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Biogas-to-Electricity Development in ASEAN:

Challenges & Opportunities

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Soemantri Brodjonegoro II Building, 6th Floor
Complex Directorate General of Electricity
Jl. HR Rasuna Said Blok X-2 Kav. 7-8
12950 Jakarta, Indonesia
Tel: (62-21) 527 8027 | Fax: (62-21) 529 6382

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www.facebook.com/sustainableenergyforasean

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Forewords

Dr. Nuki Agya Utama
Executive Director,
ACE

Sergey Makarov
Principal Advisor,
AGEP

As one of the fastest-growing regions, Southeast Asia faces immense challenges in achieving universal electrification while transitioning to renewable energy sources. In view of this, biogas technology is a viable option for diversifying the total regional energy mix and stimulating the green energy transition in ASEAN. The full potential of biogas capacity in the power sector has yet to be tapped. Therefore, prompt actions initiated at the regional level are needed to expand biogas deployment, with well-defined targets and locally adapted policy mechanisms that align with ASEAN member states' national energy agendas.

We are pleased to present the study, Biogas-to-Electricity Development in ASEAN: Challenges and Opportunities, which recognises the opportunities and challenges of the biogas-to-electricity pathway in ASEAN. The ASEAN Centre for Energy, with the support of the ASEAN-German Energy Programme (AGEP), developed the study. The project was jointly implemented by the Asian Centre for Energy and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH on behalf of the German Federal Ministry for Economic Cooperation and Development. The study complements the outcome-based strategies under the ASEAN Plan of Action for Energy Cooperation Phase II (2021 – 2025), the regional blueprint for the energy sector in the ASEAN Economic Community implementation framework.

The study aims to explore the existing barriers to biogas deployment in the ASEAN energy sector, identify appropriate technologies to utilise the feedstock potential in the region, and bridge the gap between policy and practice to accelerate biogas development in the electricity system. Information was deducted from literature reviews, and valuable input was provided through interviews, questionnaires, and a focus group discussion with key stakeholders and experts in the biogas field and power sector.

The results of this study could provide profound insights into what is lacking and needed in ASEAN biogas development and identify how biogas could supplement other renewable energies in the power sector. Thus, it could contribute as supportive literature in achieving the ASEAN Plan of Action for Energy Cooperation Phase II (2021 – 2025) of renewable energy share in total primary energy supply and installed capacity, targeted at 23 percent and 35 percent, respectively. Furthermore, the findings are anticipated to trigger discourse on biogas representation in the regional power system and lead to guidelines for ASEAN member states' governments and policymakers to establish suitable initiatives and directives for regional renewable energy targets.

As an organisation representing the interests of 10 ASEAN member states in the energy sector, the ASEAN Centre for Energy is committed to identifying existing regional energy challenges and striving for excellence in strengthening regional energy cooperation. We would like to express our sincere gratitude to the Renewable Energy Sub-Sector Network Focal Points, consultants, researchers, dialogue partners and international organisations for their valuable support and contribution to this study. We hope this study will become a valuable reference and lay the foundation for more concrete partnerships and collaborations toward the sustainable development of the ASEAN energy sector in the future.

Table of contents

List of Tables

List of Figures

Abbreviations

ACE	**ASEAN Centre for Energy**
ADB	**Asian Development Bank**
AGEP	**ASEAN-German Energy Programme**
AMS	**ASEAN Member States**
B2B	**Business-to-business**
CO2	**Carbon Dioxide**
COP26	**The 26th Conference of Parties**
DEDE	**Department of Alternative Energy Development and Efficiency**
EPPO	**Energy Policy and Planning Office**
ERIA	**The Economic Research Institute for ASEAN and East Asia**
FIT	**Feed-In Tariff**
FGD	**Focus Group Discussion**
G2G	**Government-to-government**
GIZ	**Deutsche Gesellschaft für Internationale Zusammenarbeit**
GHG	**Greenhouse Gases**
GW	**Gigawatt**
GWh	**Gigawatt-hour**
H2S	**Hydrogen Sulphide**
IEEE	**The Institute of Electrical and Electronics Engineers**
IRENA	**International Renewable Agency**
kWh	**Kilowatt-hour**
LPG	**Liquefied Petroleum Gas**
m3	**Cubic Metre**
MW	**Megawatt**
Mtoe	**Million Tonnes of Oil Equivalent**
MSW	**Municipal Solid Waste**
NBP	**The National Biodigester Programme**
PLTBg	**Pembangkit Listrik Tenaga Biogas (Biogas Power Plants)**
POME	**Palm Oil Mill Effluent**
PDP	**Power Development Plan**
RE	**Renewable Energy**
RE-SSN	**Renewable Energy Sub-sector Network**
RUEN	**Rencana Umum Energi Nasional (National Energy General Plan)**
SEI	**Stockholm Environment Institute**
TPES	**Total Primary Energy Supply**
TRL	**Technology Readiness Level**
UN ESCAP	**The United Nations Economic and Social Commission for Asia and the Pacific**
UNDP	**United Nations Development Programme**

Photo : ACE

Executive Summary

Southeast Asia is facing a dual challenge in the power sector: climate change mitigation and electrification. Considering the Nationally Determined Contribution of all ASEAN member states, biogas could be critical to climate change mitigation in reducing emissions, especially methane emissions. Additionally, biogas is a potential alternative solution to electrification issues in the regions. Thus, this study emphasises the importance of biogas-to-electricity expansion in ASEAN by examining the current state of biogas and exploring a framework for identifying ASEAN power industry barriers and opportunities.

ASEAN member states are attempting to diversify their national energy mix to attain long-term viability and have ambitious bioenergy targets. For example, Indonesia's target for bioenergy capacity is 810 megawatts by 2025, Thailand's target is 5,570 megawatts by 2036, and Malaysia is targeting 1,065 megawatts by 2025. Future energy demand will engender increased demand for capacity development and research projects, which are yet to become tangible deployment projects.

There are four biogas barrier-and-need categories or technology readiness levels in the power industry:

- The Type A (commercial) category requires a quick response to energy shortfalls and energy security
- The Type B (niche market) category demands more focus on implementation. Various economic barriers may fall into this type; therefore, research is needed to better understand and address them.
- The Type C (development) category is either economically unfeasible or requires substantial development of pilot projects
- The Type D (early research) category is unrealistic for implementation and is considered at an early research stage

Types A and B are considered the deployment stage, while Types C and D are considered the research and development (R&D) stage in the technology readiness level map in Figure ES 1. Due to technological, economic, and political hurdles, biogas-to-electricity implementation in most ASEAN countries is still at an early stage with pilot projects (Type C). Feedstock availability, collection, and processing remain critical issues in biogas technologies, which can be addressed through training and financial resources. Biogas-to-electricity early research (Type D) provides development opportunities in ASEAN when technological, economic, and political aspects show signs of other social and environmental improvements.

A triangulation approach was used in this study, integrating desktop research, an online survey, and a virtual focus group discussion. The desktop research examined pertinent literature and numerous official governmental and international agency reports. The online survey respondents comprised 66 relevant energy stakeholders, including government agencies, private financiers, non-governmental organisations, research institutes, and universities from all 10 ASEAN member states. The focus group discussion participants comprised 133 stakeholders from all 10 ASEAN member states and abroad. All three sets of findings were combined and compared.

We then conceptualised the biogas technology pathway for the ASEAN region in each member state. We classified technology readiness based on the needs-by-barriers framework to identify the biogas-to-electricity status in ASEAN. The technology readiness was adapted from various studies in Rybicka *et al.* (2016) and Dovichi Filho *et al.* (2021). The study deployed four stages of "Z-curved" technology readiness based on the four types of barriers and needs matrix, adapted from the Ministry of Foreign Affairs of Netherlands (2012) and Nguyen *et al.* (2017) (Figure ES 1).

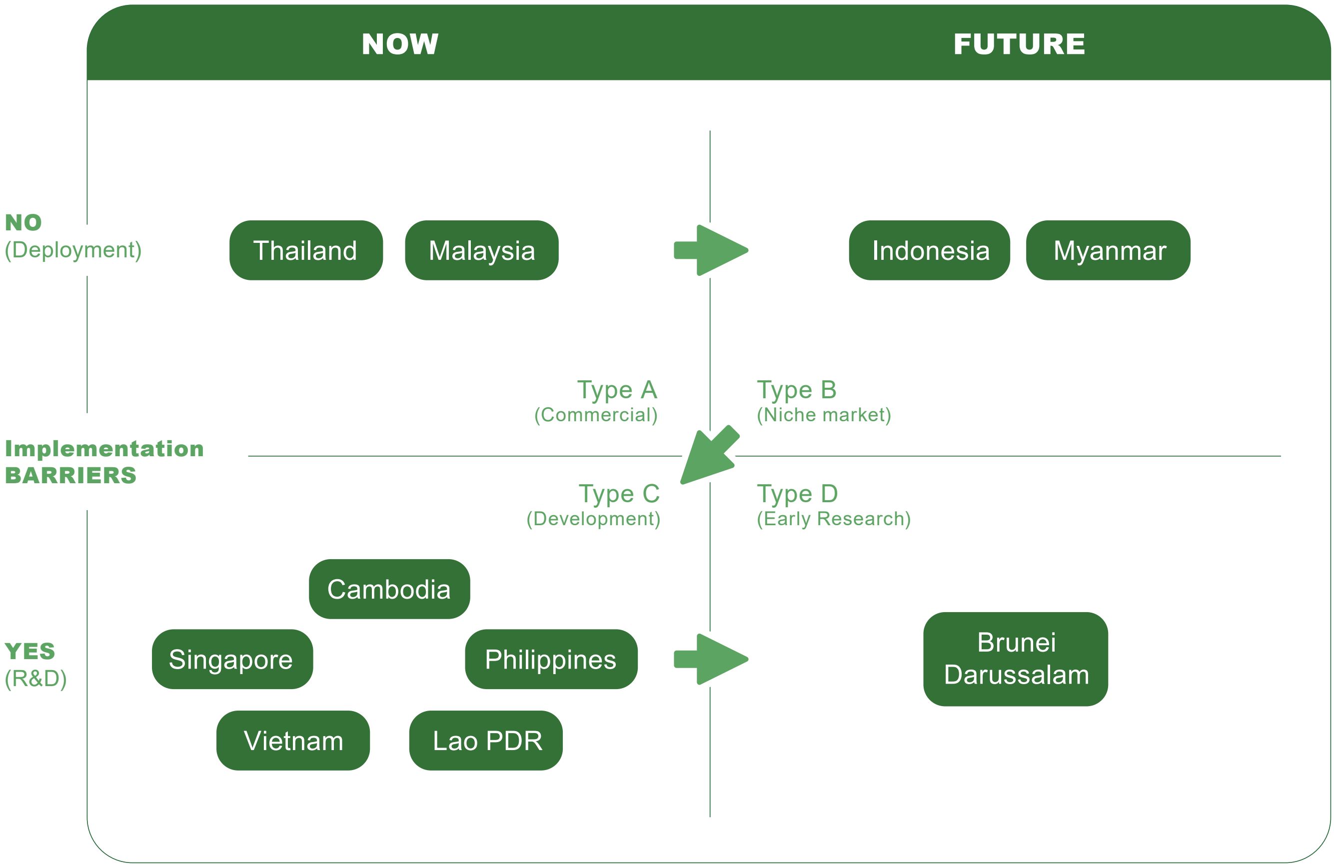


Figure ES 1. Technology Readiness Levels of Biogas-to-Electricity in 10 ASEAN Member States

The institutional, policy and project levels of each of the six implementation barrier aspects (technological, economic, political, regulatory, social and environmental) were assessed due to their relevance to biogas-to-electricity development. Then, each implementation barrier was classified into the four types of needs-by-barriers (Type A, B, C, or D). Most ASEAN member states such as Singapore, Cambodia, the Philippines, Vietnam and Lao PDR that have pilot projects were categorised in Type C (development). However, several relevant small-scale biogas technology developments potentially leading towards biogas-to-electricity were also found in the review. The categorisation of each ASEAN member state was based on the biogas technology that has been deployed to date.

Indonesia and Myanmar were categorised as Type B or niche markets as some biogas policies and targets were found in their national development plans. Thailand and Malaysia, which both have large-scale biogas technology operations, were classified as Type A (commercial). Types A and B are considered to be the biogas deployment stage. Table ES 1 summarises the findings on biogas-to-electricity in each ASEAN member state.

Country	Type	Findings
Cambodia	C	• Small-scale biogas initiatives in Cambodia have been successful, although they are still at the pilot and demonstration stages (Poch, 2013) • The National Biodigester Programme targets include the installation of 33,000 units by 2020, long-term adoption and maintenance of installed units, and widespread use of biogas for lighting (Hyman and Bailis, 2018).
Indonesia	B	• In 2014, the total capacity of biomass (oil palm-based), biogas, and urban waste power plants connected to the Indonesian State Electricity Company's grid in Indonesia was 544 megawatts. • Biogas consumption is still far below the National Energy General Plan target for 2025. In the energy sector, biogas power plants are planned to reach a capacity of 5.5 gigawatts by 2025, but thus far, only 1.33 percent of the capacity has been realised (Rianawati *et al*., 2021).
Lao PDR	C	• The Ministry of Agriculture and Forestry has tested a small family-sized biogas digester as a pilot project. • Using livestock manure to produce biogas could potentially generate 5×10^8 kilowatt hours (Lao People's Democratic Republic, 2011). • In terms of electricity generation, the biogas production in Lao PDR is predicted to provide over 313 MW of generation capacity (Asian Development Bank, 2019).
Malaysia	A	• In Malaysia, feed-in-tariff projects with a total installed capacity of 55.83 megawatts began commercial operations in 2017. Biogas generated 226 gigawatt hours in 2018, producing 464 kilotons of carbon dioxide emissions (Jain, 2019).
Myanmar	B	• In Myanmar, solid biomass and biogas electricity are carefully used and account for approximately 17 percent of total electricity generation (World Wildlife Fund, Intelligent Energy Systems and Mekong Economics Ltd., 2016). • In 2013, Myanmar's total installed biomass energy capacity was about 115 megawatts (Tun and Juchelková, 2019).
The Philippines	C	• A large-scale biogas-to-electricity facility was built in La Paz in 2008 and there are numerous other small-scale pig farms in the vicinity generating biogas. The facility uses a covered lagoon digester that generates 100 kilowatts of energy and supplies half of La Paz's electricity needs (Trosgård, 2015).
Singapore	C	• Singapore's National Water Agency and National Environment Agency assessed the feasibility of collecting and transporting source-segregated food waste from various locations to a demonstration facility for co-digestion with waste sludge in a two-year trial in December 2016. This project will begin operating in 2025 (National Environment Agency, 2019).
Thailand	A	• Thailand's current renewable energy development for biogas has reached 563.18 megawatts, with a goal of 1,566 megawatts by 2037 (Aggarangsi *et al*., 2013).
Vietnam	C	• Vietnam has a biogas production facility for electricity generation with a total installed capacity of 2 megawatts in Binh Doung province. Other biogas facilities have been designed to produce biogas to replace fuel oil for cooking (Dao, Yabar and Mizunoya, 2020).

Table ES 1. Summary of Findings on Biogas-to-Electricity

Concluding remarks

A Brunei Darussalam has recently begun exploring renewable energy resources at the Type D or early research stage. Most ASEAN member states, including Singapore, Cambodia, the Philippines, Vietnam, and Lao PDR, are classified as Type C (development) with pilot projects in operation. Several small-scale biogas technological breakthroughs were identified, potentially leading to biogas-to-electricity. Indonesia and Myanmar fall under the Type B or niche market category. Thailand and Malaysia have large-scale biogas facilities in operation; hence, they are classified as Type A (commercial).

B Globally, biogas power generation is still unable to compete with fossil fuel generated power, especially with fossil fuel subsidies. However, ASEAN member states must focus on biogas utilisation outside of electricity generation, social and environmental opportunities, and energy security. The 26th Conference of Parties' commitment to reducing methane gas has created a tailwind for biogas and is triggering Type D (early research) category nations to transform into Type C (development) environments. These nations are reducing methane gas by generating biogas power from manure, agricultural residues, and other organic waste.

C General energy demand is rising due to the COVID-19 recovery, and the market is driving up the price of fossil fuels, including natural gas. This means the energy market can also accept higher-priced renewable energy, making biogas-generated electricity more competitive. Opportunities to invest in biogas have also been created, thus enabling countries in Types C (development) and D (early research) to move towards becoming Types A (commercial) and B (niche market).

D Biogas is directly linked to social and environmental issues, such as waste management and methane gas reduction. Producing biogas from sewage means wastewater is a hidden need, and as biogas prevents methane gas from being released into the atmosphere, it contributes to mitigating global warming, which all contributes to energy accessibility.


INTRO

01 Introduction

Following the 26th Conference of Parties (COP26) climate conference in Glasgow at the end of 2021, the global community has gained interest in the importance of reducing methane. More than 100 countries have agreed to reduce current methane emissions by 30 percent by 2030. Most countries consider cutting methane emissions as the fastest way to decelerate climate change (Depledge, Saldivia and Peñasco, 2022).

As a region vulnerable to climate change, Southeast Asia is negotiating the dual challenge of achieving 100 percent electrification and adapting to climate change in the power sector, which certainly indicates potential for a broader role of biogas. Malaysia, Thailand, the Philippines, Indonesia, and Lao PDR, for instance, all emphasise the importance of improving electricity development with biogas (Ahmed *et al*., 2017).

