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Review

Technological, Economic, Social and Environmental Barriers to Adoption of Small-Scale Biogas Plants: Case of Indonesia

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Abstract: By 2025, biogas is estimated to become a larger part of Indonesia's energy mix. Biogas is a renewable energy source that also has economic and environmental advantages. Domestic biogas generation has been embraced in Indonesia as a response to the country's energy security concerns in rural areas. Since the 1970s, 48,038 biogas plants have been built in the region. To fully develop this technology, Indonesia must discontinue relying on fossil fuels and substitute current fossil-fuel-based energy. This article provides an overview of renewable technology in Indonesia, as well as addressing domestic energy demands and referring to existing literature on the socio-technical and socio-economic barriers to biogas adoption in Indonesia. Based on a rigorous review of 71 publications published in Web of Science (*WoS*) between 2010 and 2021, this study explores existing barriers for biogas adoption by summarizing the current literature from technical, economic, social and environmental perspectives. Biogas adoption is a complex process with many interwoven components. Therefore, this research addresses a gap in the strategic planning and implementation process, providing policymakers with pathways to eliminate bottlenecks in renewable energy planning. Recommendations for future research are also proposed.

Keywords: small-scale biogas; biogas adoption; developing countries; adoption barriers

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1. Introduction

Notwithstanding the major progress in reducing Indonesia's reliance on fossil fuels, renewable energy still falls short of coal and other fossil fuels. As the country's population grows, so does the country's demand for energy. Amidst substantial efforts to reduce fossil fuel use, CO_2 emissions per person in Indonesia reached 2.03 tons in 2016, an increase of 10% from the previous year (over 1.93 tons in 2015). Climate change is a major contributor to massive emissions because of Indonesia's reliance on fossil fuels. According to Indonesia's energy mix, oil, gas, and coal account for 80% of total energy, hydropower accounts for 18%, and geothermal accounts for 2% [1]. Compared to China and India, Indonesia has had difficulty disseminating renewable energy technology [2]. As a result, hydroelectric and geothermal power plants generate a greater proportion of the electricity generated because other plants are underutilized. By 2025, Indonesia has only accomplished 9.5% of its 23% renewable energy target. Indonesia has been transitioning to a sustainable energy source since discovering biogas technology in the 1970s and implementing numerous biogas initiatives. Since then, Indonesia has constructed 48,038 biogas systems that produce 75,044.2 m^3/day or around 26.72 million m^3/year of biogas. There are now 96.21 MW of commercial biogas available [3]. In Indonesia, small-scale biogas systems with fixed domes are most suited to the conditions due to the livestock waste availability from cattle and poultry [4]. Biogas, which contains methane, is produced when organic materials are not exposed to oxygen (anaerobic process). The cost of installing a system is relatively affordable for farmers [5]. However, when compared to China and Nepal, Indonesia's adoption rate is still insufficient [6]. Farmers' decisions to use biogas have been explored in several studies to understand what influences their decision [6]. Several stimulating measures have been employed in various countries. For example, in 2017, the Chinese Government offered more than 630 thousand (in USD) in biogas subsidies in rural areas (Sun, 2014). In Bangladesh [7], biogas users have increased because of public and commercial incentives, and as a result, household income and education levels have increased. Few studies have revealed constraints on biogas adoption in developing countries. Kamp and Forn [8] investigated the environmental impact of fuel prices in Ethiopia and found that the lower the fuel price, the greater the adoption of biogas. In Ethiopia and Uganda, researchers discovered that physical facilities such as decent roads and electricity access significantly impact the decision to use small-scale biogas technology [9,10].

Furthermore, according to Katuwal and Bohara [11], adopting biogas in Nepal has significant implications for agricultural production and environmental protection by reducing deforestation, reducing firewood and biomass gathering workload, and positively influencing women's empowerment. Other literature has classified the barriers to biogas diffusion in developed and developing countries. Obstacles to use animal and human waste as raw material, for example, are notably resisted by local values and culture and have delayed the expansion of biogas technology. The main hurdles to adoption growth are low literacy rates, political instability, and poor household purchasing power [12]. As a result, technical and information constraints, such as a lack of construction and maintenance skills, competition with free firewood, and a lack of awareness, are primarily widespread in developing countries [12,13].

Our research differs from other studies, as we incorporated variety of studies from socio-technical and socio-economic factors that influence the adoptions of biogas in developing countries, in particular Indonesia. Since 2007, Indonesia has started employing energy mix technologies [14,15]. Animal waste, human waste, household garbage, and other items are all fermented. Conversely, the government continues to subsidize the sale of liquid petroleum gas (LPG), with 6.6 million metric tons subsidized in 2008 [16]. Nearly one third of the working population in Indonesia is employed as farmers or in rural areas, where solid fuels such as wood are largely utilized for open-fire cooking, posing health risks [17]. According to a study by Budiman et al. [17], biogas could be used to cook and provide light in rural regions because it is safe and clean. Since 2014, the government has focused on boosting energy availability in rural areas, especially distant islands. According to Kementrian ESDM, Indonesia total primary energy production (coal, gas, mining, non-renewable energy) exceeded its electrification ratio target of 92.75 percent in 2017 [18].

