Bioculture
Bioculture Journal
Bioculture 2(1): 19-33
ISSN 3025-3632

Institute for Advanced Science, Social and Sustainable Future
MORALITY BEFORE KNOWLEDGE

Strategy for developing the utilization of organic waste as an alternative source of electricity in Indonesia

Farchani Putri Yuniar[1*], Grace Gardenia Ginting[1]
[1] *School of Environmental Science, Universitas Indonesia, Central Jakarta 10430, Indonesia.*
*Correspondence: farchani.putri@ui.ac.id

Received Date: June 25, 2024 Revised Date: July 30, 2024 Accepted Date: July 30, 2024

ABSTRACT

Background: Indonesia has pledged to reach its Net Zero Emission target by 2060, necessitating the shift to renewable energy sources. To achieve this, Indonesia must transition from its current reliance on fossil fuel power plants to renewable energy generators, ensuring the same or greater electricity capacity. One viable renewable energy source is organic waste. This study aims to explore strategies for developing organic waste as an alternative energy source to bolster Indonesia's energy resilience and environmental sustainability. **Method:** The research employs a qualitative approach, including literature reviews and qualitative descriptive analysis. **Findings:** Waste to Energy (WtE) processes convert waste into electricity and/or heat, aiding in greenhouse gas reduction, improving waste management efficiency, and supporting sustainable development. WtE technologies can utilize both thermochemical and biochemical methods to convert waste into energy. The Indonesian government is known to have 12 projects to accelerate the installation of Waste Processing into Electrical Energy, both the Waste Power Plants that have been in operation and under construction and using gasification as the method. The development of WtE faces various challenges ranging from completeness and consistency of regulations, high tipping fees, complex cooperation mechanisms and business models, problems with the characteristics and nature of Indonesian waste that need special handling, and rejection from residents. **Conclusion:** Strategies that can be implemented in developing WtE in Indonesia include drafting policies and regulations, increasing public awareness, collaboration with the private sector, choosing the right technology, developing infrastructure, increasing the efficiency of waste collection, and international partnerships. **Novelty/Originality of this study:** This research offers concrete strategies to develop Waste to Energy (WtE) technology in Indonesia, including policy formulation, increasing public awareness, and collaboration with the private sector to utilize organic waste as a renewable energy source to support the 2060 Net Zero Emission target.

KEYWORDS: electrical energy; organic waste; renewable energy sources; waste to energy

1. Introduction

The increasing population in Indonesia has led to a rapid increase in the volume of waste, even exceeding the capacity of the available infrastructure. As a result, several community activities emerged that damaged the environment, such as burning waste and throwing waste into rivers. Most of the waste generated in Indonesia is generally wet waste (organic waste), which covers about 60-70% of the total waste volume. For some people, waste is an item that is considered to have no value even though waste can be used as an alternative source of energy, where the composition of waste that is rich in organic matter is around 70,69% (Pujotomo, 2016). Organic waste is waste that is easily degraded/decomposed by nature and will disappear by itself even if left alone. There are

Cite This Article:
Yuniar, F. P., & Ginting, G. G. (2024). Strategy for developing the utilization of organic waste as an alternative source of electricity in Indonesia. *Bioculture Journal, 2*(1), 19-33. https://doi.org/10.61511/bioculture.v2i1.2024.950

two types of organic waste, namely animal organic waste and biological organic waste. Animal organic waste is organic waste originating from animal bodies, for example leftover meat, bones, fish innards, and so on, while biological organic waste originates from plant body parts, for example vegetable scraps, fruit peels, fallen leaves of gardens, and the like (Alkautsar et al., 2020).

Currently, waste management, particularly in urban areas, is neither efficient nor effective due to its centralized nature and reliance on mixed waste disposal systems (Pujotomo, 2016). Waste management that is less comprehensive can lead to pollution and environmental damage. Based on its type, organic waste has the largest percentage in Indonesia, namely 54,1% in 2022 and the largest waste generation based on its source comes from households (Arfidianingrum et al., 2023).

Energy is an essential requirement for daily human survival. The demand for electrical energy in Indonesia is continuously rising in tandem with economic and population growth. It is projected that Indonesia's electricity needs will surge more than sevenfold to 1,611 TWh by 2050 (Al Hakim et al., 2022). As the largest tropical archipelago in the world, Indonesia possesses abundant biomass resources that can be harnessed as a source of energy. The potential of Indonesia's bioenergy resources reaches 32.000 MW, but in reality the installed capacity is only 1.740,4 MW or the utilization is only 5,4% of the total potential of electricity-based bioenergy resources (Ma'arif et al., 2019). Numerous successful studies and initiatives worldwide have demonstrated the implementation of Organic Waste-to-Energy (OWtE) technology for managing and treating solid organic residues. Specific examples of these practices have been developed and implemented in Latin American and Caribbean (LAC) countries. Over the past 40 years, the strategies and sectoral applications for OWtE have been shaped by the political context and technological advancements of the time. However, challenges such as high initial costs, limited access to advanced technologies, lack of stakeholder participation, and insufficient public policies have impeded the effective implementation of OWtE technologies for organic waste treatment (Silva-Martínez et al., 2020).

Indonesia is dedicated to reaching the Net Zero Emission goal by 2060, which involves generating energy from renewable sources as part of its Net Zero Energy strategy. This transition necessitates converting energy generation facilities that are currently predominantly fueled by fossil fuels such as coal and oil. Not only converting the type of power plant used, but also having to provide the same or even greater electricity capacity in the process of converting this power plant. Of course, to support this statement, in addition to building new industrial areas that implement Net Zero, the Indonesian government must also be able to improve the pattern of electricity generation that is distributed to the wider community (Hertadi et al., 2022).

Switching from non-renewable to renewable energy sources is essential to support Indonesia's goal of achieving Net Zero Emissions for environmental sustainability. One of the renewable energies that can be utilized as a source of electrical energy is organic waste. High volumes of waste in landfills are still common in Indonesia. Based on research by Faridha et al. (2015), a waste power plant has the potential to use 120 tons of waste every day to produce 2,19 MW of electricity using the thermochemical conversion method. Therefore, waste has enormous potential to become an alternative source of electricity in Indonesia due to the high waste production in Indonesia, which is 3,2 million tons annually. The energy crisis and the waste problem are the two main challenges faced by people in Indonesia at this time. Using waste as a source of electrical energy presents a dual solution to address two significant challenges simultaneously. By harnessing organic waste as an alternative renewable energy source, Indonesia can mitigate its waste management issues while reducing its dependence on non-renewable energy sources, which currently dominate the energy landscape. The aim of this research is to explore strategies for developing organic waste as a viable source of electrical energy in Indonesia, aiming to enhance energy resilience and promote environmental sustainability.