A common question is how to enhance electricity in the region with biogas. However, there is little literature exploring the strengths and weaknesses of supporting biogas development in the electricity sector in developing countries in terms of technological, economic, political, regulatory, social and environmental frameworks. The overall aims of this study are:

1. Mapping current and future biogas deployment and comparative studies
2. Identifying barriers and opportunities
3. Providing policy assessment and recommendations from stakeholder engagement

Therefore, the scope of this discussion is expanded to address the following two questions:

a. What are the needs and barriers regarding the social, technological, economic, environmental, and political aspects of biogas in the electricity sector in ASEAN?

b. What are the recommendations to resolve biogas deployment barriers using regulatory and non-regulatory instruments?

This study explores the current state of biogas and a framework for identifying constraints and potential in the ASEAN power sector. Current and future biogas implementation or opportunities are defined as “needs” and unavailability as “barriers”. Following the needs-and-barrier assessment, the study presents policy assessments and recommendation input for biogas development in the electricity sector.

The concept of “needs” and “barriers” is examined from two distinct perspectives: regulatory and non-regulatory. Non-regulatory aspects include technological, economic, political, social, and environmental concerns. A triangulation strategy was used, integrating pertinent literature and reports with engagement with ASEAN stakeholders in the energy sector through an online survey and a focus group discussion (FGD) on categorising the biogas development stages (Figure 1). The results of the desktop research, the online survey, and the FGD are presented and compared. Finally, we summarise the findings and provide issue and country-specific recommendations for biogas implementation.

Research Methodology

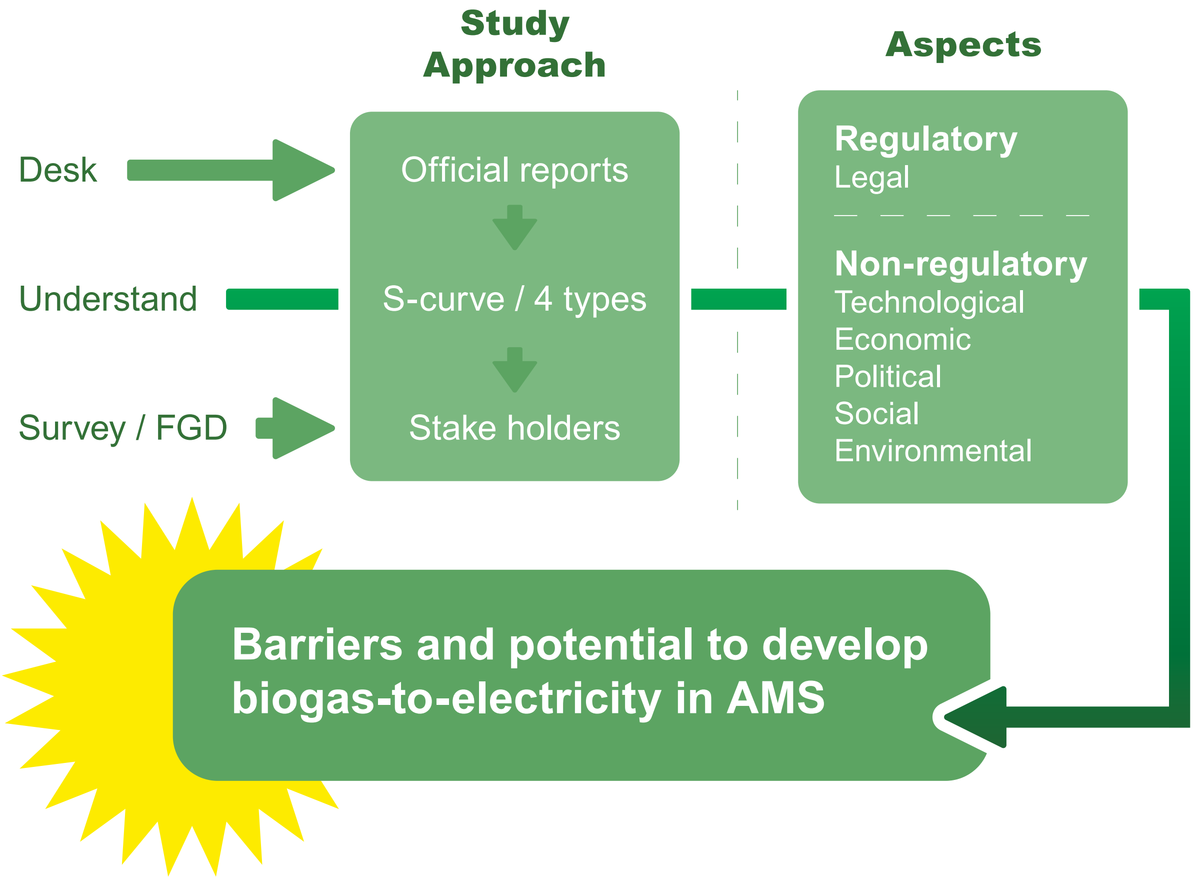


Figure 1. Conceptual Research Framework

02 Background of Biogas Development in the ASEAN Electricity Sector

Biogas is a renewable energy alternative currently gaining popularity after solar and wind (Ritchie, Roser and Rosado, 2021). It is produced from anaerobic bacterial activity over a certain period of time (Sawyerr *et al.*, 2019). Biogas consists of a blend of various gases but is primarily 45-75 percent methane (CH_4), carbon dioxide (CO_2), and 1-5 percent of additional gases, depending on the feedstock.

Biogas can be produced on a small or large-scale through anaerobic digestion of organic matter, animal manure, human waste, or crop residue. Small-scale biogas reactors can provide a sustainable and inexpensive fuel source for lighting, cooling, cooking, and electricity. Furthermore, small-scale biogas deployment in rural locations is highly beneficial in terms of providing clean energy sources while curtailing deforestation with reduced firewood usage. In large-scale biogas production, once the contaminants are removed to meet the natural gas criteria, methane can be utilised for various purposes, including producing heat, power, and transportation fuel (e.g., for cars, freight vehicles, and shipping). Hence, the methane produced by larger anaerobic digesters is a valuable by-product.

Methane is an important component in biogas as a fuel source and corresponds to an energy level of 6 - 6.5 kilowatt hours (kWh) per cubic metre (m^3). Approximately 1 m^3 of biogas has a calorific value of 22 megajoules, and 1 m^3 of methane contains 36 megajoules (Suhartini, Lestari and Nurika, 2019). Assuming a 35 percent electrical conversion efficiency, 1 m^3 of biogas will yield 2.14 kWh of electricity, while 1 m^3 of methane will generate 10 kWh. Thus, improving methane quantity and quality as a biogas by-product is exceedingly beneficial. A biomethane content of up to 90 percent can be achieved by upgrading biogas (Feiz and Ammenberg, 2017). Several methods, such as water or organic physical scrubbing, chemical scrubbing, pressure swing adsorption, membrane separation, and cryogenic technology are recognised to improve biogas quality (Nguyen *et al.*, 2021).

Although upgrading biogas is doable, the calorific efficiency of using biogas as energy resources ranges depending on the type of final energy anticipated. The efficiency in stoves, engines and lamps is 55 percent, 24 percent and 3 percent respectively. In addition, a biogas lamp's efficiency is only half of a kerosene lamp. In contrast, the most efficient use is a biogas heat-power combination that can reach up to 88 percent efficiency. However, this only applies to more extensive biogas systems where the exhaust heat is utilised profitably (Seecon International GmbH, 2015).

Biogas is also a viable option for ASEAN countries to diversify their national energy mix in moving towards sustainable energy (International Energy Agency, 2019). It can be produced from various feedstocks, including organic and agricultural wastes and dedicated energy crops. Animal waste, such as dairy manure and chicken litter, municipal solid waste (MSW), wastewaters, sludge and industrial waste, such as food processing waste, are all ideal for biogas production (Kulichkova *et al.*, 2020). Biogas demand is ever-increasing due to the dire need to shift to cleaner energy and meet the growing electricity demand within the ASEAN region. As electrification rates within the region have not reached 100 percent, biogas is a potential renewable energy alternative for remote areas due to the abundance and availability of biomass (United Nations Economic and Social Commission for Asia and the Pacific, 2019).

Bioenergy feedstock utilisation, however, is limited to certain types and needs to be prioritised for applications offering multiple renewable options. For example, biogas can be used to produce electricity and contribute to the renewable energy portion of a national energy mix in the electricity sector. Additionally, upgrading to biomethane can replace natural gas heating in buildings and industries. Prioritising large-scale biogas development for electricity generation will support the national energy security in all ASEAN member states (AMS).

Biogas conversion to power generation is promising for off-grid electrification, particularly in rural areas. The installed capacity in ASEAN, shown in Figure 2, depicts the significant potential of bioenergy, which includes biogas, in diversifying the renewable mix in the power sector. As the status of renewable energy in total primary energy supply (TPES) is still 14.2 percent, further deployment of renewable energy will contribute to increasing the renewable portion in TPES.

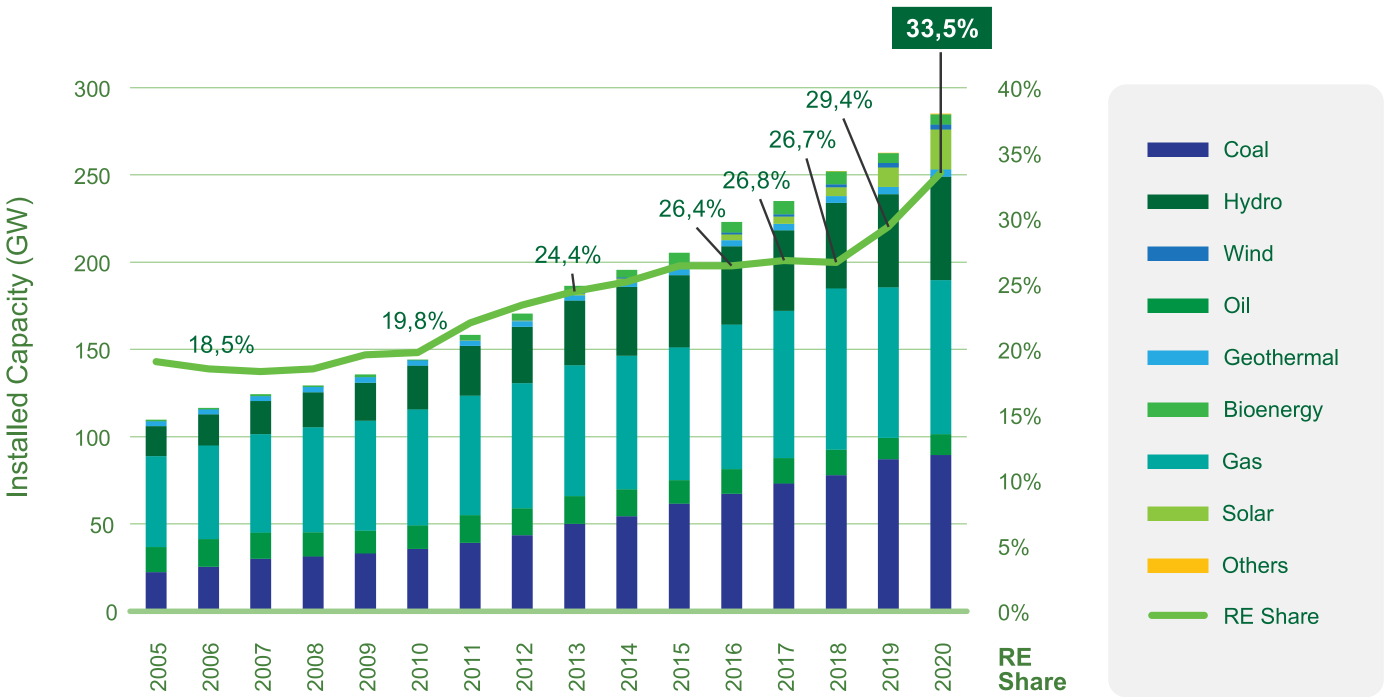


Figure 2. ASEAN's Installed Power Capacity by 2020
(ASEAN Centre for Energy, 2020)

AMS, such as Indonesia, Malaysia, and Thailand have been vigorously boosting biogas production to reach their national bioenergy targets. Indonesia's bioenergy capacity target is 810 megawatts (MW) by 2025. Thailand's target is 5,570 MW by 2036, and Malaysia aims to generate 1,065 MW by 2025.

The economics of biogas deployment in most ASEAN countries can be considered as straightforward supply and demand. For instance, given Indonesia's large cattle population, which has continuously expanded over the previous three years, biogas has enormous potential, with an anticipated capacity of approximately 9,595.6 m^3 per year. One m^3 of biogas produces the equivalent of 1.25 kWh of electricity, which can power a 60 to 100-watt bulb for six hours or alternatively produce three cooked meals for five to six people. Hence, Indonesia's biogas installed capacity potential is approximately 7,000 MW per year (Rianawati *et al.*, 2021), spotlighting the possibility of large-scale biogas-to-electricity conversion in Indonesia (Khalil *et al.*, 2019).

2.1. Concepts of Biogas in the Electricity Sector: Regulatory and Non-regulatory Aspects Sector

The study involved key biogas stakeholders from 10 AMS to explore how they perceive and plan the biogas-to-electricity pathway and address the gaps in biogas development in the power sector across Southeast Asia. The method comprised of desktop research, an online survey, and a FGD to examine the opportunities, risks, and barriers in converting biogas-to-electricity. Both regulatory and non-regulatory (technology, economic, political, social, and environmental) aspects were assessed, as listed in Table 1.

The technological aspect entailed examining the availability and accessibility of feedstock and implementation technicalities. As the growth of biogas-to-electricity technology is at a different stage of development in each ASEAN country, we grouped the stages of development into four categories (Types A, B, C, and D), which will be further discussed in Section 2.2.

We addressed the political and regulatory issues concurrently as policy directly steers the technological implementation and growth of biogas-to-electricity. When policy instruments, such as subsidies, tax exemptions, and incentives are absent, economic issues arise.

Finally, we assessed the social and environmental issues, examining how human-resource interactions affect the functioning of biogas technology. Some challenges and local issues assessed in biogas-to-electricity development included stakeholders' readiness to manage feedstocks. The associated risks of biogas deployment for electricity generation, such as sulphide gas leakage, were also investigated. Additionally, we explored new and uncharted perspectives on the barriers and opportunities in biogas technology in AMS.

Table 1. Regulatory and Non-regulatory Aspects in Identifying Biogas-to-Electricity Technology Readiness Levels in ASEAN

Aspects	Sub-Aspects	Issue	Study Approach		
			Desk Research	FGD	Survey
Regulatory	Legal	Bureaucratic processes to access support	✓	✓	✓
Non-regulatory	Technological	Feedstock accessibility and management	✓	✓	✓
		Infrastructure operations and maintenance	✓	✓	✓
		Technology appropriateness in the local context		✓	✓
		Technical information and knowledge	✓	✓	✓
	Economic	Incentives	✓	✓	✓
		Subsidies	✓	✓	✓
		Fixed and variable costs (e.g., technology and feedstock)	✓	✓	✓
	Political	Interest/goal in biogas installation	✓	✓	
		Monitoring practices	✓	✓	✓

Aspects	Sub-Aspects	Issue	Study Approach		
			Desk Research	FGD	Survey
	Social	Collective management	✓	✓	✓
		Common knowledge and interactions among actors	✓	✓	
	Environmental	Unfiltered sulphide removal and methane leakage	✓		
		Carbon offset	✓	✓	✓
		Sanitation	✓	✓	✓

2.2 . Biogas-to-Electricity: Needs and Barriers

The identified biogas-to-electricity needs and implementation barriers were categorised into three levels, namely institutional, policy, and project. Institutional needs and barriers are related to the general capacity of a government, non-governmental organisations (NGOs) and civil society. At the policy level, the absence of specific national biogas and electricity policies is deemed both a need and a barrier. Needs and barriers at the project level are tangible and specific to a particular project, problem, or location.

The different types of needs and barriers to biogas in the electricity sector are presented in Table 2. The matrix is sorted into temporal needs and barriers. A need, defined by the existence of a present barrier, reflects the current situation but may not necessarily be an issue in the future. Therefore, the need requires improved regulatory mechanisms, such as a more robust regulatory framework, specific policies, and better enforcement.

Needs are categorised into two timeframes: now and the future (5 to10 years). A current need demonstrates that direct biogas deployment is required. A future need indicates that a critical factor is needed to boost biogas deployment further. When there are no significant implementation barriers, then a need is resolvable or can be accommodated. For instance, without any implementation barriers, a biogas developer in a country with a more established supply chain and markets like Malaysia and Thailand (Type A) could easily address their cost need. When a barrier exists, responding to the needs in a system is unfeasible. Some change is necessitated to alleviate the needs.

Barriers	Needs: Now: Direct biogas deployment	Needs: Future (5-10 years): Energy + development
No	**Type A (Commercial)** • Urgent and feasible needs • Energy shortage prevention for energy security • Predictable costs • Predictable impacts	**Type B (Niche Market)** • Training, etc. • Development • Predictable costs • Unpredictable impacts
Yes	**Type C (Development)** • Realistic but unfeasible needs • Predictable/high cost • Unpredictable impacts	**Type B (Niche Market)** • Innovative development • Unpredictable costs • Unpredictable impacts

Table 2. Four Types of Biogas-to-Electricity Technology Readiness Levels

The needs of the Type A (commercial) level are the immediate solutions to energy shortages to provide options in commercialising biogas-to-electricity. Type A has the highest level of technology readiness as there are no unpredictable barriers, therefore, implementing biogas technology in the market is unimpeded. At the same time, Type B (niche market) needs are research-oriented regarding biogas technologies in niche markets. In Type B, there are no unpredictable barriers to biogas deployment, but there is a need for future biogas development to accommodate the need of existing and expanding niche markets. Types A and B are considered as the deployment stage for biogas. The needs of Type C are realistic only in a controlled context or space, thus preventing projects from developing beyond being a pilot project at the developmental stage. However, barriers, such as the high costs involved and unpredictable impacts, may prevent future biogas technology deployment on a large-scale. Lastly, the needs of the Type D (early research) level are unrealistic, thus requiring more research projects. Type D has the lowest technology readiness as although there is a need for this technology in the future, there are also barriers that need to be simultaneously resolved. Types C and D can be considered as the research and development (R&D) stage for biogas implementation.

