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Andalas Journal of Electrical and Electronic Engineering Technology

ISSN 2777-0079

The Material and Energy Conversion Potential from Municipal Waste in Padang City: Business Chance and Future Prospective

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ARTICLE INFORMATION

Received: May 29, 2024
Revised: June 20, 2024
Accepted: July 8, 2024
Available online: July 23, 2024

KEYWORDS

Municipal solid waste, Padang City, renewable energy, solid waste business, energy waste.

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A B S T R A C T

Padang City, the capital city of West Sumatra Province, is expected to grow and reach a population of 1 million by 2035. However, this growth also means an increase in municipal solid waste, projected to be about 256,000 tons annually. At the same time, there is potential for waste-to-energy conversion in Padang City due to the demand for renewable energy and business opportunities. This study is based on existing literature and data, which were analyzed using a statistical approach and municipal solid waste management calculations. The study conducted scenarios that show potential energy conversions. The first scenario involves converting solid waste to gas and using it directly as biogas. The second scenario involves converting biogas from solid waste to electricity and distributing it for household use. The last scenario consists of using small and medium-sized biodigesters to convert gas into electricity, which will then be used as a charging station for electric vehicles (EVs). The first scenario can generate the most significant profit, while the third scenario suits small and medium businesses. However, each scenario has its pros and cons. Still, it's crucial to consider regulation issues, government support, and public awareness of the environmental problems to implement these waste-to-energy conversion practices on-site successfully.

INTRODUCTION

The solid waste problem in Indonesia is very complex and involves various factors. Rapid population growth and urbanization have increased waste volumes in large cities, while waste management infrastructure and facilities often cannot keep up with this growth. In addition, public awareness of the importance of good waste management is still low in several areas, resulting in the habit of littering carelessly. Waste collection and processing systems are also still limited in many places, resulting in much waste being thrown into rivers, ditches, or empty land.

Limited facilities and infrastructure are also severe problems in waste management in Indonesia. Some areas still have difficulty providing sanitary landfills (*tempat pembuangan akhir*/TPA) or recycling facilities. Technical challenges also exist in waste processing, such as a lack of modern technology and training for waste management officers. As a result, the environment experiences pollution, which can harm the ecosystem and human health. Inconsistent policies and regulations at the national and regional levels are also an obstacle [1]. At the same time, many regions still rely on landfilling methods as the primary solution without prioritizing more sustainable approaches such as recycling and waste reduction.

As a city in West Sumatra, Padang, like many growing cities in Indonesia, faces a significant challenge with solid waste management. The amount of waste produced in Padang is increasing due to population growth and changing lifestyles. This has led to overwhelming the current waste management system. On the other hand, most waste is disposed of at the Aie Dingin landfill, which is almost overloaded[2]. Even though the municipal government claimed that 70 percent of the solid waste is processed, only a small percentage is recycled or composted. Residents do not separate waste at the source, which makes recycling and composting more difficult and expensive. There is improper waste disposal in open areas, leading to air and water pollution, as some residents burn or dump waste. Consequently, these problems have impacted the quality of life of the people. The environment is harmed due to overflowing landfills and improper waste disposal, adversely affecting public health and ecosystems. Managing waste in the city is a significant task that takes away resources from other areas, leading to strain on those resources.

Recently, energy demand in Indonesia become an essential issue. Despite being rich in natural resources, this country still faces energy security concerns, including dependence on imported fossil fuels and fluctuating energy prices. Using waste as an energy source can play a significant role in achieving Indonesia's

