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Review and Bibliometric Analysis of Biogas Power Plants in Indonesia

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***Abstract**. The demand for energy is increasing due to population growth, technological advancements, and a growing need for sustainable energy sources. Indonesia, which faces an energy deficit, is exploring alternatives to fossil fuels. Biogas, produced through the anaerobic fermentation of organic matter, offers a clean and sustainable energy option while addressing waste disposal issues. Therefore, this literature review examines various aspects of a biogas power plant, including a feasibility study that encompasses technical and economic analyses, generator design, trials, implementation, and post-implementation evaluation. In this review, we gathered scientific papers from Google Scholar using the keywords "pembangkit listrik biogas" between 2019 and 2022, with a focus on recent content. Patents and citations were excluded from the Google Scholar searches to ensure article relevance. Out of a total of 40 articles, 30 were rejected because they did not originate from scientific journals. The collected articles are categorized based on the materials used for biogas generation in power plants. This systematic approach yielded 10 relevant articles. Consequently, the literature reveals that various raw materials, such as palm oil mill waste (POME), livestock manure, and organic waste, hold the potential for biogas production. The results emphasize the economic feasibility of specific biogas projects, the environmental challenges they pose, and the positive impact they have on community well-being.*

Keywords: Biogas, Power plants, Feasibility studies, Renewable energy

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1. Introduction

Population growth and technological developments increase energy demand and have an impact globally, including in Indonesia [1]–[3]. In the last decade, Indonesia has experienced an energy deficit due to an imbalance between demand and supply [4]. According to the 2019 Indonesia Energy Outlook, the need for electrical energy from 2019 to 2050 is projected to increase by up to 9 times from the 254.6 TWh electricity demand in 2018. In addition, future electricity demand is also predicted to experience a shift from the household sector to industry, including the agricultural, paper, fertilizer, steel, and other industries [5].

In the last few decades, Indonesia's energy supply has been dominated by fossil sources, such as oil, gas, and coal [6]. Oil and coal are non-renewable energy sources because they originate from fossil deposits and accumulated plant remains, which take millions of years to form. While new and renewable energy power plants are rapidly increasing worldwide, the International Energy Agency (IEA) reported that in 2000, only 18.7% of such plants were used as a source of electrical energy. By 2018, this proportion had increased to 25.6%, and it is expected to reach 30% by 2024 [7].

Several alternative sources of electrical energy have been developed in Indonesia, including water, wind, solar energy, and more. However, these alternative energy sources still come with several disadvantages [8]–[10]. Hydroelectric power plants require a large investment. Wind power plants require large areas of land. Solar power plants are constrained by high initial costs because solar panels are made of expensive materials. Even with price reductions that occur almost every year, they still feel expensive [11], [12]. Therefore, other alternative energy sources are needed that are economical, sustainable, and environmentally friendly [13].

The use of biomass for biogas is an alternative that has attracted worldwide attention as a clean and sustainable energy source in recent years [14], [15]. In addition, biogas production also serves to reduce the problem of inefficient disposal of municipal waste, which causes uncontrolled methane emissions [16]. Biogas is a gas produced by microbes when organic matter undergoes a fermentation process in an appropriate anaerobic condition, in terms of temperature, humidity, and acidity [17]. Biogas has great potential as a renewable energy source because it is obtained from the decomposition of organic matter (such as animal waste, human waste, and plants waste) by methanogenic bacteria. Most of the biogas produced consists of 50 - 70% methane (CH4), 30 - 40% carbon dioxide (CO_2), and small amounts of other gases [3]. As is known, methane has only one carbon in each chain. Thus, burning methane allows for more environmentally friendly emissions compared to long carbon chain fuels, such as butane (C_4H_{10}) or gasoline (C_8H_{18}). In addition, the amount of CO_2 produced from burning low carbon fuels tends to be lower. The high methane content in biogas can help reduce the role of LPG and gasoline. The chemical composition of biogas is presented in Table 1.