Economic costs are relatively easier to estimate for the needs in Types A and B as these levels are at the deployment stage. Estimating the impact of needs in Types C and D is more complex and comes with future uncertainty as these two categories still require research or a controlled environment; thus, these types are considered to be at the R&D stage. For example, as there are unpredictable barriers (e.g., poor policy support and resource management), current and future needs may not be feasible. Some national energy outlooks (e.g., the Indonesian Energy Outlook and the Thailand Energy Outlook) have created a list of “priorities for biogas in the electricity sector”. Due to the energy loss in biogas-to-electricity conversion, the most economically viable biogas-to-electricity examples are combined heat and power cogeneration. However, in the ASEAN context, as there is little demand for heat, heat and power cogeneration is less attractive economically.

The scope of this study aligns with the AMS’ interest to decarbonise energy systems and shift to renewable resources with reference to the 6th ASEAN Energy Outlook, Nationally Determined Contributions, and AMS’ energy development plans and roadmaps. A complete list of the technical, economic, political, regulatory, social and environmental documents assessed (Table 3) from all AMS is presented in Appendixes I, II and III. The assessment also included a review of academic journals to complement the desktop research.

Photo by Dewi Sri Malida
Indonesian APC Winner


A
C
B
D

03 Desktop Research: Current and Future Biogas Deployment in ASEAN

This section details biogas deployment and developments in the electricity sector based on the ASEAN documents reviewed. This literature assessment involved searching for keywords regarding biogas deployment and developments specifically related to power generation. The summary (Table 4) outlines the six aspects assessed.

Each aspect was examined at the institutional, policy and project levels in relation to biogas-to-electricity development. Each identified barrier was then classified into one of the four types of needs-by-barriers (Type A, B, C, D). The results showed that most document reviews were focused on the technological aspects of biogas, with a total of 124 technological issues identified, followed by regulatory, economic, political, social, and environmental issues.

Findings showed that Type C nations in ASEAN still require significant improvement to facilitate biogas-to-electricity deployment, particularly in regard to technological, economic, and political issues to scale up current pilot projects. Institutional barriers dominated the technical aspect of biogas deployment, with 16 issues identified (Table 4), including a lack of training and poor biogas plant maintenance. Similarly, 12 economic issues were found at the institutional level, pointing to much needed financial support to adopt biogas and increase renewable energy investment in Southeast Asia (International Renewable Energy Agency, 2018). In comparison, Brunei Darussalam and Singapore did not demonstrate a need for financial support (APAEC Drafting Committee *et al.*, 2020). Nine political issues were identified at the institutional level in the Philippines, Vietnam, and Cambodia, most notably a lack of government support for biogas promotion. These results indicate the urgent need for training, monetary funds, and policy reform to mainstream biogas-to-electricity generation.

The Type D biogas-to-electricity category provides research opportunities in ASEAN. Most biogas implementation barriers identified were related to technological development and were typically found at the institutional level, with seven technological, eight economic, and four political issues found. Several countries, such as Cambodia, Indonesia, Thailand, and Vietnam, highlighted the undeveloped potential of biogas projects. In Cambodia and Vietnam, tax incentives and soft loans play an essential role in setting up the investment environment for biogas.

In the political domain, findings showed that the AMS are mainly focused on increasing renewable energy shares to achieve their national targets and the regional target of 23 percent of renewable sources in the TPES by 2025 (ASEAN Centre for Energy, 2020). In Cambodia and Lao PDR, the government plays a significant role in setting specific biogas-to-electricity targets. Therefore, the technological, economic, and political environments require Type D projects to resolve implementation barriers and explore needs in the future to further uptake biogas technology.

Aspects	Level	Type A (Commercial)	Type B (Niche Market)	Type C (Development)	Type D (Early Research)	Total
Technological	Institution	10	5	16	7	**40**
	Policy	0	1	1	0	**2**
	Project	37	26	15	6	**84**
	Total	47	32	32	13	**124**
Economic	Institution	4	4	12	8	**28**
	Policy	8	3	1	0	**12**
	Project	2	3	4	0	**9**
	Total	14	10	17	8	**49**
Political	Institution	0	5	9	4	**18**
	Policy	10	9	6	2	**27**
	Project	3	1	1	3	**8**
	Total	13	15	16	9	**53**
Regulatory	Institution	0	2	2	1	**5**
	Policy	11	44	0	0	**55**
	Project	1	2	0	0	**4**
	Total	12	48	2	1	**63**
Social	Institution	5	7	11	4	**27**
	Policy	0	0	6	0	**0**
	Project	1	1	1	0	**3**
	Total	6	8	12	4	**30**
Environmental	Institution	2	6	2	2	**12**
	Policy	0	5	0	0	**5**
	Project	1	2	3	0	**6**
	Total	3	13	5	2	**23**

Table 3. Summary of the Institutional, Policy, and Project Level Needs in the Key Issues in the Four Technology Readiness Levels

Figure 3 depicts the ratio of the six regulatory and non-regulatory barriers in the four technology readiness levels. Technology appeared as the main issue throughout all four levels, followed by economics. However, in Type B, regulatory barriers were the most prominent category, followed by technological barriers.

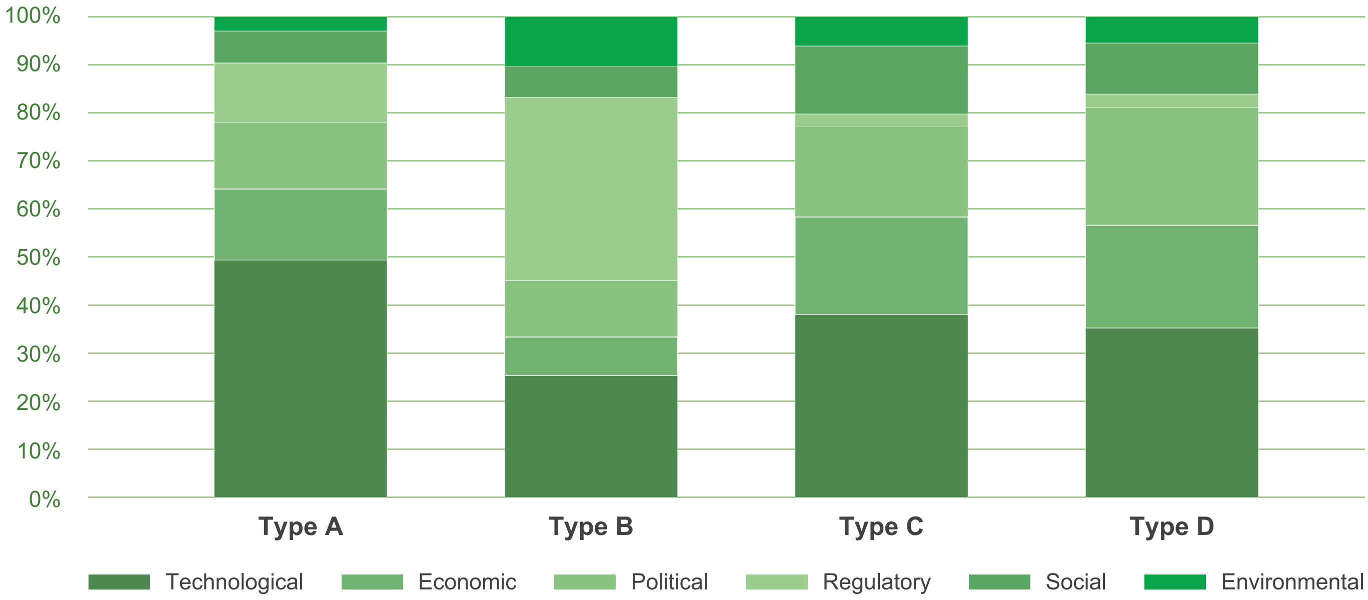


Figure 3. Regulatory and Non-regulatory Barriers in the Four Technology Readiness Levels

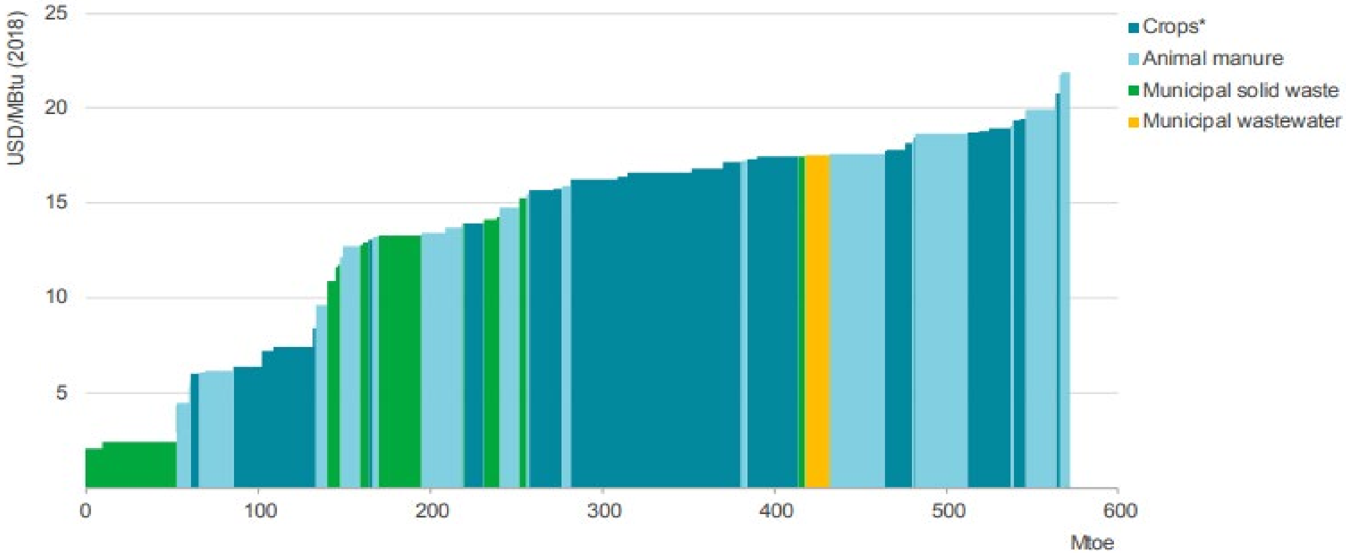
3.1. Technological Issues

Feedstock plays a crucial role in biogas quality as a renewable energy source (Zhu, Curtis and Clancy, 2019). Given the abundant availability of feedstock, there is enormous potential for biogas to utilise MSW, agricultural residues and animal manure (ASEAN Centre for Energy, 2020; International Renewable Energy Agency, 2022).

In some Southeast Asian countries, agricultural waste (e.g., animal manure and crop residues) is the primary feedstock used for biogas in the electricity sector (Figure 4 and Figure 5). Crops, MSW, and wastewater are other potential biogas feedstock resources. Most ASEAN countries have at least one potential feedstock available for biogas-to-electricity (Ahmed *et al.*, 2017; Jain, 2019; Rianawati *et al.*, 2021).

Agricultural land covers 62.3 million hectares of land in Indonesia, making up approximately one-third of Indonesia's land surface area. About 82 percent consists of cropland, including temporary and permanent crop cultivation (Food and Agriculture Organization, 2022). Given the broad scale of cropland, agricultural waste could serve as feedstock for large-scale biogas plants (Sardiana, 2021).

The IEA (2019) estimated that Southeast Asia produced 35 million tonnes of oil equivalent (Mtoe) of biogas in 2018, meeting over 25 percent of the region's natural gas demand. By 2040, this figure may rise to 55 Mtoe, with roughly 40 percent coming from crop residues, 30 percent from urban solid waste, and 25 percent from animal manure. The supply of potential biogas feedstock continues to grow, and the cost trend is declining, implying further opportunities for biogas development (Figure 4 and Figure 5).



* *Crops* includes only crop residues and sequential crops (not dedicated energy crops).
Notes: The curve integrates technology and feedstock costs. Technology costs include the biodigester only, i.e. excluding any costs for equipment to transform biogas into power and heat. 1 MBtu = 0.29 MWh.

Figure 4. Biogas Feedstock Costs in ASEAN in 2018 (International Energy Agency, 2019)

Crops includes crop residues only, energy crops are excluded given concerns about sustainability.
Note: MBtu = million British thermal units; Mtoe = million tonnes of oil equivalent; MSW = municipal solid waste

Figure 5. Projected Feedstock Costs (in USD) for Biogas-to-Electricity in ASEAN in 2018 and 2040 (International Energy Agency, 2019)

3.1.1. Technological Knowledge

Most technological issues were encountered at the institutional level, followed by the project and policy levels and indicated an array of needs and barriers. Based on the desktop research and analysis of biogas-to-electricity technology and development, we found that Type C or the development stage with pilot projects was most representative of the majority of AMS in terms of technological knowledge. This indicates an urgency in resolving the barriers to current biogas deployment.

Barriers regarding civil society and government capacity were primarily encountered at the institutional level, with 17 issues identified. The primary implementation barriers identified in Cambodia, Indonesia, the Philippines, Thailand, and Vietnam included a limited understanding of biogas digester maintenance and a lack of both technical assistance and equipment supply. Brunei Darussalam is more focused on energy efficiency and low-energy intensive industries rather than renewables, while the Philippines is prioritising other energy options, such as fuelwood, liquefied petroleum gas (LPG), and grid electricity, due to their wide availability compared to biogas feedstocks.

In Thailand, technological issues are derived from a lack of bioenergy supply chains and an absence of equipment standards, which is typical in countries importing technology. It is difficult for power developers to procure technology without a performance guarantee. Therefore, knowledge and manufacturing capacity are essential to promote biogas production and utilisation, which need to be endorsed through energy policies.

Despite the limited understanding of biogas technology at the institutional level, the desktop research showed that several countries have implemented biogas technology at the project level. In Indonesia, utilising the methane produced from palm oil mill effluent (POME) is an excellent way for palm oil mills to reduce environmental impact and generate electricity. However, only 10 percent of approximately 640 palm oil mills in Indonesia are treating their POME using biogas technology.

3.1.2. Technology to Utilise Untapped Feedstocks

In 2015, Thailand's Department of Alternative Energy Development and Efficiency (DEDE) estimated that Thailand's biogas potential was approximately 4,651 MW. However, the vast majority of biogas is generated from energy crops only (4,186 MW). Malaysia is demonstrating biogas-to-electricity deployment on a commercial scale. More than 50 percent of its palm oil mills are using anaerobic technology followed by aerobic treatment (i.e., fermentation). In Myanmar, biogas electricity constitutes about 17 percent of the electricity mix. Due to its geographical constraints, Brunei Darussalam has strived to increase its landfill biogas projects. Table 5 summarises the literature review results of the feedstock availability identified in each ASEAN country. The available feedstocks in AMS vary from manure, agricultural waste, MSW, and wastewater.

Table 4. Literature Review Results on Potential Feedstocks for Biogas-to-Electricity in the ASEAN Member States

Country	Type of Feedstock			
	Manure	Agricultural Waste	Municipal Solid Waste	Wastewater
Brunei Darussalam	✗	✗	✗	✗
Cambodia	✓	✓	✓	✓

Country	Type of Feedstock			
	Manure	Agricultural Waste	Municipal Solid Waste	Wastewater
Indonesia	✓	✓	✓	✓
Lao PDR	✓	✓	✓	✓
Malaysia	✓	✓	✓	✓
Myanmar	✓	✓	✓	✓
The Philippines	✓	✓	✓	✓
Singapore	✗	✗	✓	✓
Thailand	✓	✓	✓	✓
Vietnam	✓	✓	✓	✗

Several countries (Indonesia, Malaysia, and Vietnam) highlighted the short supply and poor quality of their feedstocks. Inadequate availability of biodegradable feedstock in some countries may be due to infrastructural challenges (Bong *et al*., 2017). In Singapore, the lack of available biodegradable waste contributes to the infeasibility of biogas-to-electricity projects (Nevzorova and Kutcherov, 2019).

Singapore is researching alternative feedstock potential from co-digestion of food waste and used water sludge, scheduled to be completed in 2025. Furthermore, a pilot project from this research has been commissioned to explore feedstock potential on a larger scale. The project involves collecting food waste from various premises, which is transported to an off-site facility for treatment and conversion to biogas. Singapore's Public Utilities Board and National Environment Agency (NEA) will collaborate on this project located at the upcoming Tuas Nexus water and waste treatment plant. The research undertaken in Singapore highlights the need to assess the availability of each feedstock type so that biogas-to-electricity production can meet large-scale demand (Sheng, 2021).

In addition to power generation, biogas applications are often used for cooking and heating. Biogas is also beneficial for land-based mitigation, increasing soil nutrients through the bio-slurry by-product (Lal, 2003; Sardiana, 2021; Wankhede *et al*., 2021). Biogas systems differ vastly in terms of location, potential resources, usage, and cost structure, in line with a country's development. The wide availability of agricultural waste in East and Southeast Asia has driven the expansion of large-scale biogas plantations (Food and Agriculture Organization, 2015). However, in terms of carbon cost, waste-to-biogas emits a higher carbon footprint than waste management, energy production, and agricultural practices (Noordwijk, Khasanah and Dewi, 2017; Farooq, Rehman and Pisante, 2019).