Renewable energy solutions including biogas must be low-cost, clean, geographically and culturally appropriate fuels that meet energy needs while being relatively simple to implement and use. However, compared to LPG biogas technology, it is costly to install, operate and sell [19]. It faces enormous economic challenges due to Indonesia's low feed-in tariff and the price at which companies can sell their electricity to Indonesia's government-owned utility. Several legislators wish to strengthen feed-in tariff legislation and implement it to make the policy more favourable to renewable energy companies. Reduced or shifted LPG subsidies to biogas may be acceptable to the government, especially in areas where agricultural waste is generated. Subsidizing the biogas program would instil a sense of ownership of the farmers [19,20].

Furthermore, this paper investigates the potential of biogas technology and the costs of adoption as complex processes influenced by various factors. While some studies have looked at barriers to renewable energy in general (others have looked at biogas in particular regions) [15,21]. Unlike previous studies, ours is unique. We used an integrated approach that included an analysis of factors influencing household adoption from the perspective of users and potential adopters and broader factors influencing the transition process from the perspective of policymakers and the role of private sectors.

This study aimed to comprehend the niche character of Indonesia's energy systems and the landscape dynamics. In this study, we analyse the socio-technical and socio-economic constraints for biogas adoption in Indonesia by synthesizing and reviewing previous studies to provide additional explanations about barriers and explanatory factors in developing biogas in Indonesia. There has been no recent, comprehensive review of the barriers to broader biogas adoption in Indonesia. Recent research on the wider adoption of biogas in Indonesia has been lacking [5,20,22]. This study's contribution is as follows. First, it includes the current discussion of Indonesia's energy policy, which is centred on biogas production history from 1970 until 2019 that has promoted the use of biogas through a variety of national initiatives, each of which was supported by a different institution and was influenced by several socio-institutional factors. Second, this study contributes to the current evaluation of the problem tree of biogas adoption in Indonesia due to the abundance of livestock dung that can be utilized by separating the effects of technical, economic, social, cultural, and environmental factors. Indonesia has some of the world's most promising rural locations for biogas generation. Finally, this study contributes significantly to the most recent literature review from 2010 to 2021, particularly on adopting renewable energy in rural households, which impacts Indonesia and other developing countries. This study intends to fill this gap by offering a systematic and thorough state-of-the-art review. A state-of-the-art report examines the most recent research in the studied field or issue, summarizes emerging trends, and proposes new perspectives and/or research requirements. This study is organized into three sections: an introduction, a methodological approach, and findings and a discussion of the major findings in each domain (technical, economic, market, institutional, socio-cultural, and environmental), and is closed by conclusions.

2. Materials and Methods

2.1. Methodology

By overcoming current constraints but still following empirical procedures, several approaches properly describe the methodical process of developing state of the art. This study adopted the Systematic Literature Review from Kitchenham (cited in Torres Carrion et al., 2019) [23]. Based on this methodology, they construct guidelines with revisions and their standards for software guidelines for conducting a review that allow for a rigorous approach to acquiring the desired results by considering the research problem, research questions, inclusion and exclusion criteria, and analysis. Figure 1 show the step-by-step guide to using the Systematic Literature Review.

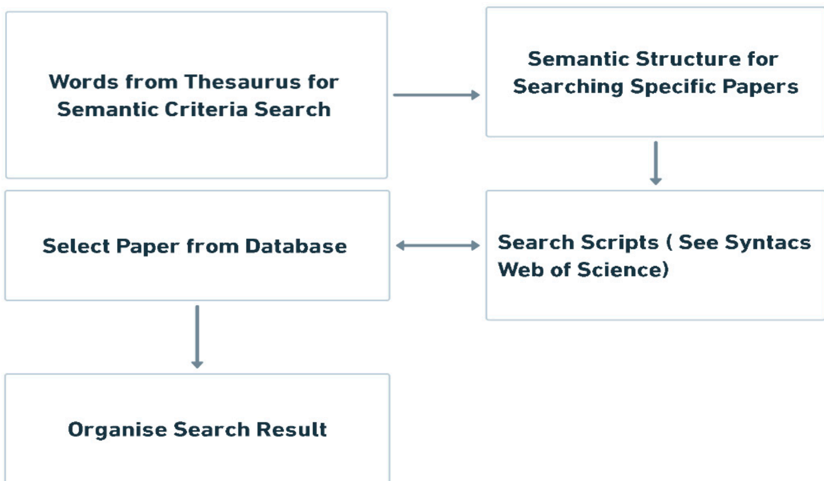

Figure 1. Systematic Literature Review search procedure (adapted from Kitchenham et al., 2019 [23]).