https://doi.org/10.25077/ajeeet.v4i1.104

renewable energy targets. Waste incineration can produce heat, while anaerobic digestion can transform organic waste into biogas. This sustainable energy source can be utilized for various purposes, such as cooking, heating, and electricity generation [3]. As part of West Sumatra province, Padang City still depends on fossil fuels as its primary energy source, especially coal and fossil oil, which is undoubtedly a source of heavy air pollution. On the other hand, Padang has the potential to utilize renewable energy sources like water, geothermal, and solar due to its geographical location. Thus, according to the Energy and Mineral Resources Agency of West Sumatra Province (*Dinas Energi dan Sumber Daya Mineral Provinsi Sumatra Barat*), about 30% of renewable energy is utilized in West Sumatra nowadays [4]. Besides, waste, as the source of biomass, also has a high opportunity as novel energy that is genuinely sustainable but has not yet been utilized. By investing in waste-to-energy infrastructure, Padang can actively participate in cutting down greenhouse gas emissions and combatting climate change. Embracing the energy potential of waste can enable Padang City to diversify its energy sources and reduce dependency on conventional fuels. This is an excellent opportunity for the future since the penetration of this business model in Padang is still low.

Besides the environmental benefit, the waste-to-energy concept also provides opportunities in the business and economic domains. Waste management businesses have high potential sources of revenue and factors that can influence their profitability. Alternative fuels or generated energy from waste have relatively good margins compared to conventional energy sources. Waste-to-energy projects can be financially viable, converting waste into electricity or other forms of energy. Embracing innovative technologies and implementing efficient processes can support this business and improve profitability [5]. While waste management can be profitable, the challenges and potential risks associated with the industry also need to be considered.

However, the concept of waste for energy is not appealing to the development of Padang City at this time. In terms of cost, building and maintaining waste-to-energy plants can be expensive. Implementing waste-to-energy projects involves substantial upfront costs for infrastructure development, equipment procurement, and operational expenses. The city might be prioritizing other waste management solutions due to budget constraints. On the other hand, waste conversion technology might still develop in Indonesia, and Padang requires technical expertise in waste management, energy production, and environmental engineering. Even though there are several environmental-related majors in Padang’s universities, there may still be a lack of skilled personnel, knowledge, and experience in planning, designing, and operating waste conversion facilities. This point is also supported by the absence of supportive policies and regulatory frameworks, which may hinder the implementation of waste-to-energy projects in Padang City. In the end, there can be public concerns about emissions or safety from waste-to-energy plants. Concerns about potential environmental impacts, health risks, and social implications of waste conversion technologies may lead to opposition or resistance from local communities.

The problem of implementing the waste-to-energy concept in Padang poses a significant challenge. This article discusses how solid waste conversion can be a viable solution both environmentally and economically in the future. The study's data is based on relevant literature and existing data, which is analyzed to provide a holistic approach to the issue. The goal is to provide academic suggestions for addressing the municipal waste problem in Padang, estimating the business potential, and finding a solution for it in the future.

METHOD

This study is literature-based, using the existing data, which was analyzed using a statistical approach and municipal solid waste management calculation. The data in this study was related to municipal waste management in Padang City. Thus, the primary data, such as geography and population, were taken from the *Badan Pusat Statistik/BPSk* (Central Bureau of Statistics of Indonesia), available on the website (https://padangkota.bps.go.id/). The other parameters, such as waste production rate, waste composition, and biogas conversion rate, were obtained from reputable publications, including journals and other academic sources related to Padang City. Since there was a lack of data regarding the waste condition in Padang, several parameters were also adapted from the textbook, or waste parameters were used in general. Several scenarios, including price simulation, were applied to the data to make the analysis more convincing. This approach would make the discussion much more realistic and could be used for practical purposes. Finally, the results of the analysis were provided in a graph and table to support the conclusion for this problem.

RESULTS AND DISCUSSION

Population Growth and Solid Waste Generation Forecast

The city's population growth directly influences solid waste management in Padang City. As the population increases, more waste is produced due to higher consumption of goods and services, leading to more packaging waste and disposable items. Population growth also leads to changes in lifestyle, with people adopting more convenient and disposable habits, contributing to increased solid waste generation. Urban areas produce more waste per person than rural areas due to higher economic activity and consumption. As people move from rural areas to cities in search of better opportunities, population growth in urban areas increases. Additionally, housing and infrastructure development demand rises with population growth, increasing construction and demolition waste.