2. Methods

This study employs a qualitative approach, which is a method used to investigate and comprehend the meanings that individuals or groups attribute to human or social issues. The research procedure encompasses the formulation of inquiries and methods, gathering of data typically within research participant contexts, analyzing the data by deriving general themes from specific ones, and researchers interpreting the significance of the data. This writing method is descriptive qualitative based on a literature review involving previous studies and research on the use of waste as a source of renewable electrical energy. Information is obtained from scientific journals, articles, and other related publications. The description of the literature study includes waste problems in Indonesia, non-renewable energy and renewable energy, energy consumption in Indonesia, waste to energy, waste to energy technology, waste power plants in Indonesia, waste to energy challenges in Indonesia, waste to energy development strategy in Indonesia.

The data is collected from relevant journals so that conclusions can be drawn according to the objectives of the topic to be studied. The initial stage of this research is to identify the research topic to be reviewed, involving searching and selecting journals that are relevant to the research topic to be reviewed. After analyzing the relevant articles, the researcher will combine these findings and interpret them in terms of the research objectives being carried out.

3. Results and Discussion

3.1 Waste problems in Indonesia

As Indonesia's population and economic activities grow, urban areas experience a corresponding increase in waste volume each year. High-density urban areas are major contributors to Indonesia's waste generation. According to the Indonesian Ministry of Environment and Forestry, the per capita waste generation exceeded 0.7 kg per day in 2015, with only 69% of total waste disposed of in Final Disposal Sites; the remainder is burned, dumped in public areas, or managed informally. Household waste recycling rates across Indonesia are notably low, at approximately 1.7% (Kubota et al., 2020). Indonesia currently has a very high waste generation problem and 60% of the waste generation comes from organic waste (OW). The scope for anaerobic digestion (AD) of OW is still not optimal in its management, with many reactors not functioning properly (Tassakka et al., 2019).

Indonesian people who live in several big cities, especially in the household sector, still exhibit the behaviour of littering. There are also many urban communities who do not know about good and correct waste management. In fact, urban communities already have a good understanding of a healthy and clean environment in urban areas. The results of the study also show that there are differences in environmental awareness among people in several regions with different economic classes. Personal awareness of the local environment needs to be instilled in urban communities as an initial effort to maintain a clean environment free of waste (Brotosusilo & Handayani, 2020).

Food waste is a significant contributor to organic waste and Indonesia is a major producer of such waste. The mismanagement of food waste in the country stems from insufficient processing methods, leading to adverse environmental effects. This issue extends beyond Indonesia to become a global concern, as food loss and waste occur across multiple stages of the food value chain. These include agricultural and animal production, post-harvest handling, storage, processing, distribution, and consumption. In developing nations, premature harvesting of agricultural products often exacerbates the challenge of food waste (Suhartini et al., 2022). Currently, in numerous countries, the disposal of food waste involves either burying it in landfills or incinerating it along with other flammable household wastes to generate energy. However, these approaches are facing increasing economic and environmental hurdles despite the significant organic and nutrient content found in food waste. In principle, food waste holds promise as a valuable resource that can be utilized in biofuel production through various fermentation techniques. The valorization of food waste has garnered growing interest, aiming to produce biogas, hydrogen, ethanol, and biodiesel as end products. Indonesia alone generates over 30 million tons of food waste annually (Kiran et al., 2014). Comparison of total food waste from Indonesia with several other countries can be seen in the following graph (Fig. 1).

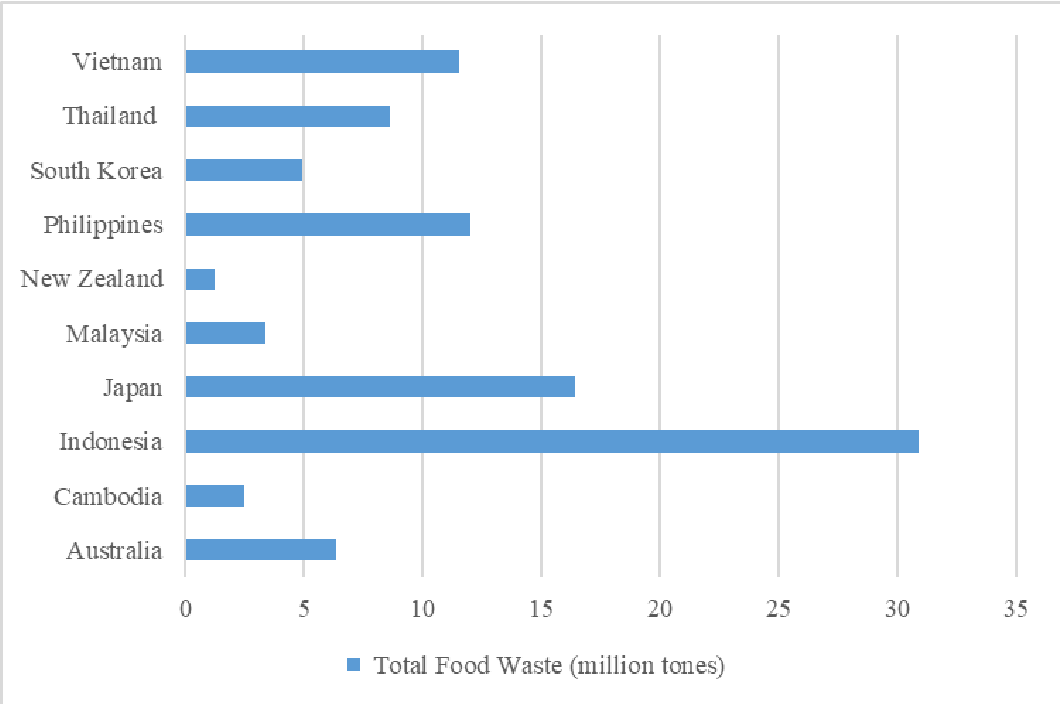

Fig. 1. Graph of total food waste in several countries
(Source: Kiran *et al*., 2014)

In Indonesia, waste typically falls into three main categories: industrial waste, solid waste, and electronic waste (e-waste). Currently, Indonesia generates around 176.000 tons of municipal solid waste every day (64 Mt per year). As much as 70% of solid waste is reported to be dumped openly in more than 380 landfill locations and only a small portion is disposed of in landfills or recycled and reused. This is caused by a lack of manpower and landfill facilities (Khalil et al., 2019).

