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Application of Refuse-Derived Fuel (RDF) Plant in Piyungan Landfill Municipal Solid Waste Management

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Abstract. Piyungan Landfill is the biggest landfill in the Yogyakarta Province that still operates in overcapacity condition. A new alternative is highly required in solid waste management in the landfill, which can reduce the volume of the waste coming into it and decrease the need for a new landfill area. Refused-derived fuel (RDF) plant is one of the technological alternatives in solid waste management that has the potential to reduce the volume of solid waste and change the waste into fuel. The study analyzed the potential of the application of the RDF to reduce the volume of solid waste in the Piyungan landfill and its economic feasibility. The results of the analysis showed that during the operational period of the RDF plant, the volume of the solid waste coming into the landfill could be annually reduced by 43% on average. The results of the economic analysis show that the RDF plant in the Piyungan Landfill is feasible to apply with an NPV of IDR 281.46 billion, an IRR of 24%, and a payback period of 6 years.

Keywords: Landfill, Refused-Derived Fuel, Solid Waste Management, Technological Alternatives

INTRODUCTION

Solid waste management was one of the challenges facing urban areas (Guerrero et al., 2013). It was predicted that the quantity of waste continuously increases (Yadav, 2015). The waste problem was one of the main environmental problems in the Special Region of Yogyakarta. Population, economic, and tourism growth contributed to the increase of solid waste in Yogyakarta. The solid waste management downstream was still conducted using the conventional landfill method. It was predicted that the conventional method would not be suitable in the future because it would not be able to keep pace with the rate of waste volume. There is also a problem in finding new landfill areas, which brings environmental and social problems (El-Fadel et al., 1997).

Piyungan landfill is the biggest landfill in Yogyakarta Province that receives wastes from Yogyakarta City, Bantul, and Sleman districts representing 70% of the population of the province. The location of the Piyungan Landfill is shown in Figure 1. Two other districts (Gunungkidul and Kulonprogo) have their own landfills. In terms of technical design, the Piyungan landfill has to be closed in 2015. However, the difficulty in finding a new landfill area has forced the landfill to be operated continuously (Purnama et al., 2018). Therefore, finding a non-landfill alternative solution for fast and safe waste processing is necessary to create a sustainable solid waste management system in the Special Region of Yogyakarta, especially in the Piyungan landfill. A new paradigm was required in solid waste management to address the problem. The new paradigm proposed is called wastepreneurship (shorter terms of waste-entrepreneurship), which changed the cost-centered waste processing pattern into a business-centered one in which waste was considered as a potential resource that could give economic value.

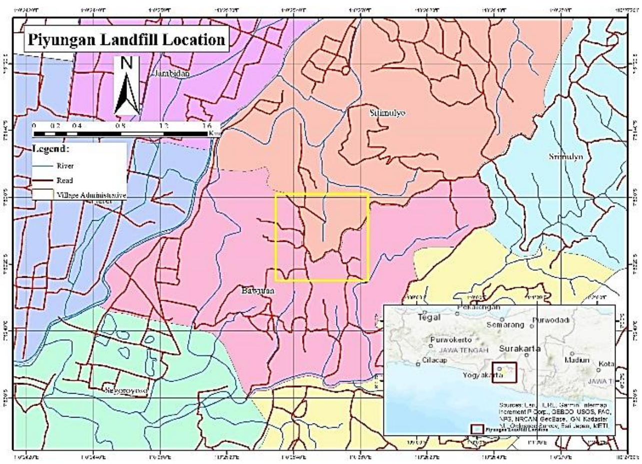

Fig. 1: Location of Piyungan Landfill indicated by yellow square (Sources: Field Observation, 2018)

The scenario of reducing waste in its source, especially organic waste through composting, could reduce 25% of the waste coming into the Piyungan landfill in the period of 1-3 years, and it could reduce 50% of it in the period of 8-15 years. However, the effectiveness of the method depends on the willingness of local people to reduce the waste at its source through the composting of organic fraction (Sudibyo et al., 2017). Another waste processing alternative to consider is WtE technology (Brunner & Rechberger, 2015; Sudibyo et al., 2017). Incinerator technology is considered as the most suitable WtE technology to apply in Yogyakarta (Prihandoko et al., 2019). The results of the economic analysis of the application of the WtE incinerator in the Piyungan landfill indicated positive economic feasibility (Prihandoko et al., 2020).