A report from BPSk in 2020 estimated Padang's population to be around 909,115 people. By proceeding with the data from 2010 to 2023 with polynomial second-order projection (R = 0.99), it could be projected that the population in Padang will be close to 1 million per capita in 2035 (Figure 1). According to a report by the Environmental Agency of West Sumatra Province (*Dinas Lingkungan Hidup Provinsi Sumatra Barat/*DLH Sumatra Barat*)*, 647 tons of solid waste were generated in a day in 2023 [6]. Hence, it means that by calculating the average municipal solid waste (MSW) generation rate for Padang City, namely 0.704

 https://doi.org/10.25077/ajeeet.v4i1.104

kg·capita^{-1}·day^{-1} by weight or 5.317 L·capita^{-1}·day^{-1} by volume [7], there will be 256,000 tons or 1,950,000 m^3 of solid waste estimated to be generated in 2035.

Figure 1. Padang's Population Projection in 2010 to 2035

Meanwhile, suppose the required landfill area is calculated based on the projection of MSW generation by volume minus the amount of waste processed by informal scavenger and waste bank (WB) communities, namely around 3.3% [8]. In that case, it can be estimated that a 1000-ha area must be available until 2035 to handle the waste from Padang City. On the other hand, only ±33 Ha area is currently available in the Aie Dingin landfill. This means that shortly, the amount of waste transported to landfills will be overloaded, and, worse, Padang will face a waste problem. The existing waste management infrastructure may struggle to keep up with the increasing waste generation rate caused by population growth, leading to inadequate waste collection, improper disposal practices, and overwhelmed landfill capacities.

As mentioned, WB and informal communities' recycling activities and participation in solid waste management in Padang are low. Even DHL of Padang reported that 70% of municipal solid waste is processed in landfills; however, this effort has not proven successful. On the other hand, much potential can be obtained by recycling and recovering the material in solid waste to utilize it for different benefits. The explanation regarding this material's potential will be discussed in the next section.

Municipal Solid Waste Compositions of Padang and Its Potential

According to Suheno, the solid waste composition in Padang consists of 41.44 % kitchen waste, 21.56% plastic waste, 11.33% paper waste, 7.85% garden waste, 6.27% other waste, 5.46% metal/can waste, 2.51% glass waste, 2.18% fabric/textile waste, and 1% of COVID-19 waste [7]. Assuming the composition will not change significantly (except for COVID-19 waste combined with other waste since it is also categorized as medical or hazardous waste), the projection for each material in 2035 is shown in Table 1.

Table 1 shows that in 2035 plastic, paper, and metal/can waste generated about 55,000, 29,000, and 13,000 tons per year. These waste types commonly become the favorite type of waste by WB or informal communities since they are easy to sell and have a competitive price. Based on the price set up by the Integrated Waste Management Centre of Andalas University, each waste type has a price range from Rp. 1000-1100 for plastic waste, Rp. 1300-1500 for paper waste, and Rp. 2000-3000 for metal/can waste. Assuming the price of those waste types does not change significantly in 2035, it can obtain around Rp. 150 billion (approximately $ 9.4 million) profit annually if those waste types are sold to recycling factories. These numbers do not include the profit from recycling factories if they can convert that material to raw or usable products. Hence, it could be said that at least collecting and selling several waste types will be economically advantageous.

Table 1. Projection of Padangs' MSW Composition in 2035

Type	%	2035	
		ton·day^{-1}	ton·year^{-1}
Kitchen waste[7]	41.44	290.65	106,088
Plastic waste[7]	21.56	151.22	55,194
Paper waste[7]	11.33	79.47	29,005
Garden waste[7]	7.85	55.06	20,096
Other waste[7]	7.27	50.99	18,611
Metal/can waste[7]	5.46	38.30	13,978
Glass waste[7]	2.51	17.60	6,426
Fabric/textile waste[7]	2.18	15.29	5,581