Table 1. Composition of biogas [18]

Element	Formula	Concentration (% volume)
Methane	CH_4	50-75
Carbon dioxide	CO_2	25-45
Water vapor	H_2O	2-7
Oxygen	O_2	<2
Nitrogen	N_2	<2
Hydrogen sulfide	H_2S	<2
Ammonia	NH_3	<1
Hydrogen	H_2	<1

Based on the raw material filling method, the biogas production system consists of two primary methods: bulk filling and continuous filling. The bulk filling system is implemented when biogas production has stopped, involving the removal of the remaining material from the processing tank and the subsequent addition of new raw materials. In contrast, the continuous filling system involves placing raw materials into the processing tank, and it continues uninterrupted for approximately four weeks from the initial filling time. The processed material does not require removal from the tank [17]. Up until the writing of this article, the most common method for converting biogas into electricity was the digester system, illustrated in Figure 1.

While various methods and raw materials for generating biogas have been explored in the literature, there remains a significant lack of comprehensive studies on biogas power plants. Therefore, this review aims to identify and analyze feasibility studies, generator designs, generator testing, implementation strategies, and evaluations. Furthermore, we also investigate global biogas research trends, as documented in Wizdom.ai, to better understand current and future opportunities.

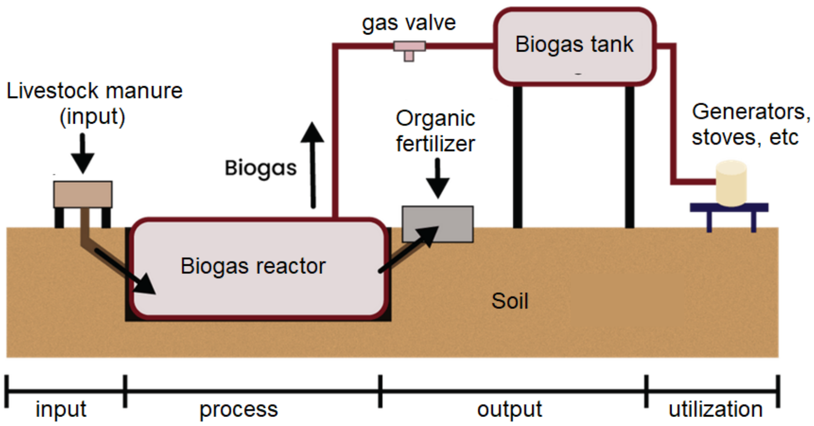

Figure 1. Schematic of biogas plants from livestock manure [4]

2. Methods

In this study, we collected scientific articles from Google Scholar with the keyword "pembangkit listrik tenaga biogas" in the period 2019–2022. This timeframe was chosen to get the most recent articles. From the search mechanism in Google Scholar, we do not include patents and citations to get the appropriate article. We found 40 articles on Google Scholar related to the keyword. However, of the 40 articles, 30 were not included because they were not from scientific journals. The collected articles are then classified based on the type of material used to produce biogas in power plants. From the structured search, 10 relevant articles were collected. The article filtering mechanism is presented in Figure 2.

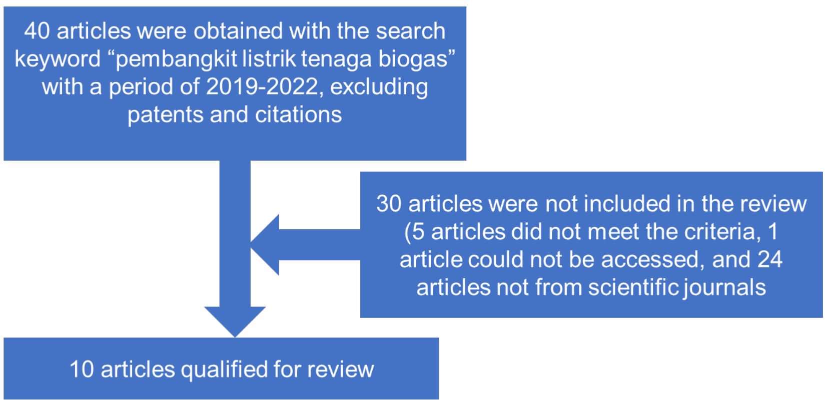

Figure 2. Mechanism for selecting reviewed articles

3. Results and Discussion

3.1 Result

As described in the Methods section, we identified 10 journal articles on Google Scholar discussing biogas. The identification of raw materials, methods, variables studied, results, and measured parameters is presented in Table 2. Furthermore, the articles are classified based on the type of raw materials, as shown in Table 3. We found that 60% of the total reported biogas raw materials were palm oil liquid waste, specifically called Palm Oil Mill Effluent (POME), followed by livestock manure at 30%, and organic waste at 10%.