Technological barriers to implementing biogas were not identified in Indonesia and Myanmar. If these countries can resolve other barriers, such as improving regulatory issues through attractive financial schemes and robust policy in addition to maintaining a sustainable feedstock supply chain, they could enter the commercialisation stage (Type A). Therefore, it is conceivable that Indonesia and Myanmar, along with Malaysia and Thailand, could rapidly scale up biogas production to meet their respective national bioenergy targets.

3.2. Economic Issues

Biogas facility design varies and is contingent upon geographical location, feedstock availability, and climatic circumstances. A biogas power facility needs a continuous and dependable feedstock supply throughout the duration of the project. Using a wide variety of organic waste as feedstock further guarantees a sustainable supply. If agricultural biomass is utilised, biogas developers need to account for the supply volume fluctuations in crop harvest seasons throughout the year. Different feedstock management techniques (e.g., storage and pre-processing) are required in the supply chain to maintain the quality of the biogas feedstock, depending on the feedstock type. Hence, project developers need reliable data on feedstocks to estimate future stocks of local biomass supply.

It is essential that developers know the biomass types, supply capacity, and feedstock quality. The logistics of biomass feedstock supply must also be considered (e.g., mode of transportation, duration, and frequency). If a feedstock supply chain process is shorter and more efficient, costs will also be lower. For example, off-grid biogas power plants in palm oil plantations have a low-cost feedstock structure.

3.2.1. High Upfront Investment Costs

The Type C (development) stage with pilot projects was most representative of the economic issues in the AMS. Appendix I highlights the economic needs and barriers found at the institutional level. Financial considerations play a significant role in energy source selection. Most findings at the institutional level (in Cambodia, Indonesia, Malaysia, Myanmar, and Vietnam) demonstrated high investment costs of a typical biogas installation.

Many AMS (Cambodia, Indonesia, Malaysia, Myanmar, the Philippines, and Vietnam) lack the upfront funding needed to build biogas plants. Some ASEAN countries like Indonesia, Malaysia, the Philippines, Thailand, and Singapore have introduced various economic incentives for renewable-generated electricity, such as feed-in-tariffs (FITs) and green bonds. However, dedicated funding for biogas technology, more accessible soft loans, and tax incentives are crucial in driving biogas deployment. Additionally, awareness needs to be raised on the economic benefits of biogas (saving on utility costs).

In contrast, Brunei Darussalam has no clear renewable energy FIT scheme policy. However, the government intends to implement FIT and net metering policy in the future to stimulate renewable energy investment and is considering issuing renewable energy certificates for renewable-generated electricity by the end of 2022. One REC will be equivalent to one megawatt hour of renewable energy power generation, with a planned price of 0.25 Brunei dollars per kWh or 250 Brunei dollars per REC. Another possible incentive that the government could consider is eliminating charges or reducing fees for using power from off-grid biogas power plants.

Despite the aforementioned planned policy incentives, substantial initial capital is still required, with bank loans being the most viable option. Findings showed that although loans for the biogas industry are offered, they are not available at the project level. Banks in Lao PDR have not issued any specific policies aside from short-term loans for sustainable energy-related businesses. One example is the Agricultural Promotion Bank, which has backed various biogas and biofuel projects. These loans have assisted in lowering product costs, which is critical in affecting consumer decisions and project implementation (Nevzorova and Kutcherov, 2019).

3.2.2. Gaps in Policies and Actual Incentive Needs

Biogas electricity cannot compete with other renewable energy sources without financial support mechanisms in Vietnam. Similarly, in Indonesia, coal-fired electricity is heavily subsidised, thus reducing the competitiveness of renewable energy. In Cambodia, household-level biogas plants are still too expensive for low-income families, preventing access to communities most in need.

In Thailand, the government has rolled out several subsidy schemes to encourage more biogas installations. Subsidies have been provided by Energy Conservation Fund under the voluntary sub-program of the Energy Policy and Planning Office (EPPO) since 1995. Start-up projects, defined as projects that provide financial support of approximately 33 percent of the total investment cost to farm owners, are eligible for these subsidies.

Additionally, Thailand has provided other funding support under the Energy Conservation Fund. It has committed 961 million baht to subsidise pig farm biogas projects. These projects have a total capacity of 326,000 m3 of biogas, equivalent to manure intake of 2.3 million heads of pigs. With 10 million heads available nationally, Thailand has enormous potential to increase biogas installed capacity and replicate projects with other livestock.

On a larger scale, Thailand initiated a 30 percent subsidy for biogas design and construction in industrial plants in early 2022, whereby nine cassava starch factories were subsidised.

In 2005, the Board of Investment under the Ministry of Industry began to offer more attractive incentives to business enterprises producing biogas from waste. The incentives include import duty exemptions on machinery and energy-efficient equipment as well as a corporate income tax exemption for up to eight years without any financial limit. In 2008, EPPO promoted biogas for industrial factories by subsidising design consultants and investment costs.

In Malaysia, due to the cap on the Renewable Energy Fund, the overall FIT quota granted to prospective biogas applicants in 2017 was insufficient to meet existing demand. The Renewable Energy Fund is funded by a 1.6 percent fee added to the power bills of all consumers (excluding those in Sarawak) who meet the minimum use threshold. Malaysia’s government is now transitioning to an e-bidding system for biogas FIT, ensuring a more competitive market and attracting more biogas projects.

In 2009, the Indonesian Ministry of Energy and Mineral Resources issued flexible FIT-based pricing regimes for biomass (less than 10 MW), biogas, and waste-to-energy power plants. The FITs for biomass and biogas were later revised in 2014 with higher tariffs offered to encourage more renewable energy developments, including biogas. However, few projects have succeeded as the issue of unknown availability of feedstock at the outset was not resolved.

3.2.3. Market Accessibility

The lack of biogas market accessibility significantly affects the agriculture and electricity sectors (Khairul Alam *et al.*, 2020). Therefore, establishing national-level policies and incentives to accelerate the electrification rate and ensure sustainable energy usage is pivotal to market accessibility. Malaysia’s renewable energy policies, however, are an exemplary example of energy policy. Although other AMS exhibit many opportunities typical of Types A (commercial) and B (niche market) readiness levels, uncertainty around other issues, such as financial schemes and feedstock supply chains, further compound the economic issues. As Types A and B are considered as the deployment stage, there are fewer implementation barriers to be addressed and resolved.

3.3. Political and Regulatory Issues

Political decisions significantly impact biogas uptake. Much of the support for biogas production comes from policy decisions, and policymakers largely determine the strategic direction of sustainable development (Nevzorova and Kutcherov, 2019). Appendix I outlines the political needs and barriers identified.

Several countries, such as Cambodia, the Philippines, and Vietnam are encountering barriers to biogas deployment at the institutional level due to a lack of government support for biogas. Several government sub-offices in Thailand have moved forward in facilitating biogas-to-electricity deployment to boost biogas development. However, this has not been without issues.

3.3.1. Overlapping Governing Agencies

In the case of Thailand, two different offices, EPPO and DEDE, govern energy, which may lead to future conflicts, such as overlapping policies or initiatives. Similar problems were observed in other AMS, where multiple energy agencies with differing roles, functions, and responsibilities are often not aligned. The agencies are working under several different ministries, thus further complicating coordination procedures.

Convoluted governance often leads to unstandardised contracts, as evident in some AMS. For example, coordination between the Indonesian Ministry of Energy and Mineral Resources and the private sector lacks synergy. This is reflected in inconsistencies in biogas programs. A similar need was observed in the Philippines and Vietnam, where the gap between official biogas targets and actual biogas deployment is substantial.

3.3.2. Undefined Biogas-Specific Targets and Policies

Improvements could be made by diversifying policies to cover all energy source types and scales of power production. For instance, general renewable energy targets that do not detail each contribution are detrimental to the development of unpopular renewable energy sources and technologies. Financial policy should accommodate smaller-scale and higher-cost biomass sources as biogas feedstock to ensure biogas cost structures are more competitive.

Almost all AMS have set specific biogas targets to diversify energy source utilisation. For example, in Malaysia, biogas applications were first initiated under the palm oil National Key Economic Area of the Economic Transformation Program in 2010. The National Key Economic Area Biogas Working Group, led by the Minister of Plantation Industries and Commodities and facilitated by the Performance Management and Delivery and the Prime Minister's Office, regularly monitor biogas progress.

In Indonesia, the government has set a 23 percent renewable energy utilisation target in the national energy mix by 2025. Biogas utilisation constitutes part of the bioenergy-based renewable energy development stipulated in the National Energy General Plan (RUEN). However, current biogas utilisation remains far below the RUEN's 2025 target. For example, in the electricity sector, biogas power plants (PLTBg) are targeted to reach a capacity of 5.5 gigawatts (GW) by 2025 but have only generated approximately 1.33 percent of this target. Clearly, biogas development requires considerably more than policy emphasis that only addresses economic and financial aspects.

The Thailand government developed the Alternative Energy Development Plan (2012-2021) to boost alternative energy usage to 25 percent of total energy consumption and reduce reliance on imported energy. It aspired to generate 600 MW of electricity and 1,000 kilotonnes of oil equivalent combined heat from biogas by 2021. Similarly, Lao PDR has also set specific heating targets for biomass, biogas and solar within its broader renewable energy targets.

In contrast, Singapore and Cambodia have not included biogas-to-electricity in their strategy to meet their renewable targets. Singapore's Zero-Carbon Stimulus Package includes expanding the ASEAN Power Grid to enable AMS and other regional neighbours to purchase up to 4 GW of power by 2035. In terms of carbon emissions, Singapore aims to reduce greenhouse gas (GHG) emissions by half of their peak by 2030 to 33 million tonnes of carbon dioxide equivalent by 2050. After 2050, it aspires to achieve net-zero emissions as part of its Long-Term Low-Emissions Development Strategy. In line with the Research, Innovation, and Enterprise 2025 Plan, Singapore will invest in research and development of renewables; low-carbon technologies; novel carbon capture, utilisation, and storage technologies; nature-based solutions; and multifunctional greenery.

The Cambodian government has continuously expanded electricity access, reflected in its 81.6 percent electrification rate in 2020. Cambodia initiated the following strategies to provide nationwide access: (i) grid extensions, (ii) obtaining cross-border power supplies from neighbouring countries, (iii) rehabilitating existing isolated grid systems in provincial towns, (iv) creating new remote grid systems, and (v) rural electrification using sources such as solar, micro-and mini-hydro, wind power, biomass, and biogas.

As the only AMS with a minor renewable energy share, Brunei Darussalam has put some effort into establishing a regulatory framework to facilitate renewable energy development. According to the Brunei Energy White Paper, the country plans to have 10 percent or 954 gigawatt hours (GWh) of its electricity consumption from renewable energy by 2035. This document has set the ground for renewable energy policy; however, other strategies or plans (aside from the White Paper) supporting the target are yet to be established.

3.3.3. Unclear Legal Frameworks

ASEAN countries have consistently received high ratings for their legal, institutional, and administrative frameworks. Countries with weaker enabling frameworks have attracted less investment in renewable energy, although rising electricity demand in some countries could result in sizable markets. Unclear legal and regulatory frameworks and weak FIT pricing are significant barriers (International Renewable Energy Agency, 2018). This was observed in Vietnam and in Myanmar, where the problem is further exacerbated by the minimum technical know-how of government officials and grassroots communities.

In contrast, Thailand has showcased substantial biogas production in the starch and palm oil industries due largely to its technology development aligned policy. Sound environmental legislation, adequate monetary funds and numerous privileges have been essential factors that are driving companies to invest in biogas power generation. Due to financial incentives, the initial construction costs of biogas systems have been reduced by 20-30 percent. Accommodating small electricity producers to sell directly to the grid has also contributed to the success of projects.

Overall, the policy and regulatory aspects of biogas have improved slightly; however, some mechanisms, such as FITs, have been premature. No standardisation across the ASEAN region has also discouraged investors, which inevitably impacts the technological and economic aspects of biogas development. The lack of standardised monitoring and reporting of biogas development was also noted as a primary barrier. To date, ASEAN does not have a monitoring, reporting, and verification methodology or mechanism, although some AMS have developed their own national level mechanisms. Predictably, most current policy and regulatory frameworks across AMS are still at the development and early research stages, typical of Types C and D.

The study's in-depth analysis indicated the possibility of low-level readiness AMS types elevating to a higher level type. For example, despite Indonesia's multitude of palm oil commodities and ambitious renewable energy targets, surprisingly, biogas-to-electricity deployment remains low. Indonesia could clearly progress to Type A, the commercial stage; however, policy and regulatory adjustments are essential to facilitate this process.

3.4. Social and Environmental Issues

Both small-scale and large-scale biogas-to-electricity initiatives often overlook the social and environmental issues at the project development stage (Dyah and Sriharti, 2019), as indicated in Appendix I. In Indonesia, there is a reluctancy to collect cow manure on a daily basis due to the long distances between biogas plants and livestock. Additionally, a low level of awareness of the potential of biogas to reduce emissions and decarbonise the energy system was evident in Brunei Darussalam.

In Cambodia, the social assessment at the institutional level in Appendix II showed that many households and the National Biodigester Programme (NBP) staff indicated that labour migration, reduced livestock numbers, and electrification are factors undermining farmers with household biogas facilities. Biodigester construction agents who perform warranty and maintenance work confirmed these findings and noted that some biodigesters are abandoned as families sell their livestock or leave the village and not because the technology failed. In conducting 62 semi-structured interviews with biodigester users and NBP employees, funders, and other key stakeholders, across ten of fourteen provinces nationally, 352 biodigesters were recorded as abandoned since 2007.

In Cambodia, another report at the institutional level verified that the overall satisfaction rates of biogas projects reported in biodigester user surveys, independent verification reports, and independent research reports ranged from 94-98 percent, an exceptionally high level. The satisfaction rate is so high because biogas has been providing health benefits, such as reduced indoor particulate emissions, improved sanitation and agricultural productivity through digester bio-slurry usage and environmental benefits in reducing GHG emissions and wood consumption.

In Vietnam, poor manure management has become a major source of agricultural GHG. Current biogas uptake in Vietnam remains far below the actual demand for organic waste treatment. However, at the project level, demand has increased significantly.

The emergent social and environmental issues related to domestic biogas use remain largely unaddressed in large-scale biogas-to-electricity generation. Better integration of POME could capture methane and provide renewable energy sources. In addition, processing sewage and waste as biogas feedstock could resolve some severe social problems, such as unmanaged waste, unclean drainage systems, and flooding. However, these options have not been widely adopted in countries at the Type C (development) or Type D (early research) levels. Thus, further innovation is necessary. The need to utilise sewage and waste in Type C and D countries is becoming more pronounced. Managing and utilising the available waste as feedstock would facilitate Type C and D level nations to move towards commercialising into Type A or Type B. For example, maximising the utilisation of palm oil waste into biogas-to-electricity in Indonesia could generate early commercialisation markets (Type A).

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Indonesian APC Winner

04 Survey

4.1. Survey Method

The primary data are from an online survey, which aims to investigate the root causes of the capacity gap in biogas deployment in the ASEAN region, identify potential sectors for biogas-to-electricity deployment, and better understand biogas barriers. The survey contains three elements: (i) Scoping: to understand the current state of biogas technology; (ii) Institutional capacity assessment: to comprehend the roles and capacity of respective stakeholders to develop and institute biogas-to-electricity in ASEAN member states; and (iii) Visioning: to capture respondents perspectives on future biogas-to-electricity deployment in ASEAN member states.

The survey provided open-ended questions to allow respondents to further elaborate and provide up-to-date and country-specific data based on five assessment categories: technical knowledge (feedstock, technology), political barriers (policy, regulations), economics and financial issues, and social and environmental issues (such as land acquisition and feedstock ownership).

The survey was distributed to 66 energy and biogas stakeholders from various backgrounds in the ASEAN region. They are scholars and experts in the field, and all have roles in biogas development either in governmental agencies, as private financiers, or in NGOs, research institutions, or universities. The 66 respondents critically examined sectoral barriers and explored promising options and strategies in each AMS. They provided perspectives on biogas-to-electricity deployment across AMS and relevant regulatory and non-regulatory issues.

4.2. Survey Results

4.2.1. Technological Issues

In terms of feedstock accessibility and availability, the respondents highlighted the promising potential of agricultural residues (e.g., animal manure, crop residues) and MSW for biogas-to-electricity. Over 70 percent of respondents asserted that the agricultural and forestry sectors are the most prominent biogas users (Figure 6). Subsequently, several respondents identified the manufacturing and household sectors as the second and third alternatives for biogas use.

The respondents identified anaerobic digestion as the most commonly used biogas technology for ASEAN (Figure 7), followed by landfill gas recovery and gasification technology. However, some respondents also referred to other technologies, including biomass boilers and fermentation.