On the other hand, kitchen waste, until now, is not a favored waste type for WB and informal communities in Padang. As shown in Table 3, vast amounts of kitchen waste will be generated in 2035, around 100,000 tons per year. However, the utilization of this waste type is still low and is mainly ignored by communities. No exact data shows that, but most WBs do not accept this kitchen waste type since no big collector will buy it. Besides, people dump kitchen waste improperly or burn it with other burnable waste at home. Some WB and communities have tried to utilize this waste by composting. However, since the C/N ratio for kitchen waste sometimes cannot be fulfilled, it is difficult to proceed, so combining it with garden waste is necessary [9]. That is why the conversion rate for kitchen waste is still low in Padang. In another city in Indonesia, kitchen waste some time is collected to be utilized as swine food [10]. Nevertheless, because in West Sumatra, including Padang, swine is taboo to farm, this alternative potential is difficult to execute. However, if it can be applied, some farmers will buy kitchen waste with a range of around Rp. 1300-1500. So, if this price is still used in the future, about Rp.150 billion (approximately $ 9.4 million) profit can be earned roughly from recycling food waste into animal feed in Padang.

The other option for utilizing kitchen waste is energy conversion. Because this method requires specific technology and economic considerations, there is limited public discussion about it. The following section will detail the potential for converting kitchen waste into energy and its commercial feasibility.

Energy Potential from Kitchen Waste and Commercial Feasibility

It has been known that organic waste is easily degraded, especially from kitchens. The biological process in organic waste can reduce and convert the material into simple components such as organic volatile fatty acid and methane gas. Methane gas produced during this process is a harmful gas categorized as Green House Gas (GHS). However, this methane gas can also be utilized as an energy source with proper conditioning and process optimization. No specific gas conversion unit in the Aie Dingin landfill can achieve this. Yet, the methane gas is discharged through the gas line to avoid gas accumulation, which can trigger the explosion. Some pilot projects to utilize this gas have been conducted but are inactive. According to Hidayat, based on the simulation, the methane gas released from the Air Dingin landfill could be estimated to be about 3.119 tons of gas annually or equal to 4,351 m^3 annually [11]. However, these numbers seem unlikely to be achieved on the site due to several problems, namely the irregularity in the solid covering period, improper coverage of solid waste cells which failed to capture gases from the degraded material, the dis-setup of gas pipe head to the sources, and lack of maintenance to gas treatment units in the landfill. Hence, extra effort is required to achieve this methane gas production.

Another application that can be used to recover energy from kitchen waste is a bioreactor or biodigester. In this system, degradable organic waste is conditioned using microorganisms to control the degradation process and gas production. Several studies have proved that bioreactor or biodigester is much more efficient than without treatment [3]. For illustration, by using the projection data in Table 1, it is assumed that the bioreactor could reduce 85% of organic compound [12] and the methane conversion rate is 0.215 $L{\cdot}kg^{-1}{\cdot}VS_{rem}{\cdot}day^{-1}$ [13], 1,150 m^3 methane gas can be generated daily or equal to 419,750 m^3 annually. Thus, this number is ten times bigger than utilizing methane gas directly from the landfill (Figure 2). Nevertheless, substantial investment costs, high technology applications, required expertise, and strict maintenance are challenges for this alternative.

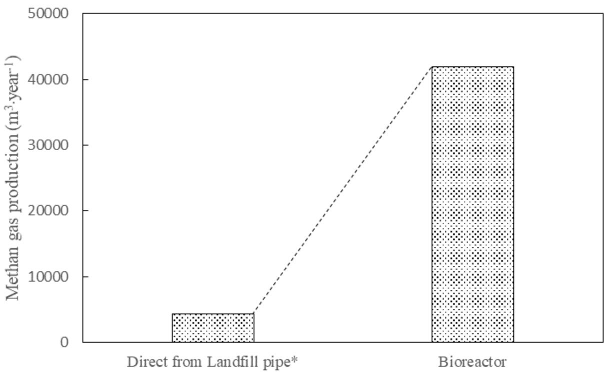

Figure 2 Comparison of gas production projection between direct yield from landfill *[11] and application of bioreactor in Padang

Scenario in Utilizing Methane Gas from Kitchen Waste

The next challenge in energy recovery from MSW is how to deliver it to consumers. This component has economic advantages as it can reach people and is affordable daily. To analyze this situation, several scenarios were conducted to explore the possibilities of efficiently and economically utilizing this energy.