The following information was already investigated or published in biogas literature to support the analysis. State of the art is appraised, compared, and collated in this literature review, and a summary of the available literature on biogas adoption is presented. The investigation also discovered discrepancies between earlier research and contemporary literature. Various literature, published and unpublished papers, including research publications, energy reports, and policy and regulation studies, were thoroughly investigated to identify the hurdles. Barriers to biogas adoption in developing countries, particularly Indonesia, were found through thorough literature analysis. Scholarly articles, energy reports, and policy and regulatory studies have all been thoroughly analysed to identify possible obstacles. This review, therefore, went over the following steps (Figure 2).

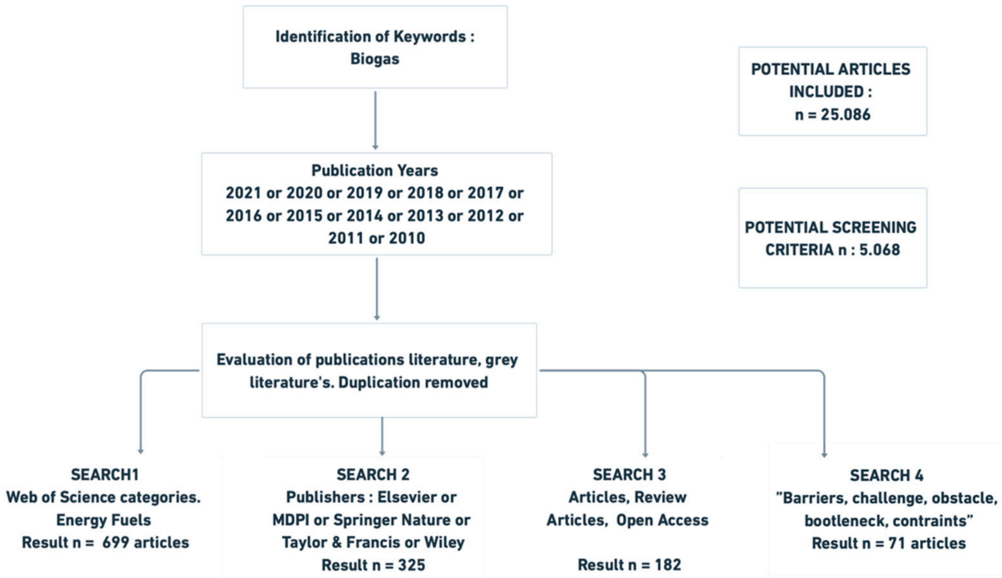

Figure 2. Procedures for conducting a literature review (developed by author, based on [24–26]).

1. To find relevant literature, *Web of Science* was used. We used the identification keyword, biogas, to start with the elimination of articles. The number of potential articles included in the first screening process was 25.086 articles.
2. Mendeley was used to extract each publication's title, abstract, and keywords utilized in publications between 2010 and 2021. Several types of papers were discovered in the retrieved publications, including articles, reviews, and articles in the press. There were 5068 articles found when the first search step was the year of publications. Figure 3 explained about the publications and citations trend from year 2013–2021 as the most cited from this study, while in 2010, 2011, 2012 and 2022 are the least cited year [27].

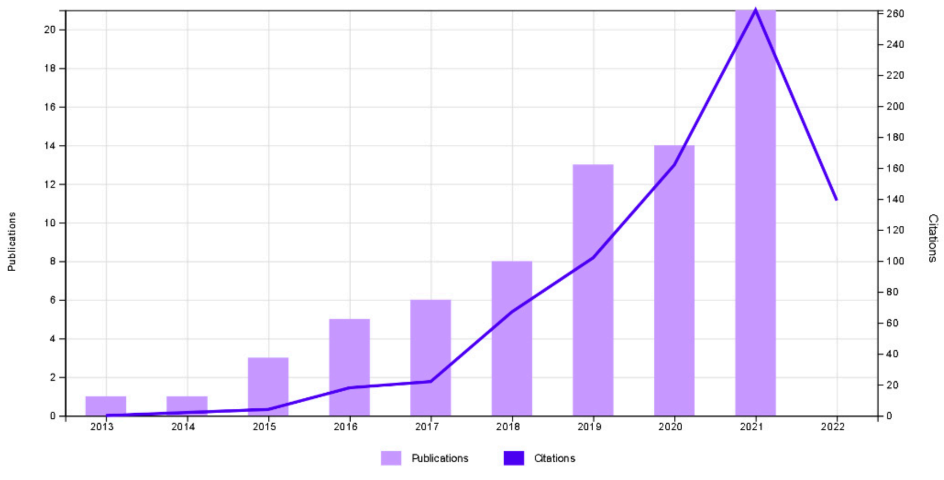

Figure 3. Years of publication (2013–2021) author adapted from Mendeley. 2022 [27].

3. The next step, *Search 1*, was used to retrieve the article web of science with *energy fuels* categories, which were document-type articles or review articles, with a result

of 699 articles. *Web of Science* (*WoS*) was used as the primary database to retrieve the examined papers. Due to the high proportion of exclusive journals, Gao et al. [28] recommended the WoS database for social sciences. Moreover, the database gained a high reputation and recognition in the scientific community, becoming a primary source of citation data. As a result, WoS appears to be a better fit for searching and analysing scientific literature at the publication level. WoS was chosen because of its journals' impact factor in the Journal Citation Report (JCR) ranks, the most well-known bibliographic database. [24–26,28].