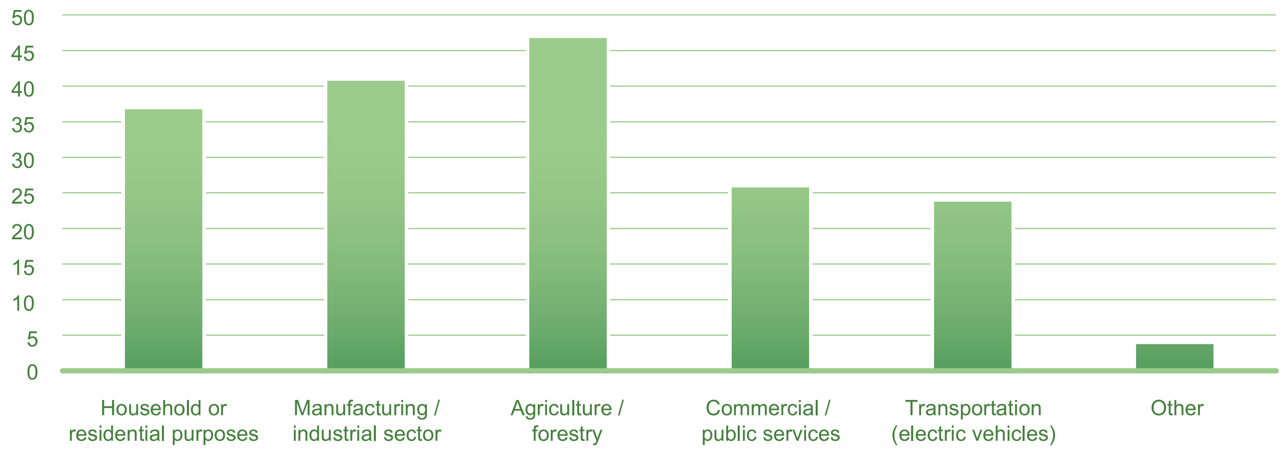

Figure 6. Survey Results: Potential Sectors for Biogas Use in the ASEAN Power Sector

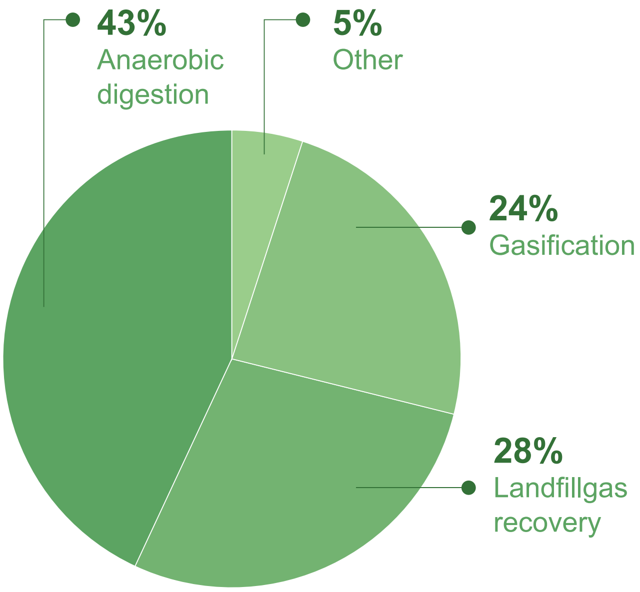

Figure 7. Survey Results: Common Biogas Technologies in the ASEAN Power Sector

In exploring capacity deficiencies in biogas development, the results indicated that there are several deficiencies in biogas technology deployment. This includes a lack of both technical knowledge and enabling political and regulatory frameworks. In terms of economic, social and environmental issues, the public's level of awareness remains low and livestock owners tend to be small-scale farmers who are unable to afford biogas technology.

Some respondents from Malaysia and Indonesia raised the issue of biogas technology readiness for electricity generation concerning the unavailability of desulphurisation and biogas purification and the inadequate transmission infrastructure in integrating biogas into the grid system. Furthermore, as biogas plants are frequently located far from energy demand, transmission grids are critical in remote areas.

The issues around technical knowledge are highly relevant to the public's lack of awareness and understanding of biogas technology, which inevitably leads to other problems like economic issues (refer to Section 4.2.2) and social and environmental issues (refer to Section 4.2.4). Many ASEAN countries, like Cambodia, Indonesia, the Philippines, and Vietnam, have limited knowledge of biogas technology. Key actors, such as social and financial institutions, namely banks and investors were reported to be lacking knowledge, which has culminated in stagnant development of biogas-to-electricity technology at the project level. Additionally, finding local experts to assess the technical feasibility of biogas-to-electricity is challenging in some South-East Asia countries, such as Thailand and Cambodia.

A range of reactions was elicited in response to the question, "What potential feedstock is available in your country?". Agricultural and MSW were identified as promising biogas feedstocks (Figure 8). One of the Indonesian respondents stated, "Based on the Bioenergy Directorate data, as of September 2021, there are 68 industrial-scale biogas power plants in Indonesia. Eighty-one percent of them are using POME feedstock (55 plants), 18 percent are using tapioca wastewater (12 plants), and 1 percent is utilising manure (one plant)". With over 850 palm oil plantations in operation across Indonesia and approximately 60 large-scale tapioca mills, Indonesia has immense untapped feedstock potential that needs to be explored.

One respondent argued that unstable feedstock availability (e.g., agricultural waste) is a significant barrier to large-scale biogas production; therefore, small-scale biogas-to-electricity is more viable in most ASEAN countries like the Philippines and Indonesia. However, a respondent claimed that the primary factor impeding small-scale biogas-to-electricity is that there is no culture of segregating household waste. Even though the survey results suggested that the agriculture sector is the most feasible option for biogas deployment (Figure 8), there are other potential barriers in this sector that must first be addressed, including feedstock availability technicalities.

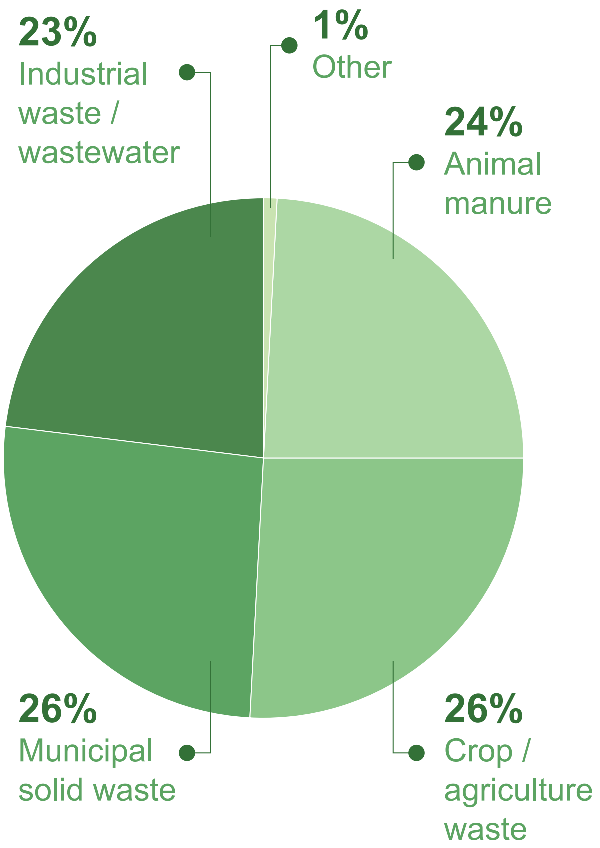

Figure 8. Potential Feedstock Available in ASEAN for Biogas-to-Electricity

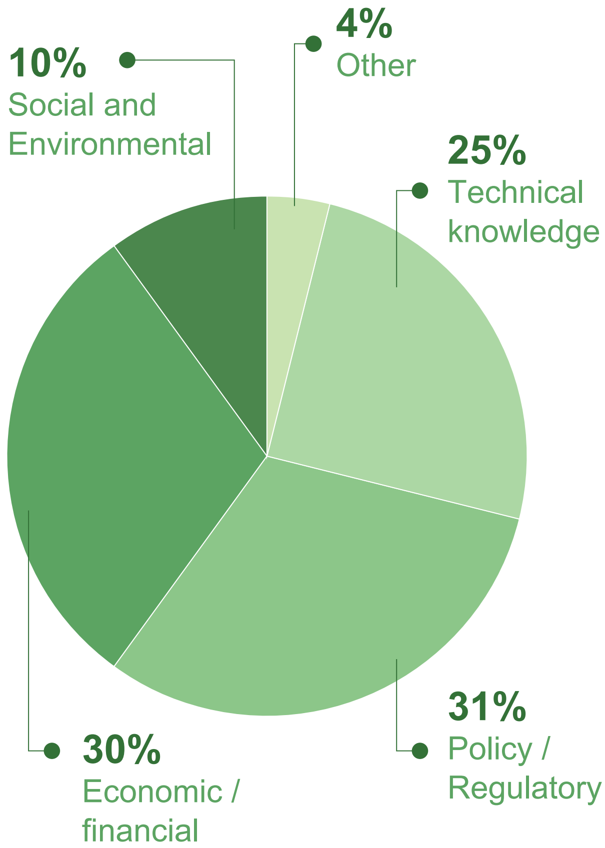

Figure 9. Survey Results: Capacity Deficiencies in Biogas Deployment in the ASEAN Region

The survey indicated the potential of utilising various biogas feedstocks. According to one of the Indonesian respondents, many countries can utilise methane gas from waste, sewage, and other agricultural residues. However, another Indonesian respondent elaborated that while feedstock availability is abundant in some areas, knowledge of how to correctly feed a biogas facility is limited, particularly at the household level, where most livestock is owned. Similarly to the agricultural sector, further technical assessment of household biogas-to-electricity is necessary to justify the technology's viability. The same respondent also pointed out the significant potential to generate power from POME. These results support the commercialisation potential of generating biogas power from the palm oil industry in countries categorised as Type A (commercial) like Malaysia.

4.2.2. Economic Issues

As shown in Figure 10, most respondents identified economic issues (47 percent) as barriers to biogas-to-electricity deployment. The majority of respondents suggested that the most plausible explanation is that coal and fossil fuels are subsidised, making biogas less competitive. A lack of supporting policies was also another factor identified. An Indonesian and a Thai respondent referred to the high investment costs and risks as well as low yield compared to fossil fuel power plants.

An Indonesian respondent highlighted that biogas-to-electricity technology is mostly imported, thus adding to the high capital investment, making it a less appealing investment. Limited technological knowledge was also recognised as contributing to biogas project risks. Consequently, local funding agencies, such as banks and investors are hesitant to provide financial aid in countries such as Cambodia, Indonesia, the Philippines, and Vietnam, which narrows the financing options for biogas development. In Cambodia and Thailand, biogas implementation is highly dependent on donor funding. Another respondent drew attention to the vague regulations that govern incentive schemes and taxation, further exacerbating financial issues. As a result, developers encounter difficulties in accessing incentives, and biogas-to-electricity plants are primarily limited to small-scale facilities.

Economic issues were the most apparent factors in the slow uptake of biogas development, as seen in Figure 10. Economic issues also indirectly pose a problem for political and regulatory aspects. If financial issues can be resolved, then there is potential for biogas development to move from the Type C and D stages to a deployment stage as either Type A or B.

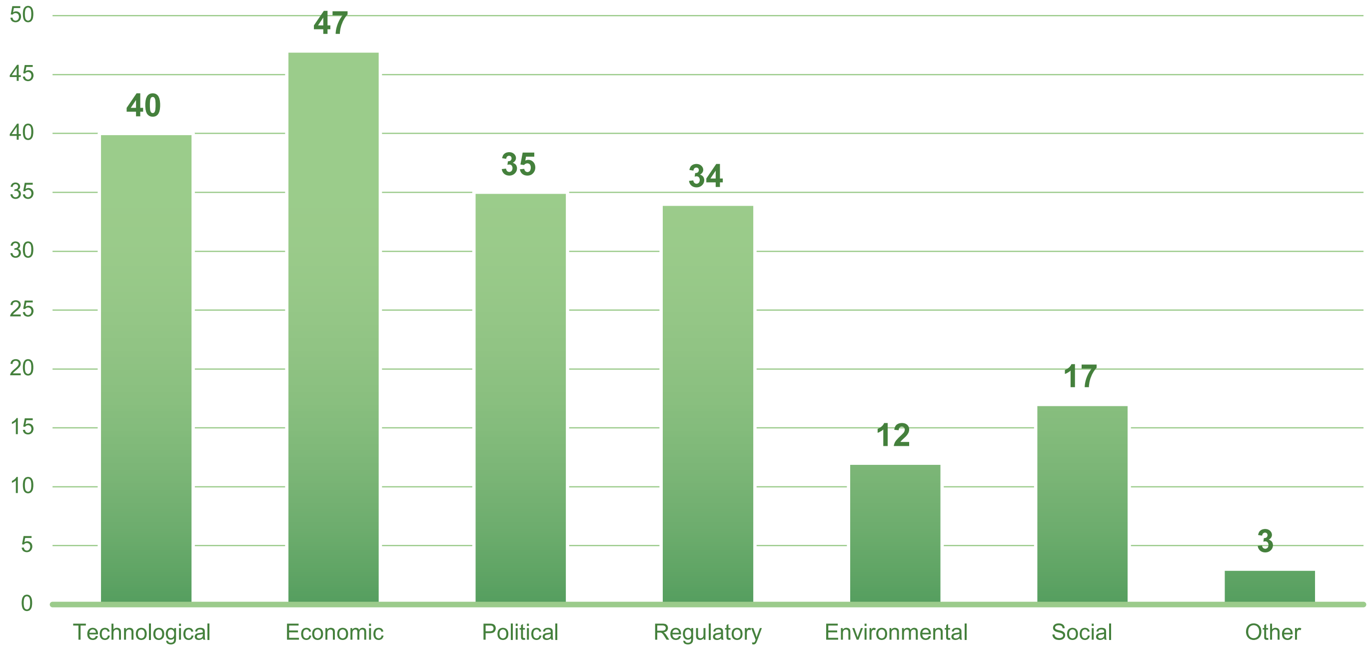

Figure 10. Survey Results: Prominent Barriers to Biogas Development in the ASEAN Power Sector Based on the Survey

4.2.3. Political and Regulatory Issues

According to the survey results, the political and regulatory issues are of comparable importance to the non-regulatory barriers (Figure 11). Respondents from Indonesia, Malaysia, and the Philippines highlighted how the lack of supportive policies and frameworks (e.g., the lack of economic incentives) impedes technology uptake and results in poor awareness of biogas technology (Figure 11). In the Philippines, the government and the private sector lack the political will to allocate budgets and initiate large-scale biogas facilities for electricity generation. According to some respondents, political commitment and enabling policies (e.g., economic incentives) that are critical to promoting biogas installation in most ASEAN countries are absent in countries such as Brunei Darussalam and Cambodia.

Nevertheless, opportunities for biogas development emerge when supportive policies are in place, as evident in Indonesia, Malaysia, the Philippines, Thailand, and Vietnam. The respondents' referred to policies, such as Thailand's Alternative Energy Development Plan 2015-2036 and Indonesia's National Energy Policy (KEN) as well designed high-level policies needed to set targets for biogas-to-electricity installation.

One respondent explained that although Philippine legislation promotes biogas development, the conflicting political interest of some local and even national leaders has slowed down the implementation process. Respondents from Brunei Darussalam, Malaysia, and the Philippines alluded to the lengthy bureaucratic process of obtaining permits for biogas development as the primary regulatory issue.

Ambiguous regulations were identified as problematic in several countries like Cambodia and Indonesia. For instance, a national budget that favours fossil fuels and overlapping governmental duties can thwart investment momentum in biogas development. The need for incentives was also mentioned, although this needs to be examined in more detail. Inconsistent implementation of regulations was seen as a barrier, which, if rectified through effective policy planning and enforcement, could facilitate biogas development, even in a niche market.

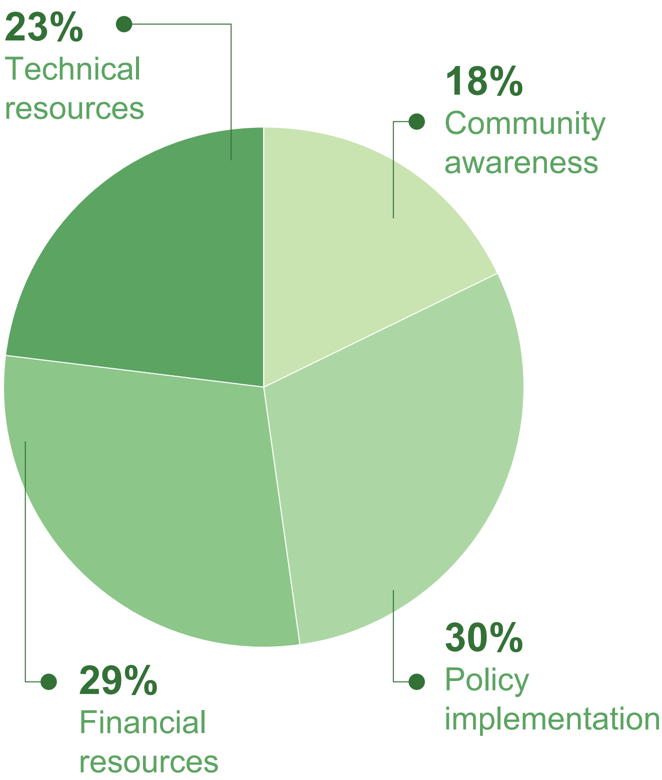

Figure 11. Survey Results: Resources Needed in Biogas-to-Electricity Development in ASEAN

4.2.4. Social and Environmental Issues

The survey respondents claimed that prominent biogas actors' lack of relevant technical knowledge and their low awareness of the co-benefits of biogas are critical issues. The pie chart above (Figure 11) shows that 18 percent of respondents agreed on the need for advocacy to raise community awareness. Some respondents claimed that poor awareness has led to misconceptions regarding biogas technology that impedes biogas deployment. Low social acceptance of biogas-to-electricity was also identified as a primary challenge.

The majority of respondents asserted that biogas actors need to be better informed on biogas technology and the benefits it provides, such as its vital role in resolving waste issues and supporting food and energy security. Some respondents stressed the importance of waste segregation and how it should be enforced to maximise available feedstock, particularly in regard to MSW and animal manure, which mostly contributes to existing small-scale biogas facilities. In Indonesia and the Philippines, for instance, feedstocks at the upstream level are mainly owned by individuals and typically not separated.

Some respondents raised the issue of constrained relations with key players such as government agencies (at national and local levels), academics, and financial institutions. This is problematic as engagement is deemed vital for knowledge acquisition and raising awareness.

Furthermore, several respondents from Thailand, Cambodia and the Philippines alleged that interest in biogas-to-electricity research is limited due to the fractured coordination and poor communication among key actors.

Compared to other non-regulatory aspects, the respondents generally perceived environmental issues as somewhat irrelevant to biogas adoption in the ASEAN region (Figure 9), although several respondents agreed that biogas technology does address environmental problems such as waste generation, deforestation, and climate change. One respondent suggested that mandatory biogas deployment would be a win-win solution for large agro-industry companies seeking to reduce their carbon footprint, while meeting their energy self-consumption needs.

Social and environmental issues pertaining to large-scale biogas-to-electricity were adequately discussed. Poor coordination and arbitrary information dissemination have led to low social acceptance, minimal research, and limited installation funding. Although further awareness of biogas's social and environmental co-benefits is clearly needed, respondents perceived biogas as the optimum solution for addressing environmental issues such as waste and climate change mitigation.

05 Focus Group Discussion

5.1. Focus Group Discussion Method

The FGD component of this study was conducted online with key biogas stakeholders across the AMS region to validate how they perceive and plan the biogas-to-electricity pathway. Overall, this activity aims to: 1) explore the barriers, risks, and opportunities of biogas-to-electricity in ASEAN; 2) identify the appropriate technologies and feedstock for biogas in the power sector of ASEAN; 3) understand the policy gaps to promote biogas development in the electricity system of ASEAN; and 4) validate the desktop research and the survey biogas development in ASEAN.

The FGD was divided into two sessions. The first session focused on identifying the barriers and opportunities according to regulatory and non-regulatory aspects for biogas development in ASEAN countries. The second session examined the feasibility of biogas-to-electricity technologies and feedstocks. One hundred and thirty-three participants attended the FGD session, representing all AMS. All participants have a background and expertise in biogas-to-electricity in either inter-governmental or governmental agencies, private entities, NGOs, financial institutions, or as researchers or academics. The FGD questions were provided on an online platform, and participants were divided into three rooms to share their insights on the three primary aims. All discussions were recorded to be used for further analysis.

5.2. Focus Group Discussion Results

5.2.1. Technological Issues

Feedstock accessibility and sustainability were raised as concerns among participants, and some participants referred to the competitiveness in accessing feedstock for other equally essential purposes (e.g., cooking fuel and transportation). The participant's concerns regarding sustainability were related to social issues affecting the stability of biogas power plant operations, such as inadequate feedstock collection or poor management. Small and medium-scale biogas power plants are operating in most ASEAN countries, except Brunei Darussalam and Singapore. The FGD participants highlighted the importance of planned large-scale biogas power plants feedstock not jeopardising environmental conservation and climate change mitigation efforts.

Most FGD participants agreed that anaerobic digestion technology has matured in Indonesia, Malaysia, the Philippines, and Thailand, as indicated by the small (<5 MW) and medium (<50 MW) capacity commercial-scale biogas-to-electricity plants in operation. Indonesia and Malaysia are using off-grid anaerobic digestion systems for generating electricity from agricultural residues (e.g., POME and tapioca waste), but only on a small and medium scale. Similarly, Thailand has successful biogas power plants producing 4 MW from poultry waste and wastewater.

On the other hand, biogas-to-electricity is still in its infancy in other countries like Lao PDR and the Philippines (restricted to a niche market). Singaporean participants tended to prioritise energy security and the practicality of the technology, indicating a lack of enthusiasm for promoting biogas technology. This view was a unique starting position for developing biogas-to-electricity. However, it was universally agreed that large-scale biogas-to-electricity is ripe for exploration in the ASEAN region.

The FGD called attention to the increasing trend of biogas development in the Philippines and Thailand. Initial biogas power generation was also observed in Lao PDR, albeit limited, indicating Type C readiness. In light of this, technologically speaking, ASEAN is not only at the development (Type C) and early research (Type D) stages but is moving towards the deployment stages of Types A and B.

5.2.2. Economic Issues

Many FGD participants perceived funding shortfalls as a region-wide constraint to biogas deployment. Biogas-to-electricity generation is not always competitive compared to other renewables such as solar and wind energy. Although small and medium-scale biogas power plants exist, large-scale operations are constrained by the limited availability of investment. Biogas technology needs to be competitive with more affordable and practical alternatives than fossil fuels and other renewables. One of the Philippines representatives highlighted that incentives to invest in large-scale biogas in the power sector are rare and pointed out the difficulty in competing with fossil fuels that have far more favourable subsidies.

In addition to limited incentives, scaling up biogas-to-electricity entails the same financial barriers, regardless of an operation's magnitude (small, medium or large-scale). However, large-scale biogas-to-electricity conversion (>50 MW) was deemed uneconomical due to the high investment and maintenance expenses compared to small and medium-scale operations.

Nevertheless, the development of biogas power plants remain promising. For instance, since the 1990s, Thailand's one-of-a-kind 4 MW biogas power plant has proved that constant and appropriate subsidies and incentives make biogas-to-electricity conversion practical. Thus, profit must not initially be the primary motivation for implementing such technologies. Additionally, participants claimed that a hybrid system (co-generation may be a viable alternative to encourage biogas-to-electricity conversion, given the continued importance of biogas technology in addressing sanitation and waste management challenges.

The FGD results showed that economic issues remain a crucial challenge for power generation concerning biogas. However, the results indicated that small-and medium-scale biogas projects are likely to be more viable. This could be a challenge for regions where the biogas-to-electricity conversion is at the research and development stage or the Type C and Type D levels.

5.2.3. Political and Regulatory Issues

As most ASEAN countries are developing, most governments are dealing with an array of challenges to alleviate poverty. Some participants indicated that there is a lack of political will to scale up biogas-to-electricity. Political instabilities are a considerable constraint to any development plan, including developing biogas for electricity generation. For instance, the uptake of biogas technology may be hindered due to a country's diverse districts when local political goals are in conflict with the national political interest.

A participant from the Philippines alluded to the misaligned geopolitical interests of local and national actors, which potentially affects biogas-to-electricity feedstock availability. Additionally, participants identified the limited knowledge of feedstock owners and managers as an issue that commonly results in unstable supply and hence is a risk to implementation. For instance, the price and quality of feedstock, such as MSW, fluctuates depending on the feedstock owners and managers. Another issue observed affecting feedstock availability was the use of land for plantations, which can clash with local spatial regulations.

According to the FGD participants, poor coordination among government agencies is rampant and complex, for example, in the Philippines and Thailand. One respondent claimed that mismanagement of wastewater in the industrial sector is rife, as there are no regulations prescribing wastewater usage as feedstock for biogas-to-electricity.

Political interests are associated with high-level regulatory directions. The FGD participants claimed that changes in governing regimes can cause uncertainty in the continuation of existing programs. Governing administrations also affect to what extent incentives will favour biogas development. Additionally, most ASEAN nations face political challenges as developing countries, leading them to focus on other development plans such as alleviating poverty and improving the economy. Thus, biogas-to-electricity development is not prioritised. As already exemplified, the FGD output did not explicitly confirm the need for more comprehensive policies on both waste and sewage beyond the local level or climate change mitigation.

5.2.4. Social and Environmental Issues

The FGD found that limited user (or community) awareness of biogas technologies was typical in most ASEAN countries, including Indonesia, Lao PDR, Malaysia, Myanmar, the Philippines, and Thailand. The lack of understanding and technical expertise, particularly for large-scale biogas technology, poses a higher risk of stagnant or failed technology implementation. The FGD participants stressed that raising awareness through community engagement is pivotal to improving biogas-to-electricity technology utilisation.

Further discussion on collective efforts, particularly involving the private sector and business entities with government support, is needed to scale up biogas deployment to a larger capacity (Nevzorova and Kutcherov, 2019).

Insufficient recognition of the environmental and social co-benefits of biogas-to-electricity was particularly apparent in the FGD. However, as technical challenges become more workable and economically competitive, a better understanding of biogas-to-electricity could illuminate the social and environmental benefits. Raising awareness on the considerable benefits of biogas would enable biogas-to-electricity to progress from the development (Type C) and early research (Type D) phases to the commercial (Type A) or niche market (Type B) stages.

06 Comparison of Three Sets of Findings

Table 6 below validates the findings from the desktop research by using the results and conclusions obtained during the FGD session and the online survey. Each point in the desktop research was compared to an equal point in the online survey and the FGD. N.A. stands for “not applicable” or “not available”. The table combines both political and regulatory issues and social and environmental issues. The complete list of all topics in the desktop research is presented in Appendixes I, II and III.

The table also displays the similarities between the online survey and the FGD results regarding feasible biogas technology options in the ASEAN region, with anaerobic digestion being the most practicable technology identified. Landfill gas recovery was the second option in the overall response in the survey. Surprisingly, several participants from Vietnam and Singapore supported the gasification technology despite the land availability and price issues in these countries, as this technology requires comparatively extensive areas of land. However, the readiness of landfill gas recovery in both Vietnam and Singapore is more advanced than other AMS.

The primary issue found regarding technology in Type C was a lack of understanding of biogas technology resulting in limited development of only small and medium-scale biogas power plants. A common theme across the desktop research, the survey and the FGD was the absence of utility-scale biogas deployment. In the survey, large-scale biogas facilities were deemed unfeasible in Indonesia due to the remote locations of manure feedstock supplies and the fact that livestock is mainly privately owned by small-scale farmers. The desktop research results were consistent with the FGD output on the limited availability of locally produced biogas equipment. FGD participants from Lao PDR, for example, emphasised the need to import equipment as the primary barrier to biogas development. In reference to Type D, the survey and the FGD results did not identify biogas maintenance or efficiency as significant issues. They did, however, validate other problematic issues, such as fluctuating feedstock supplies and the absence of policies on sewage treatment and harnessing available sewage and palm oil waste products for biogas. The results of all three assessment methods consistently highlighted common economic problems pertaining to the high upfront costs at the development readiness level or in Type C countries.

Although the desktop research showed that knowledge of utilising palm oil residues as a biogas feedstock is low, the survey results confirmed that 68 biogas plants are operating in Indonesia, with the majority using palm oil residues. The desktop research also indicated that biogas derived from MSW and livestock manure is not in demand or, in some cases, not yet known of. However, the FGD results identified significant potential for these feedstocks in biogas.

Finally, linking MSW and sewage treatment to biogas generation was not a major topic of discussion and biogas was rarely linked to mitigating climate change. This lack of awareness was consistent across all three sets of results. Raising awareness on these pertinent issues would enable countries at the Type C (development) and Type D (early research) biogas-to-electricity stages to move forward to commercialisation at the Type A and Type B levels. For example, awareness raising efforts together with robust policies on treating MSW and sewage would significantly increase the availability and utilisation of biogas feedstock, henceforth allowing capacity expansion and simultaneously driving down operational costs.

Table 5. Comparison of Findings on Types of Biogas Development in the ASEAN Member States

Topic	Type	Desktop Research	Online Survey	FGD
Technology	Type C (Development)	1) According to the desktop research and the FGD, a lack of understanding of biogas technology regarding maintaining digesters and providing technical assistance hinders further development of the biogas-to-electricity pathway for all ASEAN countries. In the online survey, it was agreed that enhanced technical support from governments and NGOs is crucial to bridge the technical gap at the country level, especially for the Philippines, Indonesia, and Cambodia;		
		2) Although biogas programmes for power generation do exist, the technologies used are yet to be applied on a larger scale. Based on the inputs in the FGD, most biogas technologies in the Philippines, Indonesia and Lao PDR are operating on a small scale. In the online survey, the Indonesia representatives explained the reason for small-scale biogas from manure is due to the livestock being in multiple locations and the fact that they are owned individually;		
		3) The ready availability of energy options;	3) N.A	3) N.A
		4) The desktop research showed insufficiency in terms of land and livestock requirements. The quality of the livestock was not up to expectation, impeding biogas-to-electricity development in the region. Furthermore, in the online survey, respondents also expressed their need for an up-to-date database for biogas (e.g., on price stability, competition, seasonality, and accessibility). Also, in the survey and the FGD, participants identified challenges in feedstock collection due to the absence of waste segregation at the household level and the multiple locations of feedstocks in individual households. In addition, the FGD results showed that Indonesia and Vietnam are rich in animal manure – a potential feedstock for biogas;		
		5) More attention is drawn to energy efficiency than renewable energy;	5) N.A	5) N.A
		6) Intensive maintenance and the short life span of the floating drum;	6) N.A	6) N.A
		7) Biogas is only used for cooking and coal distillation;	7) N.A	7) N.A
		8) Biogas technologies are mostly imported from other countries (e.g., China and the European Union), resulting in high investment costs. According to the desktop research, there are no testing and quality control regulations for imported biogas technologies.		
	Type D (Early Research)	1) Only one household connected to the grid using biogas indicated further development of biogas;	1) N.A	1) Municipal solid waste is a potential feedstock for biogas in Lao PDR, Indonesia, the Philippines, and Singapore;
		2) The potential of energy crops from Thailand is 4,168 MW, with only 500 MW of undeveloped potential;	2) N.A	2) Crop residues, municipal solid waste and animal manure are potential feedstocks for biogas;
		3) The potential of POME as feedstock for electricity generation from biogas is high, especially in Indonesia and Malaysia. In Indonesia, 81 percent of biogas plants installed are using POME (in 55 plants) as feedstock;		

Technology	Type D (Early Research)	4) Potential in livestock manure, food waste, and MSW to produce biogas, but currently, large-scale projects only focus on treating wastewater;	4) N.A	4) It is difficult for Lao PDR to transition to commercial electricity due to a lack of affordable finance mechanisms, high electricity costs, and infrastructure issues;
		5) The Long-Term Development Plan acknowledges that oil and gas resources will be insufficient to meet rising demand and population growth;	5) N.A	5) N.A
		6) The Geographic Information System can identify optimal locations for biogas;	6) N.A	6) N.A

Topic	Type	Desktop Research	Online Survey	FGD
Economy	Type C (Development)	1) High investment cost, particularly for maintenance and transmission, is the main economic barrier to biogas installation. Furthermore, the respondents in the online survey also pointed out the challenge of resolving this barrier due to the lack of both supporting incentives and available funding, as well as existing political issues;		
		2) The policy gap (e.g., tax incentives) also poses a challenge for the biogas-to-electricity pathway. Coal-fired power plants receive more subsidies, making them more affordable and lower risk compared to renewable energies;		
		3) Most biogas projects rely on external funding. In the FGD, the unavailability of funding was identified as a significant barrier to renewable energy uptake for all ASEAN countries;		
		4) The income generated from FITs is low compared to the core palm oil business;	4) N.A	4) N.A
		5) Limited financial support;		5) In Indonesia, private banks (i.e., Hong Leong Bank Berhad) have been financially supporting bioenergy;
		6) Renewable energy projects are generally perceived as high-risk non-bankable investments. High investment costs and the absence of supportive policies have limited access to affordable and reliable finance;		
	Type D (Early Research)	1) To make the market more competitive, the government is transitioning e-bidding for biogas FITs;	1) N.A	1) N.A
		2) Lack of funding for biogas technology (e.g., soft loans and tax incentives);	2) N.A	2) The policy gap (e.g., no tax incentives, etc.) was considered during the FGD;
		3) Carbon finance plays an important role in finance biogas development;	3) N.A	3) N.A
		4) Introduce FIT and net metering policy to encourage investment in renewable energies;	4) N.A	4) N.A
		5) Financial subsidy for pig farming biogas projects;	5) N.A	5) N.A

Topic	Type	Desktop Research	Online Survey	FGD
Political & Regulatory	Type C (Development)	**Political**		
		1) Lack of support and commitment from governments to be involved in biogas promotion. In the online survey, it was found that political dynamics have a tendency to disrupt technological development. Similarly, in the FGD, crucial barriers to biogas uptake from the stakeholders' perspectives were policy and lack of available funding;		
		2) Ambiguous renewable energy policies in terms of targets and frameworks hinder further biogas development. In the FGD, most experts agreed that the policy framework has not been enforced effectively enough. For example, based on the results from the online survey, although the Philippines government has passed a law (RA 11285) to promote renewable energy development, the implementation process appears to have slowed down. In Indonesia, the application of biogas systems is still under development and yet to be implemented, thus regulations are yet to be applied;		
		3) Policy should focus on technical training aside from just the financial aspect of biogas;	3) N.A	3) Communities are not prepared to adopt the biogas technology;
		4) Poor coordination among government agencies;	4) N.A	4) Political instability at the local and national levels is a major risk for any technological adoption in the Philippines;
		5) Lack of specific guiding regulations on biogas-to-electricity;	5) N.A	5) N.A
		6) A vast gap between government biogas targets and actual biogas uptake ;	6) N.A	6) N.A
		7) Although the biogas roadmap and renewable energy mix have been determined, there are enormous gaps in the implementation process. Based on the FGD, Malaysia and Indonesia, in particular, were considered to have significant potential for biogas-to-electricity from POME. However, although the PLTBg projects in Indonesia aspire to reach a capacity of 5.5 GW by 2025, only around 1.33 percent has been realised;		
		8) Based on the desktop research, concrete plans for biogas development in some countries have yet to be established, as some governments do not see renewable energy as a potential future investment;		8) N.A
		9) Cooperation between ministerial levels and local research institutions needs to be enhanced to create green technologies, with financial support for biogas energy from governments;	9) N.A	9) The policy gap (e.g., no tax incentive, etc.) was considered during the FGD;
		10) Brunei Darussalam has abundant gas and oil reserves, thus there is no urgent need to develop renewable energy;	10) N.A	10) Political risks in each region need to be considered as vastly different from political interests;
		Regulatory		
		10) Long bureaucratic processes and convoluted administrative procedures;	11) N.A	11) The risks and barriers associated with biogas are not only due to technology immaturity but also ambiguous regulations;

<table>
<tr><th>Topic</th><th>Type</th><th>Desktop Research</th><th>Online Survey</th><th>FGD</th></tr>
<tr><td rowspan="8">Political & Regulatory</td><td rowspan="8">Type D (Early Research)</td><td colspan="3">Political</td></tr>
<tr><td>1) The FIT has pathed the way in the right direction for Malaysia to become greener;</td><td>1) N.A</td><td>1) N.A</td></tr>
<tr><td colspan="3">2) Government plays a crucial role in expanding the biogas-to-electricity trend. Based on the online survey results, Cambodian representatives stated that incentives and government support are especially needed to promote biogas technology in Cambodia;</td></tr>
<tr><td>3) The government has ratified grant incentives for biogas projects;</td><td>3) N.A</td><td>3) Biogas technology used in the Philippines is old technology. A lack of incentives from the government in the past has been a constraint in developing better technologies;</td></tr>
<tr><td>4) Set a specific target for renewable energy using biogas;</td><td>4) N.A</td><td>4) N.A</td></tr>
<tr><td colspan="3">Regulatory</td></tr>
<tr><td>5) Regular series of interactive sessions between stakeholders involved and relevant authorities to deal with policy interventions;</td><td>5) N.A</td><td>5) N.A</td></tr>
</table>

<table>
<tr><th>Topic</th><th>Type</th><th>Desktop Research</th><th>Online Survey</th><th>FGD</th></tr>
<tr><td rowspan="7">Social & Environmental</td><td rowspan="7">Type C (Development)</td><td colspan="3">Social</td></tr>
<tr><td colspan="3">1) Local communities lack awareness on biogas technology and have limited accessibility to implement it. In the online survey, most experts stated that misconceptions around technology have also deterred biogas uptake. In the FGD, there was some concern around the capacity of the community (to access online information), and it was concluded that aside from low awareness, poor technology readiness also poses a risk for biogas energy uptake;</td></tr>
<tr><td>2) The unfamiliarity of POME to electricity using biogas technology;</td><td>2) Based on the Bioenergy Directorate data as of September 2021, there were 68 industrial-scale biogas power plants in Indonesia. In addition, 81 percent of installed biogas plants are using POME (55 plants) as the feedstock;</td><td>2) If feedstock is not economically viable for electricity generation, then it will be sold for other purposes (i.e., fertiliser);</td></tr>
<tr><td>3) Lack of ownership of biogas installations;</td><td>3) N.A</td><td>3) N.A</td></tr>
<tr><td>4) In Brunei Darussalam, as communities have already achieved 100 percent electrification from non-renewables, it is pointless to further pursue renewable energy development;</td><td>4) N.A</td><td>4) N.A</td></tr>
<tr><td colspan="2">5) Difficulty in feedstock collection. According to the online survey, feedstock collection is a major challenge in Indonesia, as there is no waste segregation of feedstock at the upstream level;</td><td>5) N.A</td></tr>
<tr><td colspan="2">6) Limited interest in pursuing biogas technology or approaches in some countries;</td><td>6) N.A</td></tr>
</table>

Topic	Type	Desktop Research	Online Survey	FGD
Social & Environmental	Type C (Development)	**Environmental**		
		7) Current biogas plant capacity is unable to meet the actual demand for organic waste treatment;	7) N.A	7) Crop residues, MSW, and animal manure are potential feedstocks for biogas;
		8) There is an increasingly pressing issue for mitigating climate change using POME;	8) N.A	8) A power plant should comply with the emission standards required by prevailing laws. However, to date, no emission standards have been regulated for biogas power plants;
		9) Hydrogen sulphide (H2S) leakage may lead to severe health problems;	9) N.A	9) A power plant should comply with the emission standards required by prevailing laws. However, to date, no emission standards have been regulated for biogas power plants;
	Type D (Early Research)	**Social**		
		10) Biogas initiatives can increase electrification rates and achieve energy resilience, especially in rural areas;		
		11) The success stories in biomass energy are important to boost the confidence of the private sector and local communities;	11) N.A	11) N.A
		Environmental		
		12) Current biogas plant capacity is not up to par with the actual demand for organic waste treatment	12) N.A	12) N.A
		13) There is an increasingly pressing issue to mitigate climate change using POME	13) N.A	13) Potential for biogas development is from POME
		14) $H^{2}S$ leakage may lead to severe health problems	14) N.A	14) N.A

07 Country Results and Recommendations

In conceptualising the biogas development pathway for each AMS, we classified technology readiness based on the needs-by-barriers framework to identify the biogas-to-electricity status in the AMS.

We deployed four stages of "Z-curved" technology readiness based on the four types of barriers and needs matrix (Ministry of Foreign Affairs of Netherlands, 2012; Nguyen *et al.*, 2017). The Type D or early research stage refers to technology concepts that are still being tested at a laboratory scale. Type C or development refers to technology prototypes or pilot projects that are operating at the small-scale level. Type B or the niche market refers to a stage in which the technology works in a particular isolated market. Type A or the commercial level refers to a technology that is proven qualified for large-scale operation and public purposes (Figure 12).

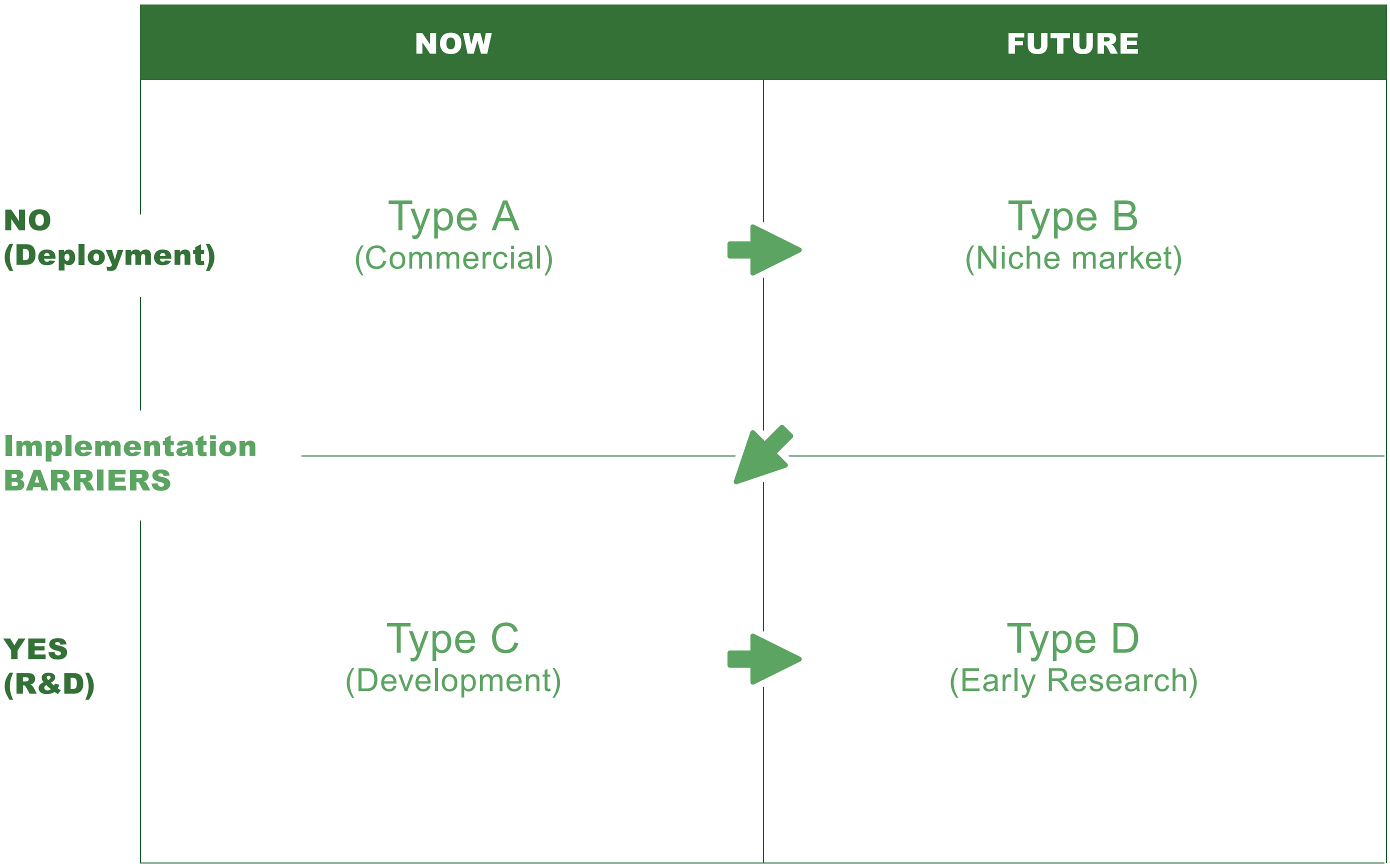

Figure 12. Technology Readiness Level Framework to Assess Biogas-to-Electricity Development in ASEAN (Adapted from Ministry of Foreign Affairs of Netherlands (2012) and Nguyen *et al.* (2017)

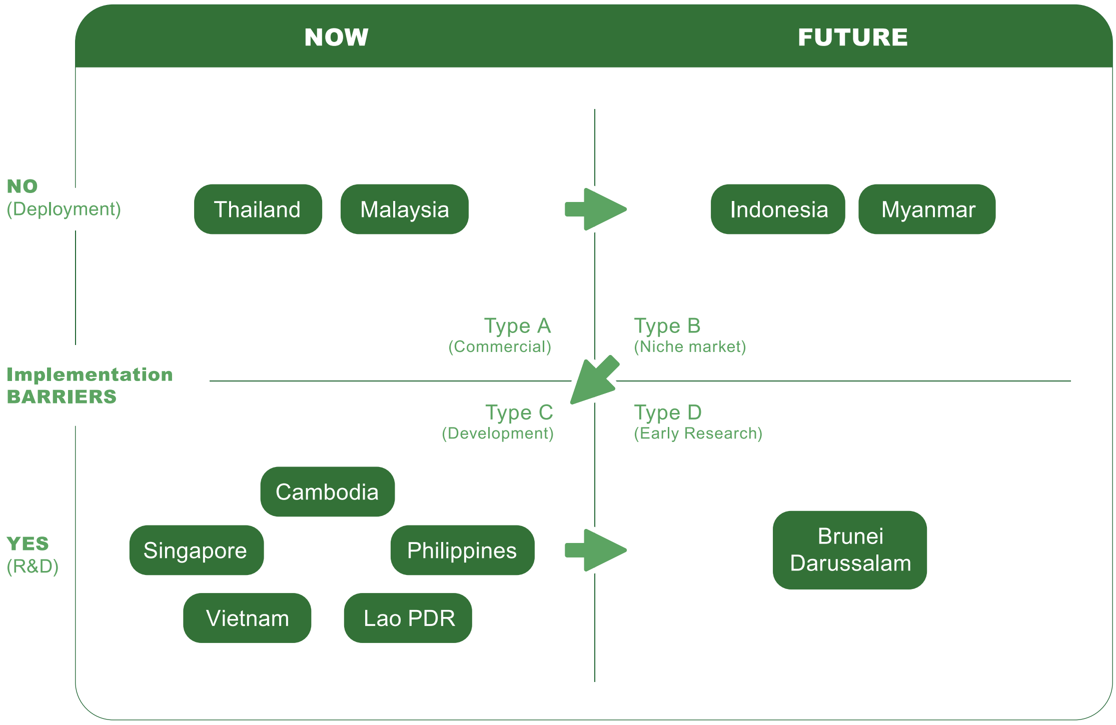

Figure 13. Technology Readiness Level of Biogas-to-Electricity in Each ASEAN Member State

Figure 13 highlights each AMS' current technology readiness, which showcases varying market stages. Starting from the Type D stage, Brunei Darussalam has begun to develop renewable energy resources that are currently feasible, such as waste-to-energy. By 2035, it is anticipated that these initiatives will enable the government to generate at least 10 percent of its electricity from renewable energy (Energy and Industry Department of Prime Minister's Office, 2016).

Many AMS such as Cambodia, Lao PDR, the Philippines, Singapore, and Vietnam are categorised in Type C. Several relevant small-scale biogas technology developments that could potentially lead to biogas-to-electricity were identified in these five countries. One example is the La Paz Pig Farm in the Philippines, which is a covered lagoon digester that generates 100 kW of energy (Trosgård, 2015).

In Cambodia, small-scale biogas initiatives, although successful, have been mostly at the pilot and demonstration stages (Poch, 2013). Furthermore, the NBP established an initial 20,000 biogas units by 2012 and another 20,000 are targeted for long-term adoption and widespread use of biogas for lighting (Hyman and Bailis, 2018).

In Lao PDR, the Ministry of Agriculture and Forestry tested a small family-sized biogas digester as part of a pilot project. It was able to generate 5x108 kWh of electricity using livestock manure to produce the biogas (Lao People's Democratic Republic, 2011).

Vietnam has a biogas power plant with a total installed capacity of 2 MW in Binh Doung province. Other facilities are designed to produce biogas to replace fuel oil for cooking (Dao, Yabar and Mizunoya, 2020). Singapore's National Water Agency and National Environment Agency investigated the feasibility of collecting and transporting source-segregated food waste from various locations to a demonstration facility for co-digestion with waste sludge for a two-year trial in December 2016. It will begin operations in 2025 (National Environment Agency, 2019).

Meanwhile, Indonesia and Myanmar are categorised in the Type B stage. In 2014, 544 MW total capacity of biomass (oil palm-based), biogas, and urban waste power plants were connected to the Indonesian State Electricity Company's grid in Indonesia. However, biogas consumption is still below the RUEN target for 2025 and the PLTBg's planned 5.5 GW capacity by 2025 is currently only at 1.33 percent of that capacity (Rianawati *et al*., 2021).

In Myanmar, solid biomass and biogas electricity account for around 17 percent of total electricity generation (World Wildlife Fund, Intelligent Energy Systems and Mekong Economics Ltd., 2016). In 2013, Myanmar's total installed biomass energy capacity was approximately 115 MW (Tun and Juchelková, 2019).

Lastly, Thailand and Malaysia have proven qualified in large-scale operations for biogas technology, hence both countries are considered to be Type A. Thailand's current biogas development has reached 563.18 MW, with a goal of 1,566 MW by 2037 (Aggarangsi *et al*., 2013). In Malaysia, FIT projects with a total installed capacity of 55.83 MW began commercial operations in 2017. Biogas generated 226 GWh in 2018, equivalent to 464 kilotons and drastically reduced CO2 emissions (Jain, 2019).

7.1. Issue-wise Results

Appendix I contains the needs of each AMS, which are classified as defined in Appendixes II and III, based on the regulatory and non-regulatory aspects of biogas uptake. Here, we only analyse the 'needs' of Types C (development) and D (early research) as governments and local private institutes are likely to provide technologies to resolve issues in Type A (commercial) and B (niche market) (see Appendixes I, II, and III). Recommendations regarding the priority needs of biogas-to-electricity in AMS across the critical challenges at the institutional, policy and project levels, along with examples of relevant cases, are discussed below.

7.1.1. Technological Issues

Biogas digester installations mostly showed varied results as users manage the digesters differently and use a variety of different feedstock sources. Mismanagement of organic waste will undoubtedly affect the results. In addition, construction materials need to be carefully selected as poor quality concrete or plastic materials, for example, affect the longevity of a plant (Hendroko *et al*., 2015; Vasco-Correa *et al*., 2018). Construction costs also depend on the materials used, but in Southeast Asia, these costs are generally stable and predictable as biogas technology has been operating longer than in other developing countries.

Locations, potential resources, utilisation, and cost structures affect biogas systems. Most AMS have at least one suitable biogas feedstock. Crop residues, animal manure, MSW, and wastewater are examples of feedstocks for power generation. Trends show that as biogas technology matures, deployment costs are decreasing, indicating greater biogas development viability.

The critical reason for delays in biogas-to-electricity deployment is primarily due to a lack of biodegradable feedstock availability in certain nations. Indonesia and Malaysia have palm oil residues as stable feedstock from the agriculture industry, but other countries do not have the same scale of potential inputs.

The survey results revealed that the AMS are striving to increase biogas production to meet their national bioenergy targets. Anaerobic digestion is the most commonly used biogas harvesting technology across Southeast Asia, followed by landfill gas recovery and gasification. According to some survey respondents, agricultural residues and MSW are also viable biogas feedstocks.

In Indonesia, POME is the main biogas feedstock source, followed by tapioca wastewater and then manure, which accounts for only one percent. Serious concerns were raised in the online survey regarding communities' lack of understanding and awareness of biogas technology. The FGD results also confirmed that anaerobic digestion technology has advanced in Indonesia, Malaysia, the Philippines, and Thailand. Some of the Indonesian experts in the FGD referred to the tremendous potential of palm oil industry residues for power production in Indonesia.

As AMS biogas-to-electricity facilities are predominantly small and medium scale, they are not generating significant amounts of electricity. The central issue identified in the development stage (Type C) was the lack of technological know-how.

7.1.2. Economic Issues

The desktop research identified the unavailability of financial aid as the AMS' central issue. Nations at the Type C readiness level demonstrated the most severe economic challenges, even though various financial incentives for renewables are available, including biogas-to-electricity. A typical biogas installation requires a substantial financial commitment. Only Thailand, in the Type A (commercial) category was found to have contributed significant investment to biogas development. Thailand has invested around USD 45 million in promoting biogas technology, specifically for pig farm biogas systems (Aggarangsi *et al*., 2013).

Some AMSs have issued policies incentivising renewable energy through FITs. For example, Brunei Darussalam, Malaysia, and Thailand plan to introduce FIT and net metering legislation. In the Type D (early research) category, Brunei Darussalam is anticipating awarding renewable energy certificates for renewable energy-generated electricity.

Economic issues varied in the Type C category. For example, banks in Lao PDR have offered limited short-term loans to promote the renewable energy sector (Sovacool, 2010). Also, the survey and the FGD results showed that biogas-to-electricity investment is less appealing due to the lack of incentives in Type C countries like Cambodia, Indonesia, and the Philippines.

Indonesia, Malaysia, the Philippines, Singapore, and Thailand have issued green bonds to diversify economic incentives for renewable energy projects. Although Indonesia issued green bonds later than Singapore and Malaysia, proportionally, it has now outpaced Singapore and Malaysia (Azhgaliyeva, Kapoor and Liu, 2020), indicating prospective opportunities for biogas technology despite the challenges. Energy price uncertainty and investment motivation, including recent energy security issues further complicate economic concerns. Despite the availability of technology, economic barriers consistently impede biogas development.

The survey and the FGD identified several economic issues that suggest some AMS are at the higher technology readiness levels of Types A and B. However, the development stage difficulties of Type C were clearly prevalent in most countries, primarily concerning the high upfront investment needed for biogas facilities. Biogas remains costly, particularly compared to fossil fuel-based power plants and other renewable energy technologies (solar, geothermal, and hydropower). Feedstock costs vary significantly based on the proportion of substrates used and the choice to source or purchase them. If the substrate is a by-product of another process or manufactured in-house, then the cost can be assumed to be almost nothing.

In contrast, the fuel price for conventional power generation (coal and gas) is largely determined by the worldwide market or contractual agreements between suppliers and power plant owners. For example, Indonesia has one of the lowest domestic coal prices globally, meaning coal generation is highly competitive. Depending on the country and market conditions, a CO2 tax or certificate may be added to the cost of fuel. While this is not the case in Indonesia, adding this carbon tax would increase the cost of fossil fuel power generation.

The average biogas levelised cost of energy is around USD 0.0804/kWh, higher than the average levelised cost of energy of hydropower, geothermal, utility-scale solar, and coal (Arinaldo and Pujantoro, 2019). If energy prices rise, the AMS could resolve this economic challenge if political incentives were better able to address environmental and social issues. For example, if incentives policy was inclusive of all environmental and economic aspects, such as support for investors and developers, co-benefits targets and feedstock management in biogas installation, then the financial scheme or economic challenge of biogas development would be sufficiently resolved. However, these issues remain unresolved at the Type C and D stages.

7.1.3. Political and Regulatory Issues

Policy choices influence political decisions to fund biogas and politicians are primarily responsible for determining the strategic path for long-term growth. Hence, clear coordination lines between government agencies are vital to align policy directions and priorities. Participants representing private companies from several ASEAN countries confirmed that the unclear and overlapping roles of institutions and agencies at different levels (i.e., national, regional and local) are problematic.

Energy development agencies in AMS are usually responsible for navigating the directions of energy development through regulatory instruments. Most ASEAN countries attempt to diversify their renewable energy supplies by enacting laws that cater to various energy sources and power generation sizes. However, discriminatory policy can hinder the development of specific energy technology. In some AMS, contract standardisation is problematic due to poor coordination. In Indonesia, for example, the ministry and the private sector require tighter collaboration if biogas programs are to improve.

The survey results indicated that although overall legislative and regulatory frameworks have improved, several pressing concerns remain. In particular, a lack of or unattractive FITs are preventing AMS from progressing to higher technology readiness levels.

For a more thorough analysis, respondents were asked probing questions on the most severe obstacles impeding biogas development in their respective nations. The most apparent cause was authority, explicitly relating to policy and regulations. Governmental agencies in some AMS, though, have attempted to help generate biogas markets, albeit niche markets, by eliminating hurdles and building momentum, which was evident in Cambodia and the Philippines. In general, the current biogas policy orientation remains commonly linked to other non-energy political goals. Overall, political instability hampers any growth strategy, including biogas-to-electricity development.

7.1.4. Social and Environmental Issues

Over 35 percent of the ASEAN population cooks and heats with traditional biomass, coal, or kerosene. Reduced indoor air pollution and improved health are among the primary goals of many countries' clean cooking programs. Biogas could be a reliable energy source for these rural areas. However, aside from a few countries with a strong institutional focus on access to clean cooking stoves, there are persistent challenges in bringing technologies, such as biogas and biomass cookstoves to rural regions (Asian Development Bank, United Nations Economic and Social Commission for Asia and the Pacific and REN21, 2019)

Although large-scale biogas-to-electricity development is often oblivious to some of the social and environmental co-benefits of biogas, biogas technology is actually still in its infancy in ASEAN. To date, there are only a few successful applications and biogas potential in some countries (Brunei Darussalam, Lao PDR, and Myanmar) is not as high as other renewable energy options. Both the desktop research and the FGD confirmed that AMS are aware of the environmental benefit of managing manure for biogas-to-electricity as a measure to significantly reduce agricultural-related greenhouse gas emissions. And the FGD participants considered environmental issues the least severe barrier to biogas growth in the ASEAN area.

Addressing sanitation issues and climate change mitigation were other environmental benefits of biogas identified in the survey, FGD, and the desktop research. The survey and FGD participants strongly linked biogas to the waste issue and climate change. Moreover, some survey respondents proposed using a carbon market to spur biogas development as part of climate change mitigation.

As smallholder farmers currently control most of the feedstock throughout the AMS, biogas production is mainly limited to the household scale and, therefore, not converted to electricity. Feedstock collection and management is problematic if not integrated into waste collection facilities. It is imperative that this issue is addressed.

In general, the study found that all AMS have not adequately acknowledged the environmental, social, and political difficulties associated with biogas-to-electricity. Resolving the existing social and environmental issues would potentially facilitate the current Type C and Type D countries at the development and early research stage to commercialise and upgrade to the Type A or Type B stages. And likewise, if countries could negotiate suitable and attractive FITs for biogas-to-electricity, they could potentially enter the deployment stages of Type A and Type B.

7.2. Good Practices Outside of ASEAN

Given the AMS' technology readiness, ASEAN has immense potential to upscale biogas production from household operations to an industrial level. Further opportunity is evident in the collaborative projects between ASEAN countries and other Asian, European, African, and North American nations that have expanded from business-to-business (B2B) to government-to-government (G2G) partnerships. For example, the Indonesian government has undertaken collaborative projects with the European Commission and the German government in the biogas sector.

Further collaborative projects would assist the AMS to eventually upscale biogas development to the Type A level through the technical know-how acquired from large-scale biogas production that is concentrated in Europe and the United States. For example, some current B2B and G2G biogas projects between ASEAN organisations and European or American institutions aim to improve the technology readiness of AMS' pilot biogas projects (REN21, 2018).

Based on studies conducted by European Biogas Association (2015) and Lora Grando *et al*. (2017) biogas plants continue to expand throughout Europe, with more than 14,500 systems currently in operation. Europe uses a 'centralised' system and 'agricultural scale' digesters that could be adopted in ASEAN countries where there is an abundant source of feedstocks from large-scale municipal, wastewater waste and industrial residues.

A centralised system can intake livestock manure from various sources along with other municipality, farm, and household level organic waste. This system effectively adds economic benefit by reducing waste and producing energy, fertiliser, and biochar (European Biogas Association, 2015). The partly digested feedstock can be either returned to the farmers or sold as fertiliser (Wilkinson and Kennedy, 2012; Rolamo and Mika Järvinen, 2017).

Denmark is a leading country in biogas 'centralised' system development, with approximately 20 centralised waste management systems and 150 large-scale biodigester plants. It's capacity is expected to increase by 50 percent. The biogas plants have large capacity digesters up to 8000 m3, and their primary feedstock is manure with other organic wastes added to the system. These plants demonstrate how the co-digestion of multiple feedstock substrates could save revenue, particularly transportation expenses (Skovsgaard and Jacobsen, 2017).

Nordic countries have piloted almost all renewable energies; therefore, biogas energy is common across the region. However, only Denmark and Sweden are major users, while usage is still partial in Iceland, Norway, and Finland. In Denmark, biogas is used in co-production plants, while in Sweden, it is generally converted to electricity (Energy Sund AS, 2010). Large-scale anaerobic digestion plants typically present a 200–1200 m3 digester capacity in Denmark (Vasco-Correa *et al*., 2018). They are often built on swine or dairy farms, where animal manure is co-digested with agricultural residues (Wilkinson and Kennedy, 2012). ASEAN nations with limited feedstock sources, such as Brunei Darussalam and Singapore, could adopt the Scandinavian technology and model.

In Latin America, full-scale biogas systems are using agro-industry wastes, such as POME generated in farms in Honduras, Columbia, and Argentina. In Brazil, 127 biogas plants use sewage, biosolids, and agro-industry wastes, producing around 584 billion m3 of biogas per year (Kapoor and Vijay, 2013). Indonesia and Malaysia both have enormous palm oil industries that could adopt a similar approach in optimising POME utilisation. Moreover, other ASEAN countries with large agricultural industries and untapped potential, such as Cambodia, Lao PDR, Myanmar, the Philippines, Thailand, and Vietnam could further explore utilising agro-industry waste as Brazil has done.

Best practices in African biogas development could also be adopted in ASEAN countries to improve the technology and market readiness of biogas-to-electricity. In sub-Saharan Africa, anaerobic digestion plants use large energy crops (e.g., barley, corn, sorghum, and sunflower) for energy production and farm usage and the bio-slurry, the final waste from biogas production, can be used as an eco-friendly bio-fertiliser in agriculture (al Seadi *et al*., 2008). In Malawi, Burkina Faso, Ghana, Zambia, South Africa, Lesotho, and Madagascar, Jatropha (Jatropha curcas L.) has been successfully used as a biogas feedstock. It is considered a promising crop for Africa's biofuel production. Sound management of biowaste has provided economic benefits for the agro-industry on both small and large-scales (Hendroko *et al*., 2015; Jabłoński *et al*., 2017).

Anaerobic digesters utilising organic wastes and agricultural residues are most commonly used in Asian nations outside the ASEAN region. Most collaborative projects between AMS and other Asian countries primarily focus on feedstock and technology assessment to improve market readiness as their political, regulatory, social, and environmental circumstances tend to be similar. For example, some projects between the Malaysian and Indian governments have introduced biogas technology in rural areas for cooking and lighting and as a substitute for chemical fertiliser for farmers in place of fossil fuels and traditional biomass (Surendra *et al*., 2014). In Sri Lanka, biogas energy has promise in reducing the global warming potential by offsetting 3.9 – 4.8 million tons of carbon dioxide equivalent (CO2eq) (Bekchanov *et al*., 2019), with biogas installation potentially covering 16-23 percent of household electricity demand.

7.3. Recommendations for Upgrading

Type C and Type D are defined as the R&D stage of biogas technology that requires improved governance and technology-specific assistance, such as research investment and technology partnership promotion. Fixing prices is a crucial step in promoting biogas technology at an early stage. The Type C and D stages of biogas technology also require comprehensive policy to support technology and research efforts, such as government funding for biogas research and pilot projects, tax credits for private companies that invest in biogas research projects and the development of knowledge sharing and education on biogas.

ASEAN governments need to introduce taxes that encourage new clean technologies like biogas and modify procurement processes to facilitate technology implementation. Market pull policy may also be a good strategy for the ASEAN countries in Type B (niche market), such as Indonesia, which require a good market environment to be competitive and progress further.

Nations in the Type B niche market are demonstrating technology improvement initiatives and have produced empirical biogas studies that focus on upgrading the market and facilitating access to financial incentives, such as tax credits and loan guarantees. For example, currently identified as Type B, Indonesia can test tax credits for biogas development in the palm oil industry. In addition, policies are needed for workshops on managing biogas technical problems and raising the technical capacity of personnel. Governments need to streamline financial incentives, tax exemptions and purchase guarantees to support heat generation and the co-generation of power and heat from biogas and solar thermal for the relatively low-temperature agri-industrial process. In 2021, 55 biogas units initially used POME but have now expanded into other potential feedstocks from industries like tapioca.

Biogas development key actors need to contribute to increasing public understanding of energy security and climate change issues, which is a much-needed external strategy. The private sector could significantly improve biogas deployment in Type B countries by providing private capital. Industry research investment appears to have only provided a short-term solution for this stage; therefore, market support is pivotal in ensuring that technology development is sustainable and continues to grow.

Government agencies must work closely with local consulting agencies and research institutions to develop innovative green technologies that are well suited to local conditions (locally accessible and affordable). In addition, a more targeted, intentional, and localised approach would be more effective, such as information campaigns in local dialects to raise awareness of indigenous communities, as observed in the Philippines. Above all, grants or financial aid are critical for energy research projects on policy, economic, and technological fronts.

Type A commercial stage nations like Malaysia and Thailand have mature technology; however, economic barriers must be addressed in this category, particularly concerning market barriers. Malaysia commenced a FIT biogas project with a capacity of 55.83 MW in 2017, but to develop more mature and lower cost options, it could consider green certification or GHG trading. Also noteworthy is a conventional strategy like implementing energy efficiency standards that need to be constantly maintained to increase the attractiveness of biogas projects. Type A might also consider information campaigns to gain public support.

08 Conclusion

This biogas research on needs and barriers in the electricity sector examined the movement of biogas development in AMS at the project, policy, and institutional levels. Nations are able to progress from Type C and D stages to Types A or B by identifying specific needs and barriers and then executing the necessary steps to facilitate this process.

Biogas power generation in ASEAN is still unable to compete economically with fossil fuel power generation. This is particularly true of subsidised fuels. Biogas operations are generally limited to small or medium-sized scale and have yet to generate electricity on a large scale. The considerable untapped potential identified to utilise more biological waste from agriculture, households, industries and sewage could capacitate large-scale biogas-to-electricity production in the future. Other critical barriers include unequal access to both information on biogas extraction and suitable feedstocks and the high logistic costs of importing biogas equipment. However, AMS are endeavouring to diversify their national energy mix through high bioenergy targets while finding solutions to obstacles and acting on opportunities that ensure long-term viability.

The study results showcase a way forward for biogas-to-electricity development in ASEAN. When technical, economic, and political issues are co-existing with social and environmental development potential, biogas-to-electricity uptake is likely to progress to the next stage. For instance, better directed policy emphasis and robust regulatory frameworks would facilitate the growth and readiness of all clean energy technologies. Coherent policymaking is essential at all stages, including tax credits, feed-in-tariffs, and loans. Understanding the roles of key actors coupled with building synergies and effective coordination are pivotal in facilitating bureaucratic processes to access biogas development aid.

A comprehensive understanding of biogas project development is also noted as a fundamental necessity, for example, identifying potential feedstocks in the vicinity of project sites, exploring alternatives for processing local waste (e.g., MSW, sewage, and household waste) and industrial waste (e.g., POME) as feedstock, addressing the technical challenges at the early stages of technology development, and maintaining the productivity of biogas facilities throughout their operations. Equally important are raising public awareness on the biogas co-benefits, such as mitigating climate change and alleviating the enormous waste management issues throughout ASEAN. Promoting and building on the success stories to date is of utmost importance in boosting private sector and local community confidence in the uptake of biogas development.

To summarise, the six essential enabling factors for scaling-up biogas-to-electricity applications in ASEAN are as follows:

1. Robust and supportive regulatory frameworks
2. Synergy and effective coordination
3. Advocacy and policymaker engagement
4. International collaborations and adoption of proven successful models
5. Key stakeholder capacity building and access to financing
6. Broad public awareness on the environmental co-benefits of biogas

The insights gained through this study are anticipated to contribute to future biogas deployment in ASEAN. The six enabling factors identified are integral to achieving the ASEAN Plan of Action for Energy Cooperation Phase II (2021 – 2025) targets. With member countries ambitious to scale up biogas development, robust regulatory frameworks and effective coordination are vital in negotiating the convoluted processes identified at the conception/licensing/designing phases of biogas projects. Furthermore, ongoing economic incentives and capacity building programmes with local governments, communities, and developers could effectively boost biogas development into the operational phase. The building of public awareness is essential in triggering broader discourse on biogas representation in the regional power system. This could ultimately lead to guidelines and better policy emphasis for regional renewable energy targets.

Due to limitations of the methods used in this study, future research is recommended to more closely examine current projects, which are based upon empirical findings (e.g., interviews and field observations) and more detailed academic research. Further analysis would enable a better understanding of national biogas prospects and trends at the project, policy, and institutional levels. Alternatively, future research could be expanded to technology-specific and economic reviews, such as identifying and addressing:

1. barriers to biodigester installation and maintenance (common barriers for all biogas projects, not only for power plants)
2. barriers specific to biogas power plants, which require stable, large-scale and low-cost feedstocks
3. barriers to the biogas-to-electricity competitiveness
4. barriers to gender inclusion in biogas project development

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