*Direct utilization as **a** biogas scenario*

The demand for gas fuel in Padang is relatively sufficient. Assuming that in 2035, there are approximately 150,000 households in Padang, and every household uses two small LPG tanks (7.3-liter volume) every month, it can be estimated that 26,000 m^3 LPG will be utilized annually. Meanwhile, from the previous analysis, it could be calculated that 419,750 m^3 of methane gas can be produced from kitchen waste in Padang. This comparison should be the turning point in the renewable energy revolution since biogas has less gas emission than fossil fuel or natural gas [14]. However, there are still a lot of issues that need to be addressed.

Methane gas can supposedly be utilized like natural gas or commercial LPG. The point that needs to be considered when using biogas is that the energy required for combustion is three times higher than that of fossil fuel or natural gas [15]. It means biogas requires a 3-fold volume compared to commercial LPG. That means the adequate volume of methane produced from waste mentioned previously equals 140,000 m^3 of LPG capacity.

Another point is that in some small-scale communities, methane gas from solid waste is delivered using direct pipes to the home. The kitchen stove used in this system also differs from a commercial LPG stove [16]. Direct piping is very convenient in this condition. However, since Indonesia, especially in Padang, is not used to applying a municipal gas piping system, making the pipeline for biogas is quite challenging and requires substantial investment costs. There are also options for compressing the gas into the tank, such as natural gas [17]. However, as mentioned before, there is to be a 3-fold volume compared to a commercial LPG tank, which might be resolved using a bigger gas tank or preparing two more spares for the tanks.

Regardless, converting the waste to biogas still has advantages. In terms of energy units, the price of biogas is almost the same as natural gas. If assumed, the equal production of methane gas from waste compared to LPG is 140,000 m^3, and the market price of LPG in Padang is Rp. 3500 per liter, there will be Rp. This production earned 490 billion (approximately $ 30 million) gross profit. Besides, this production could reduce dependence on fossil fuels and minimize GHG produced from landfills.

Electricity conversion for household demand scenario

Besides being used for kitchen gas, the other alternative to utilizing methane gas from MSW is conversion to electricity. Assuming that 1 m^3 methane gas can produce 6 kWh of electricity, it can be estimated that in 2035, the production of electric power from the methane gas will be approximately 2,5 GWh per year. By multiplying the standard price from *Perusahan Listrik Negara*/PLN (Indonesian National Electric Power Company), namely Rp. 1500 per kWh, the gross profit from this scenario is Rp 3,7 billion (approximately $ 230,000) per year. That is a very fantastic number.

However, this capacity still cannot fulfill the power demand in Padang. According to the PLN annual report, Indonesia's power consumption per capita is 1,285 kWh annually [18]. That means that Padang should receive 1,285 GWh per year of power in 2035. Compared to the power produced by MSW, it is about 32% of the total power required. Thus, this number is still interesting since electricity comes from renewable sources. However, developing the other investments in power utility related to this conversion should be considered in this scenario.

Electricity conversion for Electric Vehicle (EVs) Charge station scenario

Currently, EVs are a favorite piece of technology that is expected to be a game changer in the future of transportation. There is a dilemma nowadays since the electric power source used to charge this transportation mode still comes from fossil fuel sources, while the tagline for EVs is to reduce dependency on this non-renewable fuel. Meanwhile, the share of EVs in many countries has significantly increased over the years, including in Indonesia [19].