Another potential WtE technological alternative is refuse-derived fuel (RDF) plant. The RDF is the product resulting from transforming waste into intermediate fuel that could be used in the burning chamber of certain installations (Násner et al., 2017; Sarc & Lorber, 2013). It could be used as an alternative fuel for installation that uses coals for burning, such as Electric Steam Power Plants and cement kilns (Ouda et al., 2016). Processing waste into RDF would increase waste calorie value and reduce greenhouse gas emissions (Brás et al., 2017). Another advantage of the RDF is that it requires lower operational costs than other WtE alternatives, such as incinerators (Ouda et al., 2016). Therefore, this study aims to analyze the potential of the application of the RDF plant at municipal solid waste management in the Piyungan landfill. There were two potentials that would be analyzed in the study, which are the volume of the waste to dispose into the landfill and the economic potential of the application of the RDF plant.

METHODS

The study was conducted by modeling RDF technology at the solid waste management in the Piyungan landfill (Figure 2). In the scenario of the study, the incoming waste would be weighed and then put into the RDF plant with a capacity of 500 tonnes per day (tpd). After that, the waste was sorted, and part of it would be taken by rag pickers who also served as waste sorters. It showed the rag pickers that they could take up to 18.5% of the waste (Meira de Sousa Dutra et al., 2018). Based on field observation in the Piyungan landfill shows that the rag pickers could take the waste up to 12% of the daily waste on average (Prihandoko, 2021).

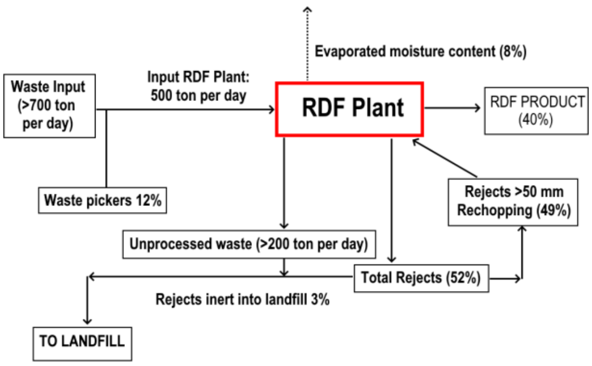

Fig. 2: The waste processing scheme of the Piyungan landfill with integrated RDF plant

There were 500 tonnes of waste per day that would be processed in the RDF plant through a cutting process, bio-drying stabilization, and filtering to find standard size (Caputo & Pelagagge, 2002). The efficiency of the RDF plant could reach 42%, as in the case of the application of the RDF plant in Cilacap that produced 50 tonnes of RDF per day from 120 tonnes of waste per day (Nasyton et al., 2018), which could be used as an alternative fuel in cement industry (Paramita et al., 2018). The RDF plant at Wonju City in South Korea produced 40.2% of RDF of waste weight (Choi et al., 2011). In the study, the RDF of the Piyungan landfill produced 40% of the RDF from the waste input.

The scenario of the RDF model of the Piyungan landfill was made using a mechanical biological treatment (MBT) system. The MBT combined mechanical sorting and aerobic or anaerobic organic fraction stabilization (Fei et al., 2018). The mechanical process of the RDF plant in the Piyungan landfill included sorting metal and glass waste fractions and recovering the materials that rag pickers could still recycle by cutting and filtering. The biological treatment was conducted using the bio-drying method. The bio-drying method was part of the MBT process aimed at stabilizing and drying waste through organic decomposing. The process reduced the water content of the waste because of the heat resulting from the degradation of the waste by microorganisms (Yang et al., 2017). The operational scheme of the RDF plant in the Piyungan landfill is shown in Figure 3.

