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(IJIREV)**www.gaexcellence.com/ijirev**STAKEHOLDER PERSPECTIVES ON MALAYSIA'S OIL
PALM BIOMASS VALUE CHAIN WITHIN THE ENERGY–
FOOD–ENVIRONMENT–WATER NEXUS**Mohamad Razlan Md Radzi¹, Syarifah Azra Budiman², Nor Adilla Rashidi^{3*}

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Abstract:

Malaysia's increasing energy demand highlights the need for renewable alternatives, with oil palm biomass offering substantial potential for sustainable energy development. However, its biomass value chain (BVC) remains underutilized due to feedstock variability, logistical constraints, limited technological capacity, and policy and financing gaps. This study addresses the limited stakeholder-focused assessment of Malaysia's oil palm BVC within the Energy–Food–Environment–Water (EFEW) nexus. A structured questionnaire was administered to 25 stakeholders from industry, government, academia, and non-governmental organizations, and the responses were analysed descriptively across six areas: industry dynamics, BVC processes, implementation challenges, EFEW interactions, and government and private-sector roles. The findings indicate that stakeholders generally perceive the BVC as cost-effective and environmentally beneficial, but identify feedstock uncertainty, high infrastructure and logistics requirements, limited technological innovation, inadequate financial incentives for smallholders, and policy uncertainty as key barriers. The findings highlight the need for stronger policy coherence, targeted financial and technical support, domestic technological innovation, and

public–private collaboration. These measures can strengthen BVC efficiency and competitiveness while supporting Malaysia’s renewable energy transition, circular bioeconomy development, and relevant Sustainable Development Goals (SDGs).

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Keyword:

Biomass Value Chain; Circular Bioeconomy; EFEW Nexus; Malaysia; Oil Palm Biomass; Stakeholder Analysis; Sustainability



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Introduction

Malaysia’s rising energy demand emphasizes the necessity to move towards cleaner, efficient and renewable energy sources. Among the available resources, oil palm biomass offers significant opportunities for renewable energy generation and progress towards multiple Sustainable Development Goals (SDGs). Malaysia, as a prominent global producer of palm oil, generates significant amount of biomass residues from the palm oil sector, enabling the nation to progress toward a biomass-driven energy transition. (Su et al., 2023).

Despite this potential, the large-scale utilization of oil palm biomass remains constrained by environmental, technological, financial, and regulatory challenges. Environmental issues such as deforestation, peatland degradation, and emissions linked to biomass transport and processing continue to be significant factors, while technological constraints, substantial investment demands, and regulatory obstacles may impede broader implementation (Behera et al., 2025). Despite the existence of national plans and renewable energy regulations that establish a foundation for biomass advancement, their incorporation of the Energy–Food–Environment–Water (EFEW) nexus is notably restricted, especially across the various phases of the biomass value chain (BVC) (Mai et al., 2025).

Previous studies have examined oil palm biomass utilization, renewable energy potential, and individual aspects of the BVC. However, limited stakeholder-focused assessment has examined the effectiveness of Malaysia’s oil palm BVC from an integrated EFEW nexus perspective. There is limited understanding of how environmental, technological, financial, and policy-related factors collectively influence BVC effectiveness based on the perspectives of stakeholders directly involved in the sector. Addressing this gap is important because decisions

concerning biomass production, processing, transportation, and utilization can simultaneously influence energy security, food resources, environmental quality, and water sustainability.

As such, this research investigates the factors influencing BVC efficacy within Malaysia's oil palm industry via the EFEW nexus. A structured bilingual questionnaire was administered to stakeholders representing industry, government, academia, and related organizations. The findings provide a stakeholder-based evaluation of factors affecting Malaysia's oil palm BVC and identify the relative importance of environmental, technological, financial and policy dimensions. The research combines stakeholder viewpoints with the EFEW nexus, offering pragmatic insights for policymakers, industry participants, and researchers to optimize biomass usage, augment resource efficiency, and foster the advancement of a more sustainable and resilient BVC. The findings further contribute to Malaysia's renewable energy transition and offer policy-relevant recommendations aligned with relevant SDGs, especially those on affordable and clean energy, responsible consumption and production, and climate action (Almulhim & Abubakar, 2026).

Methodology

Stakeholders were selected through purposive sampling to include those directly involved in biomass production, policy or research in the industry, government, academia and NGOs in Malaysia. The study involved 25 stakeholders spread across three primary groups in the biomass value chain (BVC): (1) industry: plantations, processing facilities, suppliers and logistics; (2) government: policymakers, regulatory bodies and relevant agencies; and (3) academia: universities and research institutions. The sampling method was used to ensure diverse representation from practical, regulatory, social and scientific perspectives.

A survey was developed online in Malay and English using Microsoft Forms to collect respondent information, including position, years of experience, company or institution, organization category and main business activities to verify eligibility and to ensure responses were obtained from targeted stakeholders. The study objectives and requirements for participation were clearly outlined and shared via work email and instant messaging with the survey link.

The survey comprised 100 structured questions, including Likert-scale items rated from 1 (very low) to 5 (very high), to obtain quantitative data on Malaysia's oil palm-based biomass industry. The questions were organized into six parts: (1) oil palm biomass industry dynamics in Malaysia, including energy demand, residue sustainability, land use, and biodiesel competitiveness; (2) oil palm BVC processes, including harvesting, processing, storage, transportation, and supply chain efficiency; (3) implementation challenges, including feedstock variability, market fluctuations, infrastructure costs, financial constraints, and policy gaps; (4) interactions between the BVC and the EFEW nexus, focusing on land competition, water use, emissions, and waste-to-energy potential; (5) the Malaysian government's role in policy, regulation, financial support, and initiatives such as the National Biomass Action Plan 2023–2030 (Saad et al., 2025); and (6) the private sector's role in technology adoption, investment, training, and sustainability practices.

The quantitative responses were analysed using Microsoft Excel through descriptive percentage analysis. Responses to each Likert-scale question were grouped according to the six sections of the questionnaire and classified into five response categories: strongly disagree,

slightly disagree, uncertain, slightly agree, and strongly agree (Jebb et al., 2021). The distribution of responses was calculated as percentages and presented using 100% stacked bar charts, with each question representing the complete response distribution of the participating stakeholders.

Results and Discussions

Oil-Palm Based Biomass Industry in Malaysia

The first part of the questionnaire, presented in Table 1, focused on the oil palm-based biomass industry in Malaysia and assessed stakeholders' knowledge and perceptions, with the responses presented in Figure 1.