Nowadays, just a few charging stations for EVs are available in Padang. Hence, there is also potential to invest in this kind of business. As mentioned in the previous section, providing electric power from MSW for household demand requires significant investment costs. However, investing in small-scale onsite waste for a methane gas generator unit can be good. In the rough calculation, every EV requires 7.2 to 10 kW of electricity. That means, every day, about 1000 EVs can be charged using this power source. At regular PLN prices, one EV pays Rp 18,500 to 25,000 for every charge. So, annually, this business model can earn Rp. 9 billion (approximately $ 560,000) gross profit in one year. Despite the technology and the expertise, compared to the two previous scenarios, this alternative is much more suitable for the private sector. However, the basic MSW management components, such as handling, storing, collecting, and transporting, should be considered since the government is still conducting these features.

Analysis Through the Scenarios

The analysis of the energy conversion scenarios in Padang is summarized in Table 2.

By comparing the three scenarios mentioned previously, it can be seen that the 1st scenario has the most potential profit compared to the others. Even if it should be adjusted with a combusting capacity of natural gas or LPG, the methane gas demand can still cover the demand for household gas, which is a very important need for people. However, this scenario is challenging to execute with the small capital. Infrastructure, direct pipeline systems, and gas tank compaction alternatives demand significant investment. Hence, it can only be provided by the government, the public sector, or the major private company.

A similar condition also appears for the utilization of waste converted to electric power. Compared to methane gas direct use, this scenario makes less profit and still requires massive development of infrastructures. Thus, this scenario is complex for small and medium companies to adopt since it requires significant capital for investment. Regardless, this scenario strongly recommends that government stakeholders use as an alternative power source that can support the green energy policy in Padang City.

As a novel scenario for the near future, developing power generators from waste that can be utilized as EVs charging stations is very promising. Since the market share of EVs will increase over time, this business model can generate more profit than direct household connections. Besides, the investment in equipment and infrastructure is relatively affordable for small and medium companies since this idea can be applied in small areas. Some research also proved that small EVs changing stations can contribute to reducing GHG [20]. However, similar to scenario 2, the availability of technology and expertise is crucial for this business model. Additionally, like conventional gas stations, the EVs charger business may soon be regulated, so it requires a piece of significant non-technical knowledge to run this business idea.

Table 2. Summary of Scenarios for Energy Conversion from MSW in Padang

	Potential energy production	Potential Annual Income	Pros	Cons	Prospectus investor
1st Scenario	419,750 m^3 methane gas per year	Rp. 490 billion	High demand for home gas fuel.	Required significant investment in supporting infrastructure	Public sector Major private company
2nd Scenario	2,5 GWh per year	Rp. 3 billion	Covering part of power demand with renewable energy.	Required significant investment for infrastructure.	Public sector Major private company
3rd Scenario	1000 EVs charging per day	Rp. 9 billion	High prospective green energy business. Able to be applied on a small on-site scale	Possibly a lack of available technology and expertise.	Public sector Major private company Small and medium company

Overall, the MSW management in Padang City faces common problems such as uncertain regulations, lack of security, and potential conflict with local groups. Additionally, the lack of support from the government and low public awareness of environmental matters are also hindrances to the application of these technologies in real-life conditions. It is crucial to have a holistic approach that strengthens the social, business, and technological aspects to execute these ideas effectively.
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CONCLUSIONS

The MSW in Padang has the potential to be used as renewable energy, especially for kitchen waste. Converting waste into gas is possible through technology and can earn a potential profit if it is managed appropriately by the business. Furthermore, since the trend of EVs in the near future is very open, using biogas from waste as the source of charging station energy is very promising to apply as a small or medium-scale business. Still, the regulation problem, government support, and awareness of the public environmental issues are the obstacles to running this business in the on-site situation. In addition, extensive research on these issues is necessary to support future ideas.

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Azwar Rasyidin

Azwar Rasyidin is a distinguished professor in the Soil Science Department at Andalas University. He is renowned for his soil genesis and land management expertise and has advanced soil science education. With a decades-long prolific career, he has contributed significantly to academic research, publishing numerous influential papers and books. His work emphasizes sustainable agriculture and the restoration of degraded lands. A passionate educator, Azwar supervises graduate and post-graduate students and young researchers, fostering a deep understanding of soil science. Besides, he also collaborates with local communities on various eco-friendly projects, contributing significantly to sustainable agriculture and development.