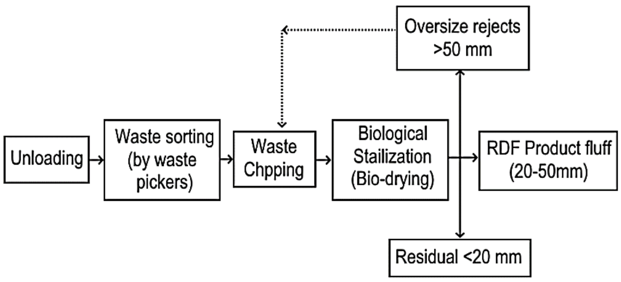

Fig. 3: The operational scheme of the RDF plant in the Piyungan landfill

The RDF plant in the Piyungan Landfill was of a capacity of 500 tonnes per day, and it was assumed that it could process 40% of the waste input into RDF. The volume of the incoming waste into the landfill reached >500 tpd, so there was still waste that could not be processed by the plant and should have been disposed of at the landfill. The bio-drying process of the RDF plant could reduce the water content of the waste by up to 35% of the initial water content of the waste input, which was 50%. The water content of the waste in the Piyungan landfill was 12% (Násner et al., 2017), while the RDF product was in the form of fluff as the one produced by the RDF plant in Cilacap that had a water content of 22% on average and water content reduction was 8%, with a similar condition to Piyungan landfill. The 200 tpd of RDF of 20-50 mm (40%) would be produced from 500 tpd of the waste input, and the rejects were 260 tpd (52%). The rejects of a dimension of >50 mm could be re-cut, while the inert residues of a dimension of <20 mm were disposed to the landfill. The residues of the RDF were 3% (Fei et al., 2018).

The waste reduction potential of the application of the RDF was calculated by comparing the volume of the waste before and after the application of the RDF plant in Eq. (1) as follows:

Reduction percentage (%) =

$$\frac{VL\,nRDF - VL\,RDF}{VL\,nRDF} \times 100\% \quad (1)$$

Where:

VL nRDF : the volume of the incoming waste into the landfill (without RDF)

VL RDF : the volume of the incoming waste into the landfill (with RDF)

Waste composition data were obtained from measurements of waste generation and composition in landfill, as well as interviews with stakeholders and rag pickers. Data on the characteristics of waste generation are used for the calculation of calorific and energy values (Prihandoko, 2021).

The economic analysis was made by calculating the cash flow potential resulting from applying the RDF plant for 15 years with the assumption that the construction began in the first year. It was assumed that the income potential resulted from tipping fees and RDF sales. The expenditure potential resulted from investment costs, the operational cost of the RDF plant, and landfilling. The factor of the conversion of the investment and operational costs of the RDF of the Piyungan landfill referred to the financing scheme of the RDF plant in Cilacap, representing the first RDF plant in Indonesia. The economic feasibility was calculated using NPV and IRR parameters and assuming that the discount rate was 12%. NPV is a standard measuring instrument in capital planning and investment feasibility evaluation to analyze the profitability of an investment, as shown in Eq. (2) (Prihandoko, 2021).

$$NPV = \frac{Rt}{(1+i)^t} \quad (2)$$

Where:

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, as shown in Eq. (3).

$$NPV = \sum_{t=0}^{T} \frac{Ct}{(1+IRR)^t} \quad (3)$$

Where:

C = Cash Flow at time t

IRR = discount rate/internal rate of return expressed as a decimal

T = time period

Net Cash flow was then calculated by Eq. (4).

$$Net\ Cashflow = Total\ Income - Total\ Expenditure \quad (4)$$

The NPV was the present value of the total cash flow in the period of the project. If the NPV > 0, the project was considered to be feasible. The IRR was the discount rate if the NPV = 0. The NPV of the project would be positive if the IRR > discount rate. The sensitivity analysis was made by identifying the most influential cash flow component on the change in the NPV.

RESULTS AND DISCUSSION

The Existing Condition of the Piyungan Landfill

Piyungan landfill was designed as a sanitary landfill, but practically it has been operating as open dumping in which incoming wastes are directly disposed into the landfill and leveled using heavy equipment without any soil cover (Prihandoko et al., 2019, 2020; Sudibyo et al., 2017). Such a condition causes environmental problems such as disturbing smells for surrounding people living around the landfill. Additionally, there are hundreds of free-range cows on the landfill looking for feed among the waste piles. Also, leachate processing installation in the landfill does not operate maximally, and the leachate is not completely processed and safe to dispose to rivers (Harjito et al., 2018; Parhusip et al., 2017; Ramadhan et al., 2019).