4. Thus, to complete the search process (review), we identified 325 publications through *Search 2*, restricted only for *Elsevier* or *MDPI* or *Springer Nature* or *Francis & Taylor* or *Wiley*. These journals are among the most reputable, especially in renewable energy and environmental studies [23–25,28].
5. To arrive at specific and reputable articles, we selected further articles, review articles and open access articles. As a result, as shown in Figure 2, *Search 3* (article in press) yielded 182 results.
6. In the fourth step, Search 4 was used to classify existing challenges to widespread biogas use, including keywords "barriers", "challenges", "obstacle", "bottleneck", and "constraints", in order to identify and remove potential adoption barriers. As a result, we discovered 71 articles discussing the adoption of biogas or the difficulties faced by emerging nations. When statistical analysis cannot be used to interpret the data, content analysis fills in the gaps. This approach frequently combines an inductive or deductive procedure with either qualitative or quantitative data [26,28].

However, there are certain methodological limitations to this literature review. To begin with, the literature review is restricted to articles published in journals. However, journal articles represent the remarkability of scholarly literature and are addressed to a broader research demographic (see, for example, [22,23]). Second, the reviewed publications were gathered from the *Web of Science* database instead of using other databases. We are aware of the benefits and limitations of several databases [24–28].

The Web of Science database was used for publication extraction since it contains a larger number of articles [27,28]. Another prominent database, Google Scholar, has been criticized for failing to check journals for quality. We only looked at scholarly journal articles that were written for a broad scientific audience and accurately represented the scholarly literature [25,27,28].

2.2. Indonesia's Biogas Development

The Bandung Institute of Technology has been using a biogas system in Indonesia since the 1970s [16,19]. Regulation No. 79 specifies Indonesia's target of lowering greenhouse gas emissions by 23% by 2025. *The Ministry of Energy and Mineral Resources* (*MEMR*) is responsible for Indonesia's energy resources [28]. In 2015, *Indonesia's Nationally Determined Contribution* (*INDC*) announced a conditional 41% reduction in 2020 but an unconditional 29% reduction in 2030 (which covers land use, land use change, and forest emissions) [29]. The MEMR created a renewable energy strategy that includes policy actions to boost renewable energy production and knowledge transfer to rural populations [30]. The Indonesian Government has several biogas programs coming from various ministries, but they are mostly related to the *Biogas Rumah* (*BIRU*) programs.

The Ministries of Energy and Mineral Resources, Forestry, and Agriculture are implementing biogas as part of an integrated agricultural initiative. Indonesia's biogas development is aimed at attaining the Government's goal of 23% renewable energy by 2025 and 31% by 2050 [31]. Bioenergy, including biogas, should be considered one of the energy resources needed to meet the aim [32]. Bioenergy has a target of 13% of total energy coming from renewable sources, although it is currently only at 5.1% [15,33].

Figure 4 shows the percent of renewable energy generation from 2011 to 2019 based on the last 10 years.

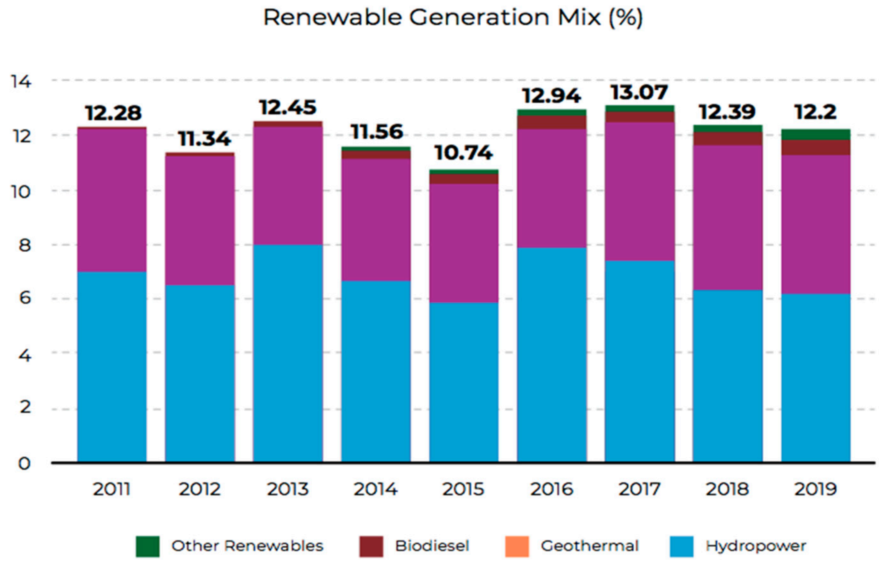

Figure 4. Indonesia renewable energy mix 2011–2019 (developed by author based on [33]).