Table 2. Raw materials, methods, and results

No	Materials	Objective	Results
1.	POME [19]	Economic analysis of the construction of a biogas power plant with a capacity of 700 kW using a continuous stirred tank reactor (CSTR) biodigester.	The results of economic calculations show that the investment costs reach IDR 26.3 billion with a 70% loan scheme from banks and the remaining 30% with their own capital. Operation and maintenance costs reach IDR 2.3 billion/year. The construction of a biogas power plant is feasible with an IRR value of 11.44%, a payback period of 7 years and 11 months, and an NPV of IDR 1.1 billion.
2.	POME [16]	Converting POME into biogas for electrical energy while reducing the impact of climate change from the palm oil production process.	The results of this study show that the POME flow rate is 146,880 m^3/year. With this potential, a power plant of 4.5 MWe can be designed and has the potential to generate 42.34 kWh of electricity/year.
3.	Organic waste [20]	Analysing the installation of a biogas power plant on the social, economic, and environmental aspects of the community in residential areas in Manado.	This research proves that the installation of a biogas power plant has a significant influence on the social, economic, and environmental aspects of the community in Manado.
4.	Livestock manure [17]	Identify the potential for livestock manure to be developed into a biogas power plant in the Province of Bali.	Based on the results of the analysis conducted, it is known that biogas can produce as much as 246,130.81 m^3, which is equivalent to 1,156,814.81 kWh/day or around 1.16 GWh/day.
5.	POME [7]	Simulating the connection of a biogas power plant to a commercial power grid and investigating the requirements stipulated in S.K/DIR/0357/2014.	The result of connecting the biogas power plant to the commercial electricity network meets the requirements.
6.	Livestock manure [21]	Utilizing cow dung to produce electrical energy that can meet electricity needs technically and economically.	The results of the analysis show that methane production per day is 1.22 m^3 and generates 1.22 kWh of electricity. With four maintenance times per year, the electrical energy that can be generated is 1.90 kWh × 362 days = 686 kWh/year.
7.	POME [22]	Analyzing the connection of a biogas power plant from POME with a 20 kV distribution network using ETAP simulations.	The connection of the biogas power plant improves the voltage profile so that it does not drop more than 10%. Total power losses decreased by 6.42% during WBP.
8.	POME [23]	Implementing a PLC-based instrumentation and control system to support the operation of a biogas power plant.	The inlet pressure in the gas engine during the two hours of commissioning trials complied with the requirements of the gas engine, while the methane concentration proved to be stable during operation.
9.	Livestock manure [24]	Assessing the potential utilization of cattle ranch waste in livestock areas as raw material for biogas power plants and assessing the carbon value that can be reduced if proposed as a Clean Development Mechanism (CDM) project.	Based on the data obtained, the production of cow dung of 400 kg/day has the potential to generate 4.89 kW of electrical energy.
10.	POME [5]	Analyzing the technical and economic aspects of the Solar PV Biogas power plant.	Based on technical and economic analysis it can be concluded that this hybrid power system can be developed.

Table 3. Classification of raw materials for biogas

Raw material	References	Articles	%
POME	[19], [16], [7], [22], [23], [5]	6	60%
Livestock manure	[17], [21], [24]	3	30%
Organic waste	[20]	1	10%
Total		10	100%

Based on the data presented in Table 2 and Table 3, the articles are classified based on the type of raw material. Furthermore, Table 4 presents the classification based on the feasibility study, generator design, generator trials, implementation, and evaluation. The data is then presented in Figure 3.