The data collected from the Piyungan landfill management office showed that there were 200 incoming dump trucks on average and unloaded the wastes at 2 points in the active zone of the landfill. The wastes were then leveled using heavy equipment (excavators and bulldozers). The data also showed that the mean increase in waste generation in the period of 2015-2018 was 12%. Based on the data, it was predicted that there would be waste generation of 924 tonnes/day, 1,257 tonnes/day, and 1,847 tonnes/day in 2021, 2025, and 2030, respectively. A more conservative prediction was made using the baseline of the waste generation in 2016 was 470 tonnes/day with annual waste generation growth of 8%. Based on the data, it was predicted that there would be landfill waste generation of 690.6 tonnes/day, 939.5 tonnes/day, and 1,380.5 tonnes/day in 2021, 2025, and 2030, respectively (Sudibyo et al., 2017).

The study would use the assumption of the waste generation in 2021, which would be 700 tonnes/day, as the basis for calculating the capacity of the applied RDF in the Piyungan landfill and the annual waste generation growth of 8% as the basis for predicting the waste generation in the coming 15 years. Based on the weight of the waste, the biggest component of the waste in the landfill was food waste (remnants of foods, vegetables, and fruits), followed by plastic, paper, and diapers (Figure 4). The results of the proximate analysis of the complete composition of the waste in the landfill are summarized in Table 1.

Waste that can be thermally processed should have a minimum dry calorific value of 7,000 – 9,000 kJ/kg (Olisa, 2018). If drying pretreatment was conducted, all of the waste categories in Piyungan could be thermally processed and gave the biggest mean calorie value of 19,961 kJ/kg, where the organic waste had the highest calorie value (Prihandoko, 2021).

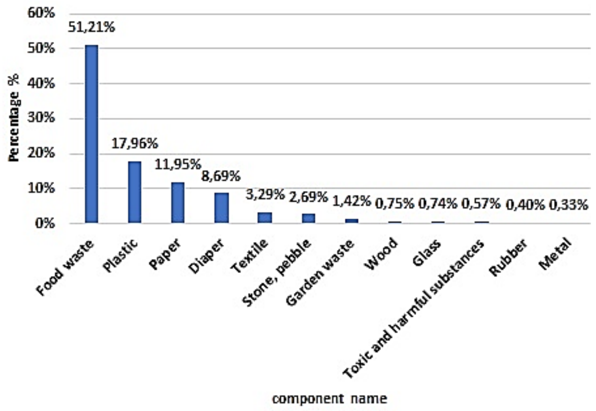

Fig. 4: The waste component in Piyungan Landfill (Prihandoko, 2021)

Table 1. Results of proximate analysis in Piyungan Landfill (Prihandoko, 2021)

Parameter	Value
Ash content (%)	5.14
Moisture content (%)	29.47
Volatile matter (%)	55.47
Fixed carbon (%)	9.93
Wet caloric value (kJ/kg)	13,669.50
Dry caloric value (kJ/kg)	19,381.50

Potential of the Waste Reduction in the Piyungan Landfill with the RDF Plant

It was estimated that applying the RDF plant in the Piyungan Landfill for 14 operational years would decrease the volume of the waste disposed into the landfill by approximately 43% annually. The percentage resulted from comparing the volume of the waste without the RDF plant and that with the RDF plant. The biggest reduction took place in the first operational year of the RDF, which was 67%. The percentage of waste reduction by the RDF would also decrease with the annual increase in the volume of the incoming waste because the fixed capacity of the plant is 500 tonnes per day. The reduction of the waste disposed to the landfill would result in the reduction of the need for the landfilling area in the Piyungan Landfill. This calculation is based on the condition that 12% of the waste are picked by rag pickers, the waste volume resulting from the waste density of the landfill, which is 600 kg/m^3, and the capacity of the RDF plant 500 tpd (Figure 5).