3.2 Non-renewable energy in Indonesia

Indonesia possesses significant capabilities for electricity generation from diverse sources. As one of the world's largest exporters of coal with substantial oil reserves, the country heavily relies on these resources for electricity production and economic activities. However, Indonesia's energy sector productivity has shown a declining trend since the 2010 baseline, potentially impacting its export share. This decline is attributed to domestic barriers that hinder increased production without cost subsidies, as well as insufficient investments to foster local and international collaborations (Dutu, 2016). Besides that, the unbalanced emphasis on new and renewable energy sources is also one of the crucial reasons for the decline in Indonesia's industrial output. This condition poses a major threat to the stability of energy supply and industrial output so that it tends to hinder the growth process (Saudi et al., 2019).

Indonesia's primary energy sources predominantly consist of fossil fuels such as coal, oil, and natural gas. Between 2011 and 2012, coal reserves saw a slight decrease from 120 billion tons to 119 billion tons. In terms of oil, total reserves in 2012 amounted to 7.41

billion barrels, comprising 3.74 billion barrels of proven reserves and 3.67 billion barrels of potential reserves. During this period, crude oil production also declined from 329 million barrels in 2011 to 315 million barrels in 2012. Considering the ratio of production reserves for these fossil energy sources, coal has the highest potential utilization, estimated to last for approximately 75 years. Natural gas reserves, on the other hand, can potentially last for nearly 33 more years. Oil, however, has the least potential for long-term viability as a fossil energy source, estimated to be utilizable for only about 12 years if no new alternative energy sources are discovered (Kholiq, 2015).

3.3 Renewable energy in Indonesia

In response to declining fossil fuel production, especially in oil and gas sectors, and global initiatives to reduce emissions, governments worldwide are increasingly turning to new and renewable energy sources. This shift is aimed at enhancing energy security and independence. Indonesia, guided by Government Regulation No. 79 of 2014 on the National Energy Policy, aims to achieve a minimum of 23% new and renewable energy in its energy mix by 2025, with a target of 31% by 2050. The country boasts abundant renewable energy resources that can be leveraged to meet its primary energy needs (Suhartini et al., 2022).

Renewable energy resources in Indonesia hold vast potential for electricity generation, essential for ensuring sustainable energy supply and reducing dependence on fossil fuels. Research reveals that the country's geothermal reserves alone, constituting about 40% of the global total, have the capacity to generate approximately 2.8 × 10^7 kilowatts (KW) of power. Additionally, hydro and biomass-based power plants can contribute over 1 × 10^8 KW, while solar energy has the potential to add up to 1.2 × 10^9 KW to Indonesia's energy grid. Despite these significant potentials, Indonesia currently taps into only 5% of its renewable energy resources, hindered by technical challenges and regulatory barriers. Hydropower presently represents the largest share of renewable energy in Indonesia's energy mix. However, in 2015, on-grid hydropower production amounted to just 5.2 × 10^6 KW, despite an estimated economic potential of 8 × 10^6 KW from untapped hydropower sources, many of which are located in densely populated islands such as Java, Sumatra, Sulawesi, and Nusa Tenggara (Khalil et al., 2019).

Indonesia boasts abundant new and renewable energy resources, yet these remain underutilized due to several challenges including high investment costs, remote locations of potential resources, and inadequate regulatory support. One promising area for bioenergy production in Indonesia lies in the utilization of biomass waste, particularly Municipal Solid Waste (MSW) and specifically food waste. Globally, it is estimated that 40-70% of MSW comprises biodegradable organic matter, predominantly food waste. To gain a better understanding of the renewable energy reserves in Indonesia, please refer to Table 1 below.

Table 1. Renewable Energy Reserves

Types of Energy	Potential (GW)	Realization (GW)	Utilization
Geothermal	23,8	2,1	9,0%
Solar	207,8	0,2	0,1%
Wind	60,7	0,2	0,3%
Water	94,6	6,1	6,5%
Bioenergy	32,7	1,9	5,8%
Tidal	17,9	-	-

(Suharyati et al., 2021)

In recent years, there has been increasing recognition of the untapped potential of organic waste as a valuable resource for energy generation. Harnessing energy from organic waste has emerged as an attractive alternative, especially for enhancing energy security. This heightened awareness has spurred significant research into technologies focused on extracting valuable fuels from food waste. The primary aim is to address environmental concerns associated with waste disposal, alleviate pressure on natural resources, minimize risks to human health, and maintain ecological balance (Pham et al., 2015).

3.4 Energy consumption in Indonesia

Over the past decade, Indonesia has seen a notable increase in electricity consumption, rising from 159.9 TWh in 2011 to 242.6 TWh in 2020. This surge marks electricity as having the highest growth rate among all energy sources. However, there was a slight decrease in electricity consumption in 2020 compared to the previous year, largely due to reduced industrial and commercial activities during the pandemic. Among consumer segments, households emerged as the largest consumers of electricity in 2020, accounting for 112.7 TWh or 46.4% of the total national electricity demand, driven by Indonesia's substantial household population, which reached 69 million in 2020. The industrial sector followed with 71.5 TWh (29.5%) of electricity demand, and the commercial sector accounted for 58.2 TWh (24%). The transportation sector contributed a minimal 0.3 TWh (0.1%) to overall electricity demand (Suharyati et al., 2021). The rapid growth of the economy and population in Indonesia has led to a significant increase in energy demand. It is projected that by 2026, energy demand will continue to rise, potentially reaching up to 450 × 109 KWh (Khalil et al., 2019).

It is widely recognized that Indonesia is currently facing major challenges related to energy and waste due to its rapidly growing economy and urban population. The largest energy consumption is in Java, which is equal to 56%, followed by Sumatra (25%), Kalimantan (9%), Sulawesi (6%), Bali and Nusa Tenggara (3%), and Maluku and Papua (1%). The following is a table of energy consumption in Indonesia by sector and type (Table 2).