Table 4. Parameters discussed in the reviewed articles

No	Raw material and references	Parameter discussed				
		Feasibility study	Generator design	Generator trials	Implemen-tation	Evaluation
1.	POME [19]	√	×	×	×	×
2.	POME [16]	√	√	×	×	×
3.	Organic waste [20]	×	×	×	×	√
4.	Livestock manure [17]	√	×	×	×	×
5.	POME [7]	×	×	√	×	×
6.	Livestock manure [21]	√	√	√	×	×
7.	POME [22]	×	×	×	√	√
8.	POME [23]	×	×	×	√	×
9.	Livestock manure [24]	×	×	√	×	×
10.	POME [5]	√	×	×	×	×

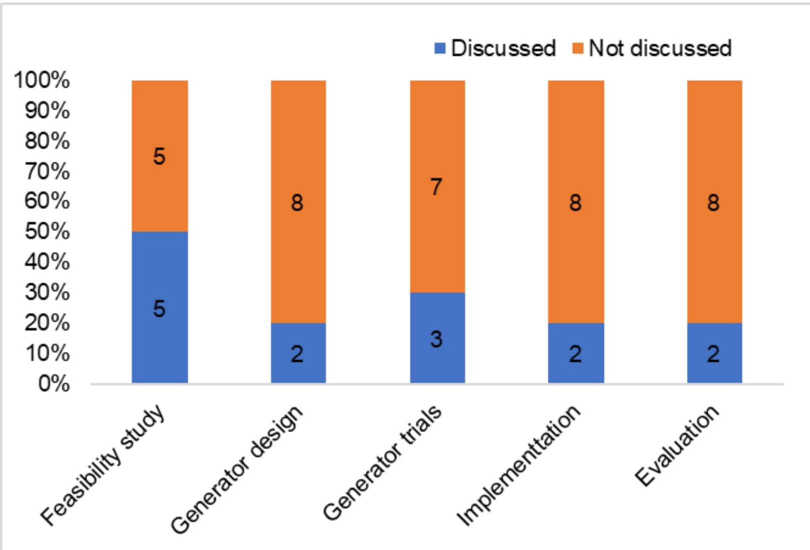

Figure 3. Parameter map discussed in the reviewed articles

3.2 Discussion

Feasibility study - The feasibility study of a biogas power plant generally assesses two key aspects: the feasibility of electricity generation and the economic viability. The feasibility of electricity generation has been examined by several researchers, including Firdausi [16] and Santoso [17]. Meanwhile, economic analysis was reported by Sugiyono et al. [19], Pasaribu et al. [21], and Putra [5].

Firdausi [16] conducted a study at PT Trimitra Lestari, West Tanjung Jabung Regency, Jambi Province. From the available data, POME production of 414,720 tons/year produces 80% of liquid waste. The liquid waste is channeled into a holding pond which produces methane. Further analysis explains that there is a potential for electricity production of 42,336 kWh/year from the POME waste. Considering the continuity of POME production at PT Trimitra Lestari and the electricity potential that may be generated, the construction of a biogas power plant at PT Trimitra Lestari is feasible to proceed to the technical feasibility study stage. Meanwhile, Santoso [17] conducted a study to estimate the potential of biogas from livestock manure for electricity in the province of Bali. Data from the Directorate General of Livestock and Animal Health states that there are 19,183,779 potential animals in Bali, consisting of cows, buffaloes, horses, goats, sheep, pigs, chickens, and ducks. Of this amount, the potential for biogas in Bali Province is 246,130.81 m^3/day and can be converted to 1.16 GWh/day.