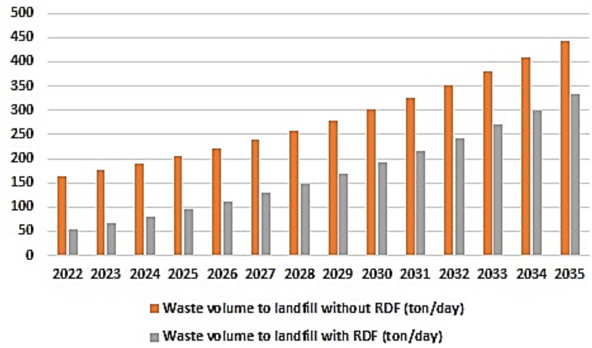

Fig. 5: Potential of waste volume reduction in Piyungan landfill with RDF Plant application

The Economic Potential of the RDF Plant in the Piyungan Landfill

In addition to the reduction of the volume of the incoming waste into the landfill, the RDF plant produced RDF non-pellet fluff that could be sold to off-takers of electric steam power plants and cement factories as a partial substitution of coals (the substitution of coals in electric steam power plants and cement coke kiln). The technical and economic parameters used in the economic analysis of the RDF plant in the Piyungan Landfill can be seen in Table 2.

The RDF plant of the Piyungan Landfill was planned for 2021-2035. During this timescale, the RDF plant was constructed in the first year, and the operation began in the second year till the fifteenth year. It was estimated that the RDF plant could produce more than 2.5 million tonnes of RDF in the period. The investment cost of the RDF plant of the Piyungan Landfill was calculated based

Table 2. The technical and economic parameters of the Piyungan landfill RDF plant

Parameter	Value	Information	References
Technical:			
Waste input capacity	500	tpd	
Waste taken by waste pickers	12%		Field survey, 2018
RDF Production (20-50mm)	200	tpd (40%)	RDF Plant Cilacap; Choi et al 2011
Oversize (>50 mm)	245	tpd (49%)	
Residual (<20 mm)	15	tpd (3%)	Fei, 2018
Initial wastewater content (A)	30%		Laboratory analysis, 2018
RDF fluff water content (B)	22%		RDF Plant Cilacap
Water evaporation	8%	(A) – (B)	
Economical:			
-Investation Cost Factor			
Physical building	Rp803.605	per ton input capacity/year	RDF Plant Cilacap
Equipments	Rp981.735	per ton input capacity/year	RDF Plant Cilacap
-Operational Cost Factor			
RDF Operational	Rp210,765	per ton MSW	RDF Plant Cilacap
Landfill Operational	Rp83,000	per ton MSW	Rahim et al. 2012
RDF Price	Rp300,000	per ton RDF	RDF Plant Cilacap
Tipping fees	Rp300,000	per ton MSW	Ministry of Energy and Mineral Resources, 2015

on annual capacity and consisted of building and equipment investments. The operational cost consisted of the operational cost of the RDF plant and the operational cost of the disposal of unprocessed waste and residue into the landfill. The cash flow of the Piyungan Landfill RDF plant is summarized in Figure 6.

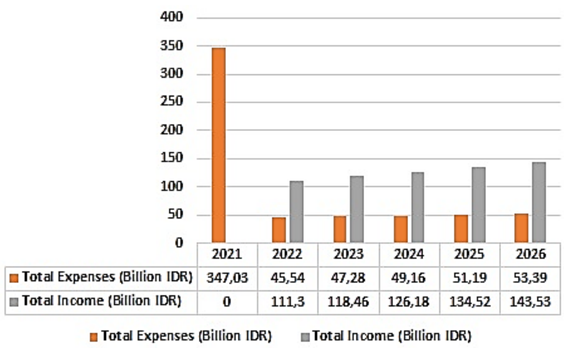

Fig. 6: The cash flow of the Piyungan landfill RDF plant

The results of the calculation show that the highest income of the project resulted from the tipping fees, while the biggest expenditure is the operational cost of the RDF plant. Considering the assumption of the discount rate of 12%, the application of the RDF plant of the Piyungan Landfill for 15 years, the NPV is IDR 281.46 billion, IRR 24%, and the payback period of 6 years. The results of the economic analysis showed that, considering some assumptions, the project is economically feasible.