Table 2. Indonesia's final energy consumption in 2015

Consumption by Sector	Share (%)	Consumption by Type	Share (%)
Industrial	31,4	Coal	10,3
Household	15,1	Natural Gas	18,1
Commercial	5,0	Fuel	42,7
Transportation	35,6	Biofuel	2,7
Non-energy utilization	2,3	LPG	8,0
Other	10,6	Electricity	18,2
Total	100	Total	100

(Khalil et al., 2019)

3.5 Waste to energy

The concept of Waste to Energy (WtE) remains highly significant and garners significant interest due to its multifaceted implications for most of the Sustainable Development Goals (SDGs). With approximately one in ten people worldwide still lacking access to electricity, WtE presents a promising solution that can benefit individuals globally (Vlachokostas et al., 2021). By harnessing waste as a valuable energy source, this approach becomes not only logical but also pivotal for fostering sustainable development and establishing a circular economy. The concept of the circular economy aims to maximize the value of products, materials, and resources by prolonging their lifecycle as much as possible. This approach minimizes waste generation and reduces resource consumption overall (Wienchol et al., 2020).

Utilizing waste materials offers significant advantages by aligning with the principles of a circular economy, where waste recycling contributes to energy production. Efficient implementation of Waste to Energy (WtE) technologies facilitates the conversion of waste into usable energy. WtE represents a modern and sustainable approach to waste management, addressing waste disposal, energy generation, and greenhouse gas emissions simultaneously. This transformation of waste into energy forms a cornerstone for establishing a circular economy system, fostering a balanced relationship between economic activities and environmental sustainability. Such an approach is crucial for addressing resource scarcity and mitigating environmental risks effectively (Sharma et al., 2020).

The concept of Waste to Energy (WtE) revolves around achieving energy sustainability through the utilization of sustainable energy sources and systems. WtE technology aims to reduce greenhouse gas emissions through three interconnected approaches: generating CO2-free power, mitigating CH4 emissions from landfills, and recovering metals from solid waste as an energy-efficient alternative to extracting them from raw materials. WtE principles underscore the importance of utilizing sustainable, renewable, and abundant material sources, particularly integrating biomass into the energy mix. Improving the quality and cost-effectiveness of biomass as a renewable energy source involves meeting legal requirements and maximizing its calorific value. At its core, WtE promotes sustainable energy through sustainable sources, processes, and aims to achieve zero waste (Gil, 2022).

The WtE technology typically comprises various elements, such as sewage treatment facilities, combustion chambers, turbines, water cooling systems, gas emission chimneys, and other related components. On-site operational areas may include designated spaces for waste storage and supply, disposal sites for residues, tanks for sludge, and drainage systems for releasing cooling water into nearby bodies of water. Additionally, the transportation of fly ash from the factory site to the disposal site and the movement of waste from the landfill to the factory site are essential components of WtE technology. It is crucial to consider the detailed process of energy generation when examining WtE technology, as it enables the identification of points where pollutants are generated, as highlighted in the Environmental Impact Assessment (EIA) (Kabir & Khan, 2020).

3.6 Waste to energy technology

Waste to Energy (WtE) represents a viable approach to managing waste by transforming it into valuable resources for energy production. It involves converting waste into electricity and/or heat through various waste processing techniques or by converting waste into a fuel source (Chen et al., 2022). Developed nations such as Italy, Germany, Finland, France, and Japan have extensively adopted this method (Khan et al., 2022).

Waste to Energy (WtE) plays a significant role in mitigating greenhouse gas emissions and offering an efficient waste management system that promotes sustainable development. Unprocessed waste constitutes a substantial source of greenhouse gas emissions. These emissions, stemming from various sectors, including power generation, pose a significant challenge to achieving sustainable development. Even renewable energy sources like hydroelectric power cannot completely eliminate emissions. Fossil fuel-based power generation significantly contributes to global greenhouse gas emissions, surpassing emissions from renewable sources. It is important to note that WtE technology is not emission free, as the emissions can vary across different technologies. Research indicates that anaerobic digestion is a more environmentally friendly option compared to incineration, gasification, and pyrolysis (Khan et al., 2022).

Waste to Energy (WtE) encompasses a variety of technologies tailored to different types of waste, involving the conversion of waste into energy through various methods. These methods include thermochemical technologies such as incineration, pyrolysis, gasification, and hydrothermal liquefaction, as well as biochemical pathways like fermentation, anaerobic digestion, composting, and landfilling, as illustrated in Fig. 2. In recent decades, there has been an increasing focus on thermochemical conversion processes due to their numerous advantages. These include higher efficiency in converting waste to energy, adherence to the zero waste principle, shorter processing times, improved economic viability, and compatibility with diverse types of feedstocks, whether wet or dry (Varjani et al., 2022).

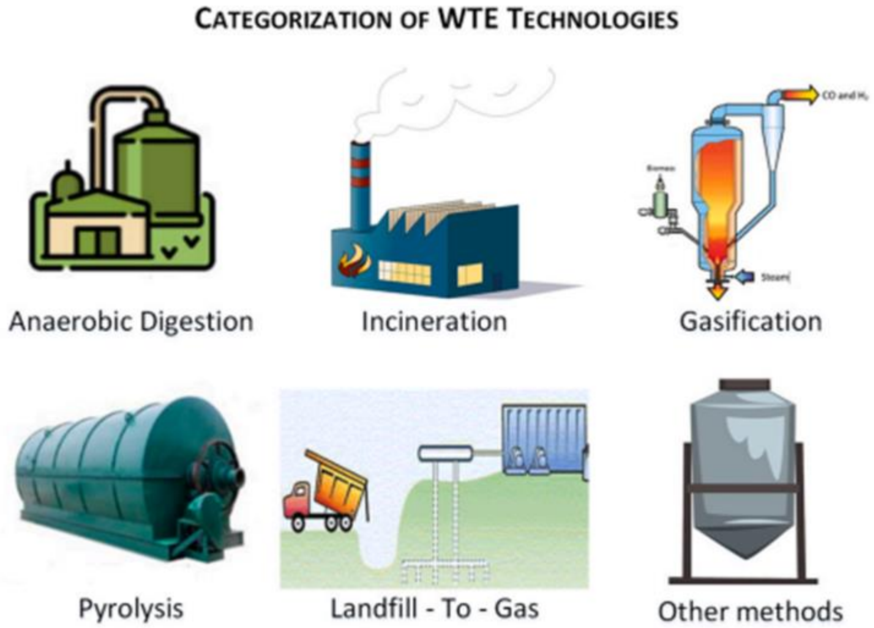

Fig. 2. Categorization of waste to energy technologies
(Vlachokostas et al., 2021)

3.6.1 Anaerobic digestion

Anaerobic digestion, a type of biochemical conversion, breaks down biodegradable materials using microorganisms in an oxygen-free environment. The process of anaerobic digestion advances through several stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. Each stage involves specific types of bacteria and microorganisms, including hydrogenotrophic, acidogenic, acetogenic, and methanogenic organisms. The efficiency and effectiveness of these metabolic stages are influenced by various factors, including pH levels, temperature fluctuations, substrate concentrations, organic load rates, and other relevant parameters (Kalaiselvan et al., 2022).