Indonesia has a vast amount of biomass that can be utilized to generate biogas. Existing biogas systems use farm manure and slurries, which can be found in rural areas. Biogas can be used for various applications, including cogeneration, electricity and heat generation, cooking fuel, vehicle operation, and lighting [33]. Liquid petroleum gas (LPG), however, has become Indonesia's most popular cooking fuel [14,33]. Several government bodies in Indonesia provide fossil fuel subsidies to households, small businesses, and transportation, according to research by the Netherlands Development Organization (SNV). Compared to many other developing countries, Indonesia has a lower number of biogas digesters [33]. The number of biogas installations has expanded in various locations in Indonesia. Since biogas incorporates methane from feedstock, it is classified as a second-generation bioenergy source [34,35]. Indonesia has an abundance of organic matter. Bioenergy should contribute 13% of total energy under Indonesia's renewable energy goal. According to Laramee and Davis et al. (2013) [36], they discovered that families are unwilling to adopt the technology due to the comparatively low prices of kerosene and subsidized LPG. Biogas production on a small scale in rural regions, conversely, has gained favour in recent years as a waste management and energy resource option. Farmers plan to use bio-slurry as a fertilizer and replace firewood in their cooking. The following history of biogas development in Indonesia from 1970 to 2019 was developed by the author using information from a variety of sources to fully comprehend its development in Indonesia, as shown in Figure 5.

Figure 5. Indonesia's biogas production from 1970–2019 (modified by author based on [5,16]).

3. Results

Previous research has highlighted some challenges to biogas fuel substitution, including bureaucracy, the time-consuming feedstock process, social acceptance, divergent priorities, monitoring procedures, and poor technology maintenance [15,37]. Barriers such as low temperatures and water scarcity in dry places have been identified in previous investigations [38]. Biogas distribution in a centralized government system is also hampered by a lack of technological infrastructure [39]. Objections to using animal and human excrement as a raw material in some cultures also impede technology adoption [13,22,39]. As a result of these studies, it was discovered that barriers vary by region, based on market maturity and the availability of natural resources such as animal waste, water, and land. However, prior studies have presented it as a collection of disparate difficulties. Biogas production in rural locations is affected by poor feedstock quality, incorrect waste segregation, and weak supply networks, whereas biogas production in urban areas is affected by poor feedstock quality, unsuitable waste segregation, and weak supply chains.

Our analysis reveals a link between these barriers and the Indonesian government's biogas policy. This assessment aims to provide a solid foundation for policymakers and practitioners in Indonesia who wish to improve biogas program policy, government, and practices. This study adds to Indonesia's little body of knowledge about the primary challenges to biogas technology adoption. Previous research on the technical, economic, and sociological aspects of biogas technology has been conducted in a few countries and using a variety of resources. However, this has not occurred in Indonesia, especially in the context of socio-technical and socio-economic difficulties; as a result, addressing these concerns can help to enrich talks.

3.1. Finding 1: Technical Barriers

Small-scale biogas facilities can cause technical challenges that are hazardous to the environment and the user. As a result, identifying the problems is critical to their resolution. A study recognised limited access to biogas and waste storage as a technical issue [40,41]. Several success stories using cattle dung as feedstock in biogas plants indicate a certain level of technological maturity at the household scale [4,37,41]. Key findings about technical barriers will be found at Table 1 as follow:

Table 1. Technical barriers for biogas adoption.

No.	Technical Barriers Description	References
1	Lack of standard quality and control measures	[18,35,40,41]
2	Inadequate design and construction	[1,14,41,42]
3	Technical knowledge and training are lacking	[30,34,40,43–45]
4	Insufficient feedstock	[34,40,44–46]
5	Local research is lacking for tailor-made technology and context	[14,40,47,48]
6	Lack of biogas technical knowledge for daily maintenance	[14,46,49–51]

Study of Bhat [43] discovered the lack of storage tanks and pipelines in communal digesters may result in insufficient biogas production, also inadequate design for biogas construction [42] and insufficient feedstock [44]. Studies carried out by Bößner and Silaen et al [20,45] found that biogas output may be insufficient if cow and poultry manure are not always available. Each home requires eight heads of cattle, according to Khan et al. [47], to produce enough energy for cooking and power. Without enough technical support, expanding the number of biogas adoptions is challenging. It is vital to consider the perspectives of biogas users. Due to a lack of expertise in creating and maintaining the process, biogas adoption would be difficult [49,50]. As a result, if insufficient expertise is applied, biogas might have negative implications.

Aside from that, Mwringi and Tumutegreieze et al [6,51] defined the failure criteria for five technical subsystems, including structural components (e.g., inlet and exit issues) and pipe systems (e.g., problems with the inlet and outlet) as well as insufficient digester feedstock, unreliable feedstock supply, anaerobic digestion, and biogas production (such as leakages in a reactor, poor quality biogas and its smell, and breakdown of anaerobic digestion) [46,48,50–52].