From an economic feasibility perspective, Sugiyono et al. [19] calculated the feasibility of building a biogas power plant from POME with a continuous stirred tank reactor (CSTR). According to them, the biogas power plant is feasible to build with an IRR value of 11.44%, a payback period of 7 years and 11 months, and an NPV of IDR 1.1 billion. However, POME-based biogas power plants can pollute the air, water, and sound. Air pollution, such as odors, pollutants, and dust, must be anticipated and mitigated by installing equipment to protect the environment. Water contamination is possible from sewage contaminating the surface or groundwater, so a separate drainage system can be used to prevent this contamination. Meanwhile, noise pollution arises due to noise from the biogas power plant. Different results were reported by Pasaribu et al. [21] who conducted an economic analysis of the potential for a biogas power plant on a cattle farm with a biogas capacity of 3.90m^3/day in a 6000-liter digester. From the available data, the biogas power plant produces 686 kWh of electricity/year. Economic feasibility is calculated through simulation with REETscreen software. From the simulation results, a financial feasibility analysis is obtained in the form of a Cash-in-flow (CF) calculation of IDR 988,320, a Net Present Value (NPV) of IDR -6,316,305.03 <0, and a Payback Period (PBP) of 15.4 years which indicates an analysis this is not economically feasible.

Finally, Putra [5] claims that the PVBiogas solar hybrid generation system has great potential to be implemented. In their research, the Solar PVBiogas off-grid system hybrid power plant is technically capable of serving loads continuously for 20 years of the project life. Until the end of the 20th year of the planned project life, production from the off-grid Solar PV-Biogas system hybrid power plant still has an excess of energy of 2,283,787kWh/year or 15.9% of total production which can be used to serve the energy needs of next year. Based on the results of the feasibility calculation of the economic aspect with 3 parameters, it shows: that the NPV is positive, the PBP is smaller than the project life, and the IRR is greater than the bank's interest.

Generator design and trial - Firdausi [16], in his research, explains several important things which are the basis for consideration for carrying out a biogas power plant process, such as collecting data for the source of raw material for biodigester feed, determining the process design, and determining specifications on generator capacity. In another study, Pasaribu et al. [21] modified an oil-fired generator set to a biogas generator set. The digester is designed by considering the potential of available raw materials, determining the digester model, designing the storage tank, and ending with determining the location.

Pasaribu [21]reports on a biogas power plant with a continuous filling digester system, which initially fills only 80% of the volume of the digester tank. After production, organic matter filling is carried out continuously every day with a daily filling volume of 1/60 of the initial filling volume. In another study, to increase biogas production, Setiawan [24] experimented to prove that there was a difference before and after adding Green Phoskko (GP-7) to a household-scale biogas power plant with cow dung as the main raw material. As a result, the sample gas production rate after the addition of GP-7 was 0.2209 m^3/kg, while the sample gas production rate before the addition of GP-7 was 0.2162 m^3/kg.

In a distinct scenario concerning the operationalization of biogas-generated electricity, Ramadhan and Abidin [7]established a linkage between a biogas power facility and a switching substation within the Sanggau district. This investigative endeavor offers valuable insights for contemplating the integration of a biogas power unit into a 20 kV distribution framework. Furthermore, this study's potential extends to an in-depth exploration of power system safeguards through the analysis of simulations involving short-circuit currents.

Implementation - In the literature studied, several electricity generators from biogas have been successfully implemented, as reported by Rizal dan Gianto [22] and Adiprabowo [23]. Rizal dan Gianto [22], undertook an investigation in Sanggau Regency, wherein the integration of a biogas power plant with a 20 kV substation demonstrated compliance with the SK/DIR/0357/2014 standards. Noteworthy is their preliminary step of employing ETAP simulation software to meticulously blueprint and evaluate the electrical power framework before the biogas-generated electricity was incorporated into the 20 kV distribution grid. This use of ETAP was integral to mimicking real-world conditions and providing a comprehensive platform for pre-implementation system analysis. ETAP, recognized as a sophisticated tool for electrical power system planning and simulation, served as an indispensable asset in these endeavors.

In a separate investigation, Adiprabowo [23] effectively executed the deployment of a monitoring system designed to oversee the initial operation of a biogas power plant. This involved the measurement of pivotal parameters including pressure, engine gas power, biogas emission, and methane concentration. The method employed a programmable logic controller (PLC)-centered instrumentation and control framework, strategically integrated to facilitate the functioning of the biogas power plant. This innovative system holds particular significance in the precise regulation of vital procedures, thereby leading to enhanced operational efficiency and performance of the biogas power plant.