Anaerobic digestion has remained a popular choice in rural areas due to the relatively low cleaning requirements of the biogas produced, primarily attributed to its high methane content. This process, also known as biomethanation, involves the production of biogas without the presence of oxygen, utilizing waste materials as feedstock. The biogas generated primarily comprises carbon dioxide (CO_2) and methane, with methane constituting approximately 60% of the composition. Biomethane finds various applications, including heating, power generation,cooking, steam generation, and as a fuel for vehicles. It is estimated that around 2,14 kW of electricity can be generated from 1 m^3 of biogas obtained through biomethanation, achieving an efficiency of 35%. Moreover, anaerobic digestion holds promise as a potential solution for addressing issues related to crop residues, particularly those left in open fields. The hydrolysis stage is crucial in the anaerobic digestion process and often acts as the rate-limiting step, influenced significantly by the type of feedstock employed. Pre-treating biomass is essential to improve the yield of product gas and shorten digestion times. Integration with pyrolysis can further enhance the anaerobic digestion process, as the anaerobic digestion-pyrolysis system has demonstrated the potential to increase power production by 42%, translating to an increase in electricity production from 9896 to 14066 kWh/d (Varjani et al., 2022).

3.6.2 Microbial Fuel Cell (MFC) and Microbial Electrochemical Cell (MEC)

Bio-electrochemical processes encompass the utilization of Microbial Fuel Cells (MFC) and Microbial Electrochemical Cells (MEC). MFC serves as a biochemical apparatus that harnesses the decomposition capabilities of aerobic and anaerobic bacteria to generate electricity from organic matter. Apart from electricity generation, MFCs find application in wastewater treatment, removal of toxic metals, and bioremediation of sulfide contaminants. Plant MFCs represent modified versions of microbial fuel cells that demonstrate enhanced efficiency by utilizing plant-based sources, such as lignocellulosic materials, and compost derived from organic waste. The bioelectricity produced through these systems holds potential as a power source and can be utilized for environmental monitoring sensors. The organic waste by-products that undergo decomposition in bio-electricity production systems can also be repurposed as soil conditioners or fertilizers, thereby contributing to enhanced crop fertility when applied to agricultural land (Ashokkumar et al., 2022).

The MFC system exhibits the ability to generate energy from organic waste by utilizing electrochemically active microorganisms as catalysts for energy production. In traditional Microbial Fuel Cells (MFCs), a cationic membrane separates the anodic and cathodic compartments. Within the anodic chamber, microorganisms metabolize organic substances like glucose, serving as electron donors. Through this metabolic process, these compounds release electrons and protons. The electrons are transported through an electric circuit to the surface of the anode, where they generate electricity. Simultaneously, the protons traverse the electrolyte and subsequently pass through the cationic membrane. MEC, like MFC, shares a comparable structure, but with one distinction—the cathode in MEC is not exposed to air. Moreover, Microbial Electrolysis Cells (MEC) demonstrate higher rates of hydrogen (H2) recovery and a broader range of substrate utilization compared to other processes such as photo-biological processes, dark fermentation, or Microbial Fuel Cells (MFC). However, MEC does not occur spontaneously due to the endothermic nature of microbial electrolysis, unless the partial pressure of hydrogen is exceptionally low. This technique facilitates H2 production, which helps overcome the endothermic barrier associated with microbial fermentation product generation, and it requires a relatively low voltage compared to the theoretical voltage of 1.23 V applied in water electrolysis. By converting non-toxic and biodegradable waste into energy sources and valuable products, MEC systems contribute to energy-positive and carbon-neutral systems, presenting numerous opportunities for future waste biorefineries (Varjani et al., 2022).

3.6.3 Incineration

Incineration, an increasingly prevalent Waste to Energy conversion technology, is widely acknowledged as a favorable option for managing waste, particularly non-recyclable waste. It offers numerous benefits such as a significant reduction in waste quantity and volume, conservation of land resources, mitigation of greenhouse gas emissions, and the generation of electricity and/or heat. In recent years, combustion has gained substantial traction globally as governments seek effective measures to alleviate the burden of waste disposal and provide a renewable and sustainable alternative energy source. Incinerators are viewed as a financially advantageous substitute for sanitary landfills, particularly in larger and medium-sized cities where landfill space may be limited. While incineration allows for the recovery of energy from organic waste, it does not facilitate the retrieval of essential nutrients such as phosphorus and nitrogen present in the waste (Chen et al., 2022).

Incineration typically involves burning waste at high temperatures (800–1200°C) in the presence of excess oxygen or air. This combustion process includes several sequential stages: heating or drying, devolatilization or decomposition, and the combustion of volatiles and char. Initially, the biomass's free water (around 80–85%) evaporates, underscoring the importance of moisture content. During devolatilization or decomposition, carbon particles in the biomass thermally degrade, releasing major gases such as water vapor, carbon dioxide, carbon monoxide, hydrogen, and methane. Volatiles are subsequently generated, while char undergoes oxidation, releasing heat. Carbon and hydrogen in the biomass oxidize, forming carbon dioxide and water. Incineration serves as a waste treatment method that can reduce waste volume by 70% to 90%, making it suitable for high-calorific-value waste. This process converts released energy into electricity and involves three main stages: combustion with air at temperatures ranging from 700°C to 1000°C, utilizing hot gases from combustion for heat and electricity generation, and implementing measures to control emissions (Varjani et al., 2022).