3.2. Finding 2: Financial and Economic Barriers

Biogas is a particularly promising as renewable energy in Indonesia. However, there are too many barriers on its implementation, including high investment costs, comparatively poor technological efficiency, location, and social considerations of the community as energy users, that have prevented this from being fully utilized. The government has encouraged the use of renewable energy to improve family earnings, education, and the vocations of the household head, all of which are indications of socio-economic constraints, according to MEMR Regulation No. 12 of 2017 and MEMR Regulation No. 12 of 2015. These major socio-economic aspects, as well as the availability of supplies such as animal feed and water, may impact a family's decision to use biogas [21,51,53]. Key findings concerning the economic challenges of adopting biogas from the literature reviews are summarized in Table 2.

Table 2. Financial barriers for biogas adoption in Indonesia.

No.	Financial Barriers Description	References
1	High initial investment cost	[15,20]
2	Lack of financial mechanism	[16,17,46]
3	Inadequate subsidies, financial assistance and incentives	[5,20,36,54]
4	High transaction cost	[5,15,36]
5	Long payback period	[5,20,46]
6	The poor purchasing power of households	[5,14,15,48]

Financial challenges are frequently mentioned in the literature regarding initial investment. *The National Energy Policy (Kebijakan Energi Nasional/KEN)* aims for 489.8 million cubic meters of biogas by 2025. According to the MEMR, 25.266 million cubic meters of biogas were in use in 2018 [33,55]. Given the low level of performance compared to the 2025 target, policy advocacy in both the central and municipal governments is urgent, with a particular focus on how household biogas competes with LPG in the energy mix [56]. The studies regarding economic barriers also support this investment constraint.

According to Chen et al. [57], construction, treatment, and transportation expenses are all substantial in biogas facilities, especially when delivering feedstock over long distances. [57,58]. Furthermore, subsidies, financial assistance programs, and soft loans are significant economic impediments [15,58]. Research and financing support in developing countries is considered a significant impediment to technological innovation. More finance assistance should be put towards research and development [58]. *State Electric Company* (*PLN*) states that only installations with capacities below 10 MW can be used, as stated in Regulation No. 4 of 2012 issued by the Ministry of Energy and Mineral Resources, which can pose a barrier to the growth of Biogas production.

This is supported by the Ministry of Energy and Mineral Resources Regulation No. 19 of 2013, with prices ranging from Rp. 970–1798/kWh for low-voltage grids (average tariffs considered) and Rp. 880–1450/kWh for mid-voltage grids (average tariffs considered). For Indonesia to achieve a total energy mix by 2025, biogas technology would replace fossil fuel by targeting farmers and other industries with advanced technology such as bio natural gas, a variety of feedstock, and the cattle industry. This is also supported by the fact that biogas is more expensive than natural gas, which concerns the end consumer, as it causes them to pay more than usual [58]. On the contrary, another study stated that the price of biogas must be more attractive compared to other fuels to reach a wider customer base [59]. However, competition between biogas with other renewable energy such as bioethanol could further prevent biogas adoption in the long run, for instance, biogas usage as a source of energy for vehicles [60]. Furthermore, the biogas market in Indonesia could reach 1 million units of digesters coming from 15.6 million cattle, which would account for 2 million unit of biogas compared to the 4898 million unit of biogas mandated by the National Energy Masterplan (*Rencana Umum Energi Nasional*/RUEN) by 2025 as part of the 23% renewable energy target [16,60]. Conversely, energy sources in rural areas, such as traditional solid biomass, are also preferable and cheaper [36,47,61]. Despite the constraints, other studies found that biogas technology reduces the use of natural gas to an amount of 5.6 kg/month [16,61,62].

3.3. Finding 3: Social and Cultural Barriers

The literature review was used to synthesize the main social challenges, summarized in Table 3.

Table 3. Biogas development in Indonesia faces social and cultural obstacles.

No.	Socio Cultural Barriers Description	References
1	Adverse perception of technology	[54,56,61]
2	Insufficient access to knowledge and skills regarding Biogas technology	[5,32,46,63]
3	Women and children's participation in decision making still low	[5,36,64]
4	Cultural and religious belief with stigmatization	[46,65]
5	Users' literacy and education are still low in using biogas	[16,36,46]

Numerous studies have revealed that Indonesian perspective differ greatly depending on location in the archipelago due to the diverse cultures and traditions. As a result, adoption of biogas varies greatly from region to region. This is also because of the lack of government support to promote biogas technology [15,66]. Another study found that a centralized system can hinder the investment of private sectors [8].

Both socio-economic and socio-technical constraints found a desire in biogas producers for clear policies and industry support [59]. Furthermore, a lack of knowledge about the evolution of energy policy might be a substantial impediment to biogas plant investment [56]. Biogas dissemination has been proven to be hindered by a lack of cooperation between the public and private sectors [36,64,65].

3.4. Finding 4: Environmental Barriers

The literature review was used to synthesize the main social challenges, summarized in Table 4.

Table 4. Indonesian biogas development: environmental barriers.