Some aspects were necessary to note related to the distribution of the resulting products. The analysis did not involve calculating the transportation cost of the RDF products from the Piyungan Landfill to the off-takers of the RDF products. Yogyakarta did not have any electric steam power plant or cement factory as potential off-takers, so the RDF products should be transported to the off-takers situated outside Yogyakarta. If the transportation cost was included in the economic calculation of the project, the project would be infeasible. Another important aspect affecting the project feasibility sensitivity is the cash flow component, such as tipping fee and operational cost. The results of the analysis of the sensitivity of the NPV showed that the economic feasibility of the project is highly influenced by the tipping fee and the operational cost of the RDF plant in which the tipping fee should not decrease by more than 40%, and the operational cost of the RDF plant should not be more than 120%. The operational cost of the landfilling and the RDF production volume did not significantly influence the NPV (Figure 7).

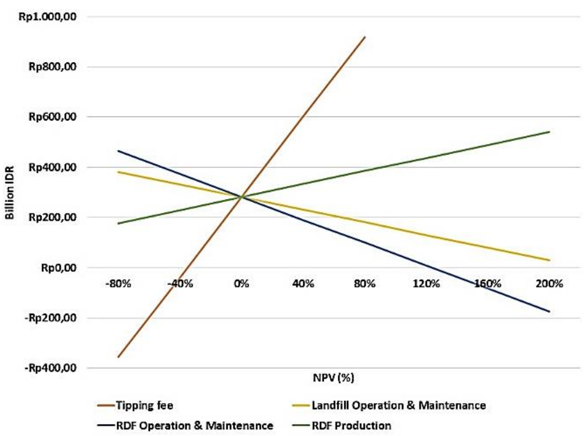

Fig. 7: The analysis of the influence of the economic component sensitivity of the cash flow on the NPV

CONCLUSIONS

The results of the study show that the application of the RDF plant of the Piyungan landfill can potentially reduce the volume of the waste disposed into the landfill by 43% annually on average in the period of operational years. The application of the RDF plant of the Piyungan Landfill is considered to be feasible as long as some assumptions and parameters are met. The sensitivity analysis shows that the tipping fee and the operational cost of the RDF plant highly influence the economic feasibility of the project. The RDF plant in the Piyungan Landfill is feasible to apply with an NPV of IDR 281.46 billion, an IRR of 24%, and a payback period of 6 years. The tipping fee should not decrease by more than 40%, and the operational cost of the RDF plant should not be more than 120%. High transportation costs could result in the economic infeasibility of the project.

REFERENCES

Brás, I., Silva, M. E., Lobo, G., Cordeiro, A., Faria, M., & De Lemos, L. T., 2017. "Refuse derived fuel from municipal solid waste rejected fractions-a case *study." Energy Procedia,* 120, 349-356

Brunner, P. H., & Rechberger, H. 2015. "Waste to energy - key element for sustainable waste management." *Waste Management,* 37, 3-12

Caputo, A. C., & Pelagagge, P. M. 2002. "RDF production plants: I. Design and costs." *Applied Thermal Engineering,* 22 (4), 423-437

Choi, Y.-S., Choi, H.-S., & Kim, S.-J. 2011. "An economic evaluation of MSW RDF production plant." *Journal of The Korean Society for New and Renewable Energy,* 7 (1), 29–35

El-Fadel, M., Findikakis, A. N., & Leckie, J. O. 1997. "Environmental impacts of solid waste landfilling." *Journal of Environmental Management,* 50 (1), 1-25

Fei, F., Wen, Z., Huang, S., & De Clercq, D.