3.7 Waste power plants in Indonesia

Waste is the main fuel that can generate electricity by using the potential volume of organic waste and inorganic waste. The process of generating electric power utilizing gas produced by waste can use two energy conversion process systems, namely the thermal conversion process and the biological conversion process. Pyrolysis technology and gasification technology are thermal conversion systems, while biological conversion processes are anaerobic digestion and landfill gasification. Combined Heat and Power (CHP) is an energy conversion system for generating several forms of energy production simultaneously in an integrated system. The CHP system is composed of several components including prime movers, generators, heat recovery, and integrated electrical networks. On-grid system, a Waste Power Plants on-grid system is a system in which a power plant is connected to the State Electricity Company network, aiming to help or optimize the State Electricity Company system. The series of Waste Power Plants systems will remain in touch with the State Electricity Company network by optimizing the use of energy from the Waste Power Plants electricity production which utilizes the potential of waste as fuel to optimize and help the electricity system. Based on the feasibility level of Waste Power Plants with other renewable energy generators, it is found that Waste Power Plants are more feasible to realize than other renewable energy generators. The main advantage of Waste-to-Energy (WtE) plants lies in the fact that their primary energy source—waste—is not influenced by weather conditions and typically increases annually alongside population growth. This differs from Hydroelectric and Solar Power plants, where energy production heavily depends on weather patterns. Additionally, WtE plants generally offer a more stable income from energy sales compared to renewable sources like solar, which can fluctuate (Muljono et al., 2022).

The Indonesian government, as documented by the Ministry of Energy and Mineral Resources, has embarked on 12 projects aimed at accelerating the implementation of Waste-to-Energy (WtE) facilities. These projects include operational Waste Power Plants as well as those currently under construction. The management of urban waste involves reducing its moisture content, followed by a gasification process to produce syngas. This syngas can then serve as an alternative fuel to coal in power plants. The establishment of Waste Power Plants is expected to address waste management challenges effectively while supporting the government's target of achieving a 23% renewable energy mix by 2025. Waste Power Plants is counted as a waste management program that has just been implemented in Indonesia, so that many studies and analyzes are needed regarding the most appropriate and efficient techniques for utilizing waste in Indonesia. Generally, Waste Power Plants use the gasification method, namely by utilizing the gas that comes out of the combustion of waste with limited oxygen or can be called incomplete combustion (Nurfadhilah et al., 2022).

3.8 Challenges of waste to energy in Indonesia

The development of WtE or waste to electrical energy development in Indonesia since 2018 has encountered various challenges and obstacles ranging from completeness and consistency of regulations, high tipping fees to WtE, cooperation mechanisms and complex business models to problems with the characteristics and nature of Indonesian waste which need special handling. Until 2021, out of the 12 planned cities, only one WtE is already operating, namely WtE Benowo Surabaya. If these problems continue, the construction and operation of WtE in 11 other cities will be further delayed. This has an impact on the increasing amount of waste that goes to the landfill so that the solid waste conditions in the 11 cities are increasingly emergency (Yuliani et al., 2022).

For investors, in this case the private sector, quality (calorific value & humidity) and quantity (amount of waste that can be supplied constantly) in a location can affect investment, type selection, and operational patterns from waste to energy. Low waste quality with high humidity and low calorific value, as well as unstable or insufficient supply in several areas are the main challenges affecting the development of WtE. Another challenge faced in implementing WtE in Indonesia is the rejection of local residents. As a land use facility that local residents typically oppose, Waste-to-Energy (WtE) plants are often heavily influenced by the Not in My Backyard (NIMBY) syndrome worldwide. Usually the benefits (efficient and effective waste management) are widely publicized, while potential hazards such as bad smells and dioxins tend to go unreported. Protests against waste to energy or anti waste to energy incinerators campaigns have been documented in many countries including Europe, Asia, the United States, and Canada. Rejection also occurred in Indonesia, one of which is in the city of Bandung. A group of Bandung city residents refused on the grounds that they would become a continuous burden of air pollution in the city of Bandung and were afraid that it would produce a toxic substance in the form of dioxins which endangers the nervous system and causes cancer in local residents (Setyono & Sinaga, 2021).

3.9 Waste to energy development strategy in Indonesia

The use of waste for energy in Presidential Regulation Number 97 of 2017 is carried out through the following strategies: (1) construction of waste-based power plants through thermal technology; (2) capture and use of methane gas as a source of electrical energy at landfills; (3) utilization of waste as a substitute fuel for the cement industry or RDF; (4) application of environmentally friendly sorting, collection, processing and final processing technology into renewable energy. The first strategy forms the basis of the accelerated Waste Power Plants development program. The second, third, and fourth strategies form the basis for the development of the regular Waste Power Plants program (Qodriyatun, 2021).

The development of Waste to Energy (WtE) in Indonesia can be carried out through various strategies involving various stakeholders, including government, industry, society, and the private sector. The following are several WtE development strategies in Indonesia: (1) Formulation of Policies and Regulations; (2) Increased Public Awareness; (3) Collaboration with Private; (4) Selection of the Right Technology; (5) Infrastructure Development; (6) Improved Waste Collection Efficiency; and (7) International Partnerships. The development of WtE in Indonesia is an important step in overcoming the problem of waste and the increasing demand for energy. By implementing these strategies, it is hoped that a more sustainable waste management system will be created so that it can increase energy security in Indonesia.

4. Conclusions

The amount of waste production in Indonesia which increases every year is a potential that can be exploited, one of which is by utilizing the excess availability of organic waste to be used as an alternative source of electrical energy in Indonesia. The declining reserves of fossil energy underscore the urgency of seeking alternative sources of electrical energy, with organic waste playing a pivotal role in the Waste-to-Energy (WtE) concept. WtE technologies enable the conversion of waste into electrical energy, such as in Waste Power Plants, although this approach is not without challenges in practice. Developing WtE in Indonesia necessitates strategic involvement from diverse stakeholders, including government, industry, society, and the private sector. The following are several WtE development strategies in Indonesia including policy and regulation formulation, increasing public awareness, collaboration with the private sector, choosing the right technology, developing infrastructure, increasing the efficiency of waste collection, and international partnerships.

Acknowledgement
The author would like to thank Dr. Herdis Herdiansyah S.Fil.i, M.Hum and Dr. Sri Setiawati Tumuyu as the lecturers of the human life system and environment course. this paper was made to fulfil the final exams assignment in the human life system and environment course.

Author Contribution
All authors contributed equally to the research, drafting, and revision of the manuscript. All have approved the final version for submission.

Funding
This research received no external funding.

Ethical Review Board Statement
Not applicable.