No.	Environmental Barriers Description	References
1	Noise and odour pollution	[20,63,67]
2	High volume of water requirement	[51,67–70]
3	Inadequate water access	[5,14,17,38,69]
4	Pollution (air, water and land)	[20,36,70,71]

Environmental impacts reported by some studies include odours in the air [36,62,67], noise pollution [69], and water resources for biogas. Inadequately sealed digester caps and escaping gas can cause serious environmental issues, such as gas escape into the atmosphere and increasing greenhouse gas emissions. [58,62,70]. Biogas leakage is one of the reasons that contributes to global warming and pollution in the atmosphere. The second challenge is related to socio-technical constraints. Two central challenges are technology transfer and technology style. For technology transfer, new context is the focus. New context, for instance different regions or sectors, may contain different social or technological features to which the system must adapt. Additionally, earlier research on the socio-technical analysis has evolving the energy systems that laid the groundwork for the large technical systems [55,68,71,72]. This theory proposed concepts in the system development process. For the adaptation of technology style, one must consider that each social and technology context has different features [71]. Even if financial and regulatory disparities may be the primary reasons for diverse technical methods, culture plays a vital part in understanding them [72].

Therefore, the author of Figure 6 created the Problem Tree of Biogas Adoption in Indonesia, as follows.

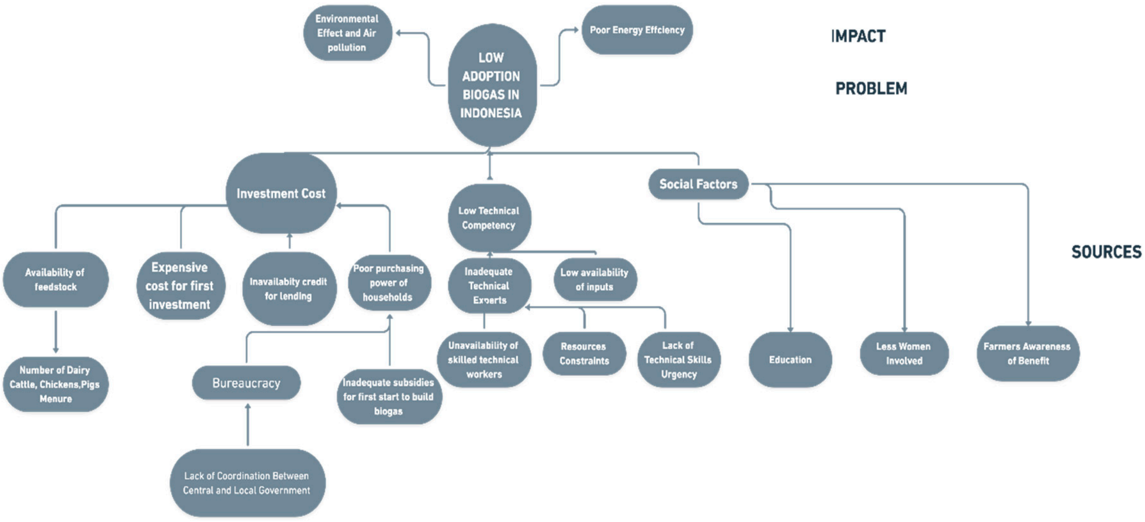

Figure 6. Logical Problem Tree of Biogas Adoption in Indonesia (created by authors, adapted from [4,15,17,32]).

Although government support is crucial in increasing the diffusions of biogas technology in developing countries such as Indonesia, this reliance can create dependency and a low sense of belonging and maintenance of the technology [22,73]. One approach developed by the *Biogas Rumah* (*BIRU*) program is the scheme where farmers can access credit with various interest rates to pay for small-scale biogas in cooperation with private sectors [60,73].

With this program, cow owners can build their small-scale biogas and receive price deductions by selling their milk products to the cooperatives [74]. A cost and benefit analysis of the biogas program is essential, especially for households to understand the impact of biogas installations before adopting the technology. Furthermore, analysis of their ability to pay and their willingness to pay will give us information about the farmers' abilities in the biogas program, particularly when they should provide their budget for installation. Farmers who participate in financing installations not only provide revenue to stakeholders by installing the digesters but should also view biodigester technology as an investment in their future. This is consistent with the findings of other studies in which co-financed biogas was used rather than purely donor-based asset provision models, which have failed in many contexts [48,55,73].

3.5. An Indonesian Biogas Adoption Recommendations

Based on our findings, several policy recommendations for overcoming these impediments are presented. Most low- and middle-income households in rural areas have a greater need for clean and affordable energy. The upfront cost of biogas plant installation is a significant impediment to the adoption of rural biogas plants among these households. To enable the adoption of biogas technology for the development of an efficient energy source in target areas, local governments and non-governmental organizations should consider the following recommendations.

3.5.1. Policy Recommendation

Policy lessons from industrialized nations such as Germany and Sweden should be learned to accelerate the spread of biogas technologies in rural and urban areas. In Germany, for example, the government's prohibition on dumping municipal solid waste in landfills has changed the waste management landscape and increased demand for biogas plants to handle organic waste [74]. Regulatory barriers do not hamper the spread of decentralized biogas in rural areas. These findings indicate that contextual variables should be considered when developing effective technology diffusion strategies. It is critical to develop guidelines allowing Indonesia to produce biogas for electricity generation.

