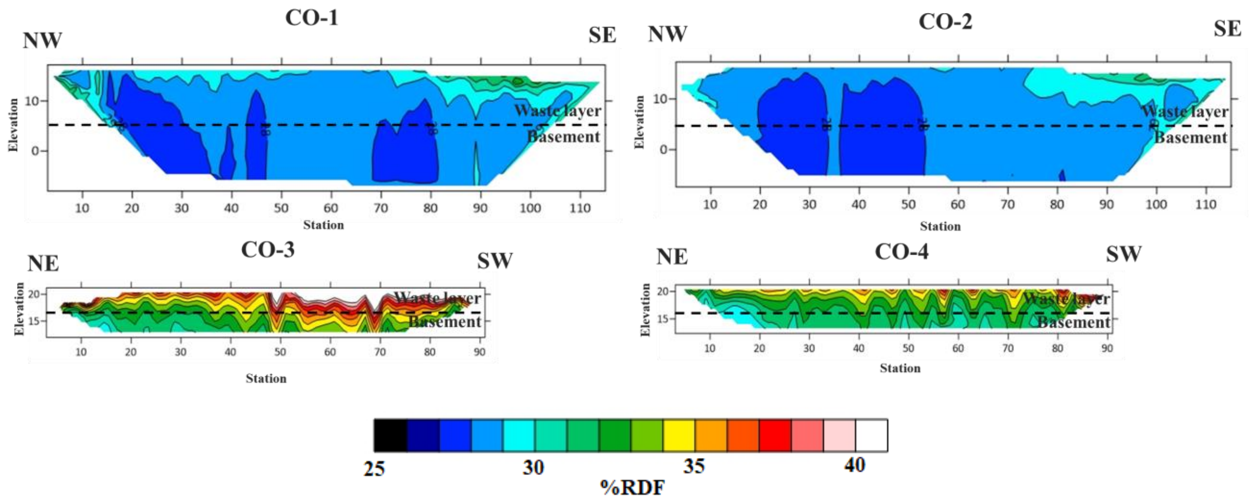

Figure 5. RDF fraction model.

The resistivity values were converted into %RDF using the linear regression explained in detail by Chungam et al. [10], and data were processed using Surfer software to create the %RDF models shown in Figure 5. The results show that the average RDF production potential for CO-1 and CO-2 is 28.80% (27.01%-35.57%), and 34.75% (28.96%-55.64%) for CO-3 and CO-4. Therefore, the potential of RDF production from old waste is approximately 30.97% which Chungam et al. [10] classified as medium potential. On the other hand, Rukijkanpanich and Suksamai [20] found that the potential of RDF production, which is plastic and paper, from the fresh waste at the Suphanburi landfill was 53%. However, analysis of the waste composition from a few samples may have errors due to spatial variation, so ERT measurements performed across the landfill provide much more reliable information.

The %RDF model and waste volume observed gave that the quantity of RDF production from CO-1 and CO-2 was 23,198 m³, the weight was 18,094 tons, while the quantity from CO-3 and CO-4 was 48,169 m³, and the weight was 37,572 tons. Therefore, the total quantity of RDF from both zones was 55,666 tons.

3.3 Economic cost-benefit analysis

Based on the old waste volume calculation, which determined the total waste to be 170,947 tons, the cost analysis of RDF production with a waste process capacity of 80 tons/hour, which is 640 tons/day, has an average RDF production potential of 30.97%. The obtained results found that the total financial cost of construction and operation was 97,642,554 THB, equivalent to an economic cost of 91,166,394 THB. The present value cost (PVC) was 80,979,904 THB.

A benefit analysis revealed that the total benefit of this project was 150,656,446 THB, comprising the direct benefit of 34,412,486 THB from RDF sales and the indirect benefit of 116,243,960 THB (47,865,160 THB from regaining soil-like materials to cover the waste, and 68,378,800 THB from landfill recovery). The present value benefit (PVB) was 131,734,704 THB.

The analysis estimated that a project would take approximately two years. The economic analysis showed that the NPV of RDF production from old waste was 50,754,800 THB. The result observed payback period of this project was approximately ten months (the net benefit of the first year calculated from direct and indirect benefits was 63,232,560 THB, while the investment cost was 50,000,000 THB). In addition, the project would not be economical worthiness if considered only the direct benefit due to the PVC being more than the PVB.

However, only mining old waste in Zone C and D was considered in this case. New waste in zones A and B could be used to produce RDF, just like an old waste. Therefore, a future study of the potential of RDF production from a whole landfill (new and old waste) must be conducted.

4. Conclusion

Despite the many old landfills in Thailand, few are suitable to produce RDF. Many landfills either produce a low quantity or poor quality of RDF, resulting in unfeasible investment. Therefore, assessing the potential of RDF production at each proposed landfill is critical before investing. This study demonstrates that a combination of UAV photogrammetry and resistivity measurement can be used to assess RDF production potential. These techniques can predict the amount of RDF that can be produced. The Chanthaburi solid waste landfill in Zone C and D has the potential to produce a profitable amount of RDF. However, resistivity measurements may not be able to estimate the results accurately because moisture content, waste density and other factors affect resistivity values. Therefore, the other geophysical technologies should be applied together with ERT to acquire a more accurate interpretation. The distance between the landfill and the RDF user is an important variable cost. This cost must be considered carefully because it affects the project benefit significantly.

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