Informed Consent Statement
Not applicable.

Data Availability Statement
Not applicable.

Conflicts of Interest
The authors declare no conflict of interest.

Open Access

References
Al Hakim, R. R., Ariyanto, E., Arief, Y. Z., Sungkowo, A., & Trikolas, T. (2022). Preliminary study of juridical aspects of renewable energy draft law in Indonesia: An academic perspectives. *Adliya: Jurnal Hukum Dan Kemanusiaan*, *16*(1), 59–72. https://doi.org/10.15575/adliya.v16i1.14063

Alkautsar, Y. Y. N. Y., Arbaatun, C. N., & Prawita, F. N. (2020). Matrash: The use of machine learning in the waste bank based IoT integrated with smart. *E-Proceeding of Applied Science*, *6*(2), 4068–4076. https://openlibrary.telkomuniversity.ac.id/pustaka/files/162087/jurnal_eproc/matrash-pemanfaatan-machine-learning-pada-smart-trash-bin-berbasis-iot-yang-terintegrasi-dengan-bank-sampah.pdf

Arfidianingrum, D., Astra, I. M., Seta, A. K., & Rustanto, S. (2023). Analysis of influencing factors community participation in organic waste. *Ecolab*, *17*(1), 1–11.

Ashokkumar, V., Flora, G., Venkatkarthick, R., SenthilKannan, K., Kuppam, C., Mary Stephy, G., Kamyab, H., Chen, W. H., Thomas, J., & Ngamcharussrivichai, C. (2022). Advanced technologies on the sustainable approaches for conversion of organic waste to valuable bioproducts: Emerging circular bioeconomy perspective. *Fuel*, *324*(PB), 124313. https://doi.org/10.1016/j.fuel.2022.124313

Muljono, A. B., Mukti, K. B. K., Natsir, A. (2022). Kajian teknis dan ekonomi pembangkit listrik tenaga sampah (PLTSa) menggunakan software LandGEM TPA Kebon Kongok Gerung Lombok Barat. *Dielektrika*, *9*(1), 68–79. https://dielektrika.unram.ac.id/index.php/dielektrika/article/view/296

Brotosusilo, A., & Handayani, D. (2020). Dataset on waste management behaviors of urban citizens in large cities of Indonesia. *Data in Brief*, *32*, 1-11. https://doi.org/10.1016/j.dib.2020.106053

Chen, H., Li, J., Liu, J., Li, T., Xu, G., & Liu, W. (2022). Thermodynamic and economic evaluation of a novel waste-to-energy design incorporating anaerobic digestion and incineration. *Energy Conversion and Management*, *252*(December 2021), 115083. https://doi.org/10.1016/j.enconman.2021.115083

Dutu, R. (2016). Challenges and policies in Indonesia's energy sector. *Energy Policy*, *98*, 513–519. https://doi.org/10.1016/j.enpol.2016.09.009

Faridha, Pirngadie, B., & Supriatna, N. K. (2015). Potensi pemanfaatan sampah menjadi listrik di TPA Cilowong Kota Serang Provinsi Banten. *Ketenagalistrikan dan Energi Terbarukan*, *14*(2), 103–116. http://repository.unpas.ac.id/28369/

Gil, A. (2022). Challenges on waste-to-energy for the valorization of industrial wastes: Electricity, heat and cold, bioliquids and biofuels. *Environmental Nanotechnology, Monitoring and Management*, *17*, 100615. https://doi.org/10.1016/j.enmm.2021.100615

Hertadi, C. D. P., Sulaiman, M., & Anwar, P. G. P. (2022). Kajian industri energi terbarukan tenaga listrik di Indonesia berdasarkan arah kebijakan dan potensi alam. *G-Tech: Jurnal Teknologi Terapan*, *6*(2), 276–283. https://doi.org/10.33379/gtech.v6i2.1690

Kabir, Z., & Khan, I. (2020). Environmental impact assessment of waste to energy projects in developing countries: General guidelines in the context of Bangladesh. *Sustainable Energy Technologies and Assessments*, *37*(August 2019), 100619. https://doi.org/10.1016/j.seta.2019.100619

Kalaiselvan, N., Glivin, G., Bakthavatsalam, A. K., Mariappan, V., Premalatha, M., Raveendran, P. S., Jayaraj, S., & Sekhar, S. J. (2022). A waste to energy technology for enrichment of biomethane generation: A review on operating parameters, types of biodigesters, solar assisted heating systems, socio economic benefits and challenges. *Chemosphere*, *293*, 133486. https://doi.org/10.1016/j.chemosphere.2021.133486

Khalil, M., Berawi, M. A., Heryanto, R., & Rizalie, A. (2019). Waste to energy technology: The potential of sustainable biogas production from animal waste in Indonesia. *Renewable and Sustainable Energy Reviews*, *105*, 323–331. https://doi.org/10.1016/j.rser.2019.02.011

Khan, I., Chowdhury, S., & Techato, K. (2022). Waste to energy in developing countries-a rapid review: Opportunities, challenges, and policies in selected countries of sub-Saharan Africa and South Asia towards sustainability. *Sustainability*, *14*(7), 1-27. https://doi.org/10.3390/su14073740

Kholiq, I. (2015). Pemanfaatan energi alternatif sebagai energi terbarukan untuk mendukung substitusi BBM. *Jurnal IPTEK*, *19*(2), 75-91. https://doi.org/10.1016/s1877-3435(12)00021-8

Kiran, E., Trzcinski, A. P., Ng, W. J., & Liu, Y. (2014). Bioconversion of food waste to energy: A review. *Fuel*, *134*, 389–399. https://doi.org/10.1016/j.fuel.2014.05.074

Kubota, R., Horita, M., & Tasaki, T. (2020). Integration of community-based waste bank programs with the municipal solid-waste-management policy in Makassar, Indonesia. *Journal of Material Cycles and Waste Management*, *22*(3), 928–937. https://doi.org/10.1007/s10163-020-00969-9

Ma'arif, S., Widyawidura, W., Aridito, M. N., Kurniasari, H. D., & Kismurtono, M. (2019). Waste-to-energy development using organic waste recycling system (OWRS): A study case of Giwangan Market. *International Journal of Renewable Energy Research*, *9*(1), 354–362. https://doi.org/10.20508/ijrer.v9i1.8822.g7622

Mutmainnah, H., Pandiangan, F. A., & Hamzah, A. K. (2023). Analisis potensi sampah di TPA Toisapu sebagai bahan baku pembangkit listrik tenaga sampah (PLTSa) di Kota Ambon.

Jurnal Al-Azhar Indonesia Seri Sains Dan Teknologi, *8*(1), 77. https://doi.org/10.36722/sst.v8i1.1384

Nisrina, S. F., & Rahmat, B. (2022). Algoritma hibrid untuk menentukan produksi listrik pembangkit listrik tenaga sampah di Semarang. *Elkom: Jurnal Elektronika dan Komputer*, *15*(1), 199–212. https://doi.org/10.51903/elkom.v15i1.798

Nurfadhilah, I., Marliana, L., Lutfiah, L., & Zahra, S. F. (2022). Optimasi pembangkit listrik tenaga sampah berbasis teknologi co-gasifikasi thermal dengan refuse derived-fuel sebagai solusi permasalahan sampah dan lingkungan. *Comserva Indonesian Jurnal of Community Services and Development*, *1*(10), 850–858. https://doi.org/10.36418/comserva.v1i10.169

Pham, T. P. T., Kaushik, R., Parshetti, G. K., Mahmood, R., & Balasubramanian, R. (2015). Food waste-to-energy conversion technologies: Current status and future directions. *Waste Management*, *38*(1), 399–408. https://doi.org/10.1016/j.wasman.2014.12.004

Pujotomo, I. (2016). Pemanfaatan sampah menjadi sumber energi. *Energi & Kelistrikan*, *8*(2), 109–113. https://jurnal.itpln.ac.id/energi/article/view/243

Qodriyatun, S. N. (2021). Pembangkit listrik tenaga sampah: Antara permasalahan lingkungan dan percepatan pembangunan energi terbarukan. *Aspirasi: Jurnal Masalah-Masalah Sosial*, *12*(1), 63–84. https://doi.org/10.46807/aspirasi.v12i1.2093

Rahim, M. (2020). Strategi pengelolaan sampah berkelanjutan. *Jurnal Sipilsains*, *10*(1), 151–156. http://ithh.journal.ipb.ac.id/index.php/p2wd/article/view/22930

Saudi, M. H. M., Sinaga, O., Roespinoedji, D., & Razimi, M. S. A. (2019). The role of renewable, non-renewable electricity consumption and carbon emission in development in Indonesia: Evidence from distributed lag tests. *International Journal of Energy Economics and Policy*, *9*(3), 46–52. https://doi.org/10.32479/ijeep.7730

Setyono, A. E., & Sinaga, N. (2021). Zero waste Indonesia: Peluang, tantangan dan optimalisasi waste to energy. *Eksergi*, *17*(2), 116. https://doi.org/10.32497/eksergi.v17i2.2619

Sharma, S., Basu, S., Shetti, N. P., & Aminabhavi, T. M. (2020). Waste-to-energy nexus for circular economy and environmental protection: Recent trends in hydrogen energy. *Science of the Total Environment*, *713*, 136633. https://doi.org/10.1016/j.scitotenv.2020.136633

Silva-Martínez, R. D., Sanches-Pereira, A., Ortiz, W., Gómez Galindo, M. F., & Coelho, S. T. (2020). The state-of-the-art of organic waste to energy in Latin America and the Caribbean: Challenges and opportunities. *Renewable Energy*, *156*, 509–525. https://doi.org/10.1016/j.renene.2020.04.056

Simanjuntak, J. P., Napitupulu, R. A. M., & Lumbangaol, P. (2022). Rancangan fasilitas pembangkit listrik tenaga sampah: Studi kasus di Kota Medan Sumatera Utara. *SJoME*, *3*(2), 84–93. https://jurnal.uhn.ac.id/index.php/mechanical/article/view/636/267

Suhartini, S., Rohma, N. A., Elviliana, Santoso, I., Paul, R., Listiningrum, P., & Melville, L. (2022). Food waste to bioenergy: Current status and role in future circular economies in Indonesia. *Energy, Ecology and Environment*, *7*(4), 297–339. https://doi.org/10.1007/s40974-022-00248-3

Tassakka, M. I. S., Islami, B. B., Saragih, F. N. A., & Priadi, C. R. (2019). Optimum organic loading rates (OLR) for food waste anaerobic digestion: Study case Universitas Indonesia. *International Journal of Technology*, *10*(6), 1105–1111. https://doi.org/10.14716/ijtech.v10i6.3613

Varjani, S., Shahbeig, H., Popat, K., Patel, Z., Vyas, S., Shah, A. V., Barceló, D., Hao Ngo, H., Sonne, C., Shiung Lam, S., Aghbashlo, M., & Tabatabaei, M. (2022). Sustainable management of municipal solid waste through waste-to-energy technologies. *Bioresource Technology*, *355*(February). https://doi.org/10.1016/j.biortech.2022.127247

Vlachokostas, C., Michailidou, A. V., & Achillas, C. (2021). Multi-criteria decision analysis towards promoting waste-to-energy management strategies: A critical review. *Renewable and Sustainable Energy Reviews*, *138*(May 2020), 110563. https://doi.org/10.1016/j.rser.2020.110563

Wienchol, P., Szlęk, A., & Ditaranto, M. (2020). Waste-to-energy technology integrated with carbon capture – Challenges and opportunities. *Energy*, *198*. https://doi.org/10.1016/j.energy.2020.117352

Yuliani, M., Otivriyanti, G., Yusuf, N. R., & ... (2022). Kajian tekno-ekonomi penerapan insinerator waste-to-energy di Indonesia (Kasus pada Kota "X"): A techno-economic study on the application of waste-to-energy .... *Jurnal Teknologi*, *23*(2), 126–134. https://garuda.kemdikbud.go.id/documents/detail/2931798

Zhou, Z., Tang, Y., Chi, Y., Ni, M., & Buekens, A. (2018). Waste-to-energy: A review of life cycle assessment and its extension methods. *Waste Management and Research*, *36*(1), 3–16. https://doi.org/10.1177/0734242X17730137

Biographies of Authors

Farchani Putri Yuniar, School of Environmental Science, Universitas Indonesia, Central Jakarta 10430, Indonesia.

- Email: farchani.putri@ui.ac.id
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A

Grace Gardenia Ginting, School of Environmental Science, Universitas Indonesia, Central Jakarta 10430, Indonesia.

- Email: grace.gardenia@ui.ac.id
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A