Indonesia needs to develop a roadmap with cutting-edge policies at all levels to attract more investment and aid in regenerating renewable energy (municipal, regional, provincial, and central). Renewable energy subsidies include feed-in tariffs, renewable energy subsidies, and virtual power plants.

3.5.2. Transfer Knowledge and Capacity Building

Providing technical assistance and ongoing training on biogas process design, construction, and operation is critical to increasing biogas deployment in Indonesia. Biogas experts can also educate and train people at existing facilities. It is critical to monitor biogas output to analyse and improve it. As a result, consumers should be taught how to manage daily waste efficiently and about the benefits of biogas produced from these waste parts. Communities, schools, and markets require ongoing consultation and training on how to run their digesters efficiently as well as how to minimize the amount of trash produced, reuse for longer periods, recycle, and recover energy from waste. Co-digestion and dry anaerobic digestion may be viable solutions in areas with cattle dung and water shortages. As a result, for biogas plants to function properly, the technology type and scale should be tailored to the local conditions. There should be an awareness for techniques and applications for enhancing biogas production, such as pre-digestion with microbial additions and mechanical pre-treatment [36,41,71,74].

3.5.3. Subsidies and Government Assistance

Both systems have financial barriers, such as a high upfront cost and limited loan availability. Because there are no regulatory requirements for injecting biogas into the natural gas grid, using existing natural gas infrastructure for biogas is difficult. Support from the government, cooperative organizations, and industry should all be encouraged. Public–private partnerships are common examples in which governments at various levels collaborate with businesses to support large-scale applications, thereby increasing biogas technology in Indonesia. An incentive program should be implemented to encourage full compliance with government policies on effective waste management. Biogas initiatives should be appropriately promoted through media coverage, posters, brochures, and other marketing tools. Local personnel must be trained, and post-installation maintenance and repair are required for long-term benefits from biogas deployment.

4. Conclusions and Limitations

To comply with the Paris Agreement, Indonesia's targets of 23% renewable energy consumption by 2025 and 31% by 2050 may prove overly unrealistic. Indonesia still relies on imported coal and non-renewable energy sources such as petroleum products. Indonesia has over 1700 islands; thus, there are many solar, wind, ocean, and bioenergy resources, but the country's energy needs are growing rapidly. It is critical for Indonesia to develop a comprehensive bioenergy plan that includes all important supply and demand parties.

High investments, low-income families, and widespread poverty are significant economic barriers for both countries. The level of economic growth plays a significant role in determining whether to accept new technology. Lack of funds is the most common reason for not establishing biogas plants. The government and business sector must work together to design a national investment strategy. The public and private sectors must develop a national commitment to invest in renewable energy with sufficient capital and high investment costs; a lack of subsidies, financial support programs, and soft loans are all regarded as fundamental economic constraints in developing countries.

Developing a group of biogas experts that can offer the most suited versions for a certain situation and/or project and preparing manuals for potential biogas manufacturers to use as a guideline could be a solution to these constraints. It is recommended to increase public participation, consumer interest and acceptability to adopt biogas, especially in rural communities, and to accept all socio-cultural challenges. Stigmatization and scepticism among potential users have an impact on market penetration. A study conducted by

Dahlin et al. [75] discovered that for some Islamic countries such as Indonesia, energy generated from digestate containing pig slurry are not allowed to be sold, which gives an excellent example of this occurrence. It is the role of the media and public organizations to provide more information to overcome the socio-cultural barriers and the urgent need to address environmental issues, the multi-functionality of biogas, and its favourable features such as improved waste management and self-provision of clean energy.

The renewable energy roadmap should be able to maximize the sustainable use of Indonesia's bioenergy resources across many sectors while also ensuring bioenergy's environmental, social, and economic sustainability. In this case, biogas technology fits the concepts because it efficiently uses biomass resources. The circular economy in biogas can reduce firewood extraction while optimizing the use of biomass resources. It may also provide significant opportunities to practice the circular economy approach. This systematic literature review adheres to the guidelines presented in scientific studies and relies on pre-planned methods that minimize bias and random errors, albeit with some limitations. In this study, for example, only empirical studies included in the articles were examined, whereas the remaining scientific literature could provide relevant information on the topic. Furthermore, the analysis of the determinants did not differentiate between different organizational sizes and private sectors.

In conclusion, this study investigated the obstacles to biogas adoption in Indonesia. It contributes to the small body of scholarly literature devoted to analysing developing countries' barriers and constraints when implementing biogas. This desk study performed an extensive literature analysis to identify and analyse the hurdles to biogas technology dissemination in Indonesia. To force the implementation of biogas technology, effective steps must be implemented to incentivize investments in biogas; these actions should include expanding technical skills and setting legislative objectives. By filling a gap in the literature, this study will be able to assist Indonesian decision makers in adopting appropriate solutions to the primary challenges of biogas adoption.

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