2018. "Mechanical biological treatment of municipal solid waste: Energy efficiency, environmental impact and economic feasibility analysis." *Journal of Cleaner Production,* 178, 731-739

Guerrero, L. A., Maas, G., & Hogland, W. 2013. "Solid waste management challenges for cities in developing countries." *Waste Management,* 33 (1), 220-232

Harjito, Suntoro, Gunawan, T., & Maskuri, M. 2018, "Underground leachate distribution based on electrical resistivity tomography in Piyungan landfill, Bantul." *Indonesian Journal of Geography*, 5 (1), 34-40

Meira de Sousa Dutra, R., Harue Yamane, L., & Ribeiro Siman, R. 2018. "Influence of the expansion of the selective collection in the sorting infrastructure of waste pickers' organizations: A case study of 16 Brazilian cities." *Waste Management,* 77, 50-58

Násner, A. M. L., Lora, E. E. S., Palacio, J. C. E., Rocha, M. H., Restrepo, J. C., Venturini, O. J., & Ratner, A. 2017. "Refuse Derived Fuel (RDF) production and gasification in a pilot plant integrated with an Otto cycle ICE through Aspen plusTM modelling: Thermodynamic and economic viability." *Waste Management,* 69, 187-201

Nasyton, K., Maryunani, Harahab, N., & Prasetyo, B. 2018. "The cost benefit analysis between conventional final shelter with refuse derived fuel waste management in Cilacap city." *International Journal of Science and Research (IJSR),* 7 (11), 867-870

Ouda, O. K. M., Raza, S. A., Nizami, A. S., Rehan, M., Al-Waked, R., & Korres, N. E. 2016. "Waste to energy potential: A case study of Saudi Arabia." *Renewable and Sustainable Energy Reviews,* 61, 328-340

Paramita, W., Hartono, D. M., & Soesilo, T. E. B. 2018. "Sustainability of refuse derived fuel potential from municipal solid waste for cement's alternative fuel in Indonesia (A case at Jeruklegi Landfill, in Cilacap)." *IOP Conference Series: Earth and Environmental Science,* 159, 1-6,

Parhusip, J. A., Harijoko, A., Putra, D. P. E., & Suryanto, W. 2017. "Assessment of leachate infiltration from Piyungan landfill using electrical resistivity method." *AIP Conference Proceedings,* 1861 (1)

Prihandoko, D., Budiman, A., Fandeli, C., & Setyono, P. 2019. "Alternative of waste treatment technology based on economic development and waste composition in TPST Piyungan, Yogyakarta." *AIP Conference Proceedings*, 2202 (1)

Prihandoko, D., Budiman, A., Fandeli, C., & Setyono, P. 2020. "A New Paradigm for Solid Waste Management in Integrated Waste Management Site Piyungan Yogyakarta, Indonesia." *Applied Mechanics and Materials, 898,* 51-57

Prihandoko, D., Budiman, A., Setyono, P., Fandeli, C., Budiastuti, M.Th.S. 2021. "Appropriate technology for municipal solid waste management based on wastepreneurship implementation", *ASEAN Journal of Chemical Engineering*, 21 (1), 113-123

Purnama Putra, H., Damanhuri, E., & Marzuko, A. 2018. "The concept of "loop Cycle" in landfill management (Case study at Piyungan landfill, Yogyakarta, Indonesia)." *MATEC Web* *of Conferences, 154,*

Ramadhan, F., Prasasti D.R, F., Firizqy, F., & Nugroho Adji, T. 2019. "Pendugaan distribusi air lindi dengan geolistrik metode ERT di TPA Piyungan, Bantul, DIY", *Majalah Geografi Indonesia,* 33 (1), 1-8

Sarc, R., & Lorber, K. E. 2013. "Production, quality and quality assurance of refuse derived fuels (RDFs)", *Waste Management,* 33 (9), 1825-1834,

Sudibyo, H., Majid, A. I., Pradana, Y. S., Budhijanto, W., Deendarlianto, & Budiman, A. 2017. "Technological evaluation of municipal solid waste management system in Indonesia." *Energy Procedia,* 105, 263-269

Sudibyo, H., Pradana, Y. S., Budiman, A., & Budhijanto, W. 2017. "Municipal solid waste management in Indonesia - A study about selection of proper solid waste reduction method in D.I. Yogyakarta province." *Energy Procedia, 143,* 494-499

Yadav, R., 2015. "Solid waste management." *Pollution Research,* 34 (1), 111-120

Yang, B., Hao, Z., & Jahng, D., 2017. "Advances in biodrying technologies for converting organic wastes into solid fuel." *Drying Technology,* 35 (16), 1950-1969