Evaluation - As reported by Florence [20], biogas power plants are not only beneficial for the community but also expand and increase public knowledge. On the economic aspect, the biogas power plant plays a very significant role in improving people's lives, and on the environmental aspect, the biogas power plant functions as a solution to the problem of waste management and environmental cleanliness in the city of Manado. They analyzed the data using the analytical technique of the T-test (one sample t-test) to analyze whether there is a significant difference produced by the biogas power plant on social and environmental aspects after 1 to 2 years of implementation. On the other hand, the economic aspect is calculated using income assumptions. Meanwhile, Rizal & Gianto [22] have provided the fact that the connection to the biogas power plant has improved the voltage profile so that it does not drop more than 10%.

3.3 Research Trends on Biogas

To illustrate research trends, we used data from Wizdom.ai [25], as depicted in Figure 4, showcasing the trend in the number of biogas-related publications from 2004 to 2023. Our analysis reveals an upward trajectory in biogas-related publications from 2004 to 2021, encompassing all publication categories, including closed, bronze, hybrid, gold, and green publishers. However, there is a projected decline in biogas-related publications for the years 2022 and 2023 (ongoing). From 2004 to 2023, a total of 26,784 articles were related to biogas, with the following distribution: 1,273 articles in green publishers, 7,317 in gold publishers, 1,721 in hybrid publishers, 1,609 in bronze publishers, and 14,864 in closed publishers. These articles also exhibit a growing scientific impact, as evidenced by the citation trend illustrated in Figure 5. The solid blue and red curves in Figure 5 represent the citation trend and citation ratio, respectively. Finally, Table 5 presents the top 20 rankings of journals and proceedings that publish articles on biogas.

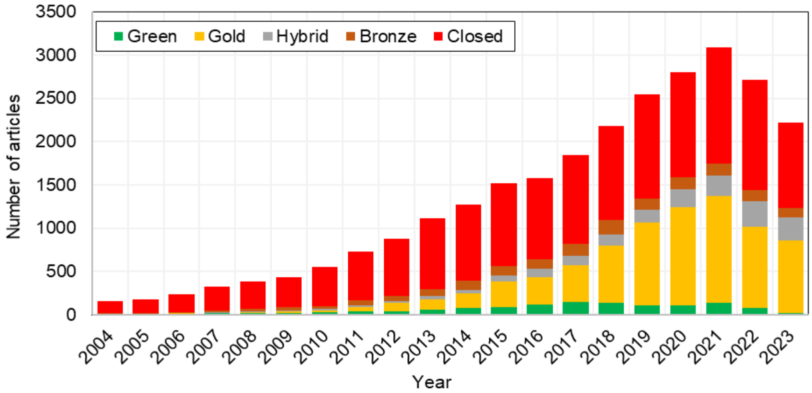

Figure 4. Number of publications about biogas in 2004-2023 recorded on Wizdom.ai [accessed: 27/10/2023]

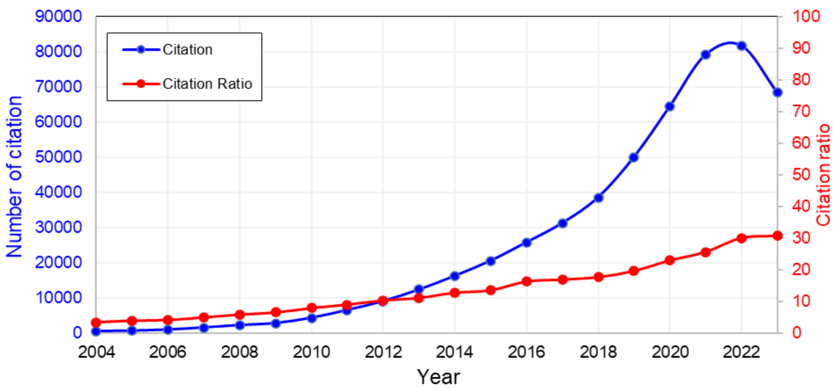

Figure 5. Trends in citations and citation ratios of articles about biogas recorded on Wizdom.ai [accessed: 27/10/2023]

Table 5. Top source title of articles about biogas recorded on Wizdom.ai [accessed: 27/10/2023]

Nr.	Source title	Articles	Percentage
1.	Bioresource Technology	1910	23.1%
2.	Water Science & Technology	665	8.1%
3.	Waste Management	588	7.1%
4.	Energies	584	7.1%
5.	The Science of The Total Environment	436	5.3%
6.	Journal of Environmental Management	409	5.0%
7.	IOP Conference Series Earth and Environmental Science	360	4.4%
8.	Renewable Energy	311	3.8%
9.	Sustainability	306	3.7%
10.	Water Research	302	3.7%
11.	Journal of Cleaner Production	299	3.6%
12.	International Journal of Hydrogen Energy	291	3.5%
13.	Environmental Technology	281	3.4%
14.	Environmental Science and Pollution Research	266	3.2%
15.	Renewable and Sustainable Energy Reviews	236	2.9%
16.	Fuel	219	2.7%
17.	Energy	211	2.6%
18.	Proceedings of the Water Environment Federation	205	2.5%
19.	E3S Web of Conferences	194	2.4%
20.	Published by EDP Sciences	179	2.2%
Total		8252	100%

3.4 Limitation

This study may not be able to fully represent the development of biogas power plant research in Indonesia because the search keywords are too narrow and use Bahasa Indonesia. As a further comparison, besides searching on Wizdom.ai, we used Scopus as another search database. With the keyword "biogas power plant", we found 12 publications in journals indexed by Scopus in 2014-2023. We restricted the country to Indonesia and articles in journals, not including articles and proceedings and book chapters. Of the 12 articles, they discuss utilization of cow dung for biogas [26], assessment, protection and monitoring system in biogas power plants [27]–[29], evaluation of the techno-economic and environmental impacts of biogas power plants from POME [30], [31], regulation of biogas power plants from palm oil mill waste [32], enhancing methane production from dairy cow manure [33], removal of H_2S from biogas with bioscrubber [34], chemical pretreatment for biogas production from water hyacinth [35], potential for electrical energy from livestock waste in a selected area in South Sulawesi [36], and utilization of fruit waste as feed for biogas plants [37].

4. Conclusion and Recommendation

A review of various studies on biogas power generation has highlighted its potential as a clean and sustainable energy source. Indonesia's energy needs are soaring due to population growth and technological advances, giving rise to an energy deficit. Fossil fuels that dominate Indonesia's energy supply are non-renewable and detrimental to the environment. Alternative energy sources such as hydroelectric power, wind, and solar face limitations in terms of cost and feasibility. However, biogas, produced through anaerobic fermentation of organic materials, is a promising alternative. In particular, palm oil mill liquid waste (POME), livestock manure, and organic waste are the main raw materials for biogas plants. The feasibility, economic feasibility, generator design, implementation, and evaluation of a biogas power plant have been explored. Comprehensive feasibility studies, technical designs, and economic analyses have demonstrated the potential success of biogas power projects.

Based on these findings, several recommendations emerge. First, policymakers and energy planners must prioritize the integration of biogas power plants into the national energy mix. Further research should look for ways to increase the efficiency of biogas production and reduce potential environmental impacts. Collaboration between the public and private sectors is essential to provide the necessary funding and expertise. In addition, a comprehensive feasibility study must be carried out for each potential biogas project, considering not only technical aspects but also economic and environmental factors. Additionally, investment in monitoring systems and control frameworks is critical to optimizing operational efficiency. Finally, public awareness campaigns can educate the public about the benefits of biogas power plants, encourage support, and speed up implementation. By making biogas a viable renewable energy source, Indonesia can overcome the energy deficit while contributing to sustainable development and environmental protection. Because this study is limited to the scientific literature studied, a detailed review involving more articles in various databases is needed to produce a more comprehensive future direction regarding research and implementation of biogas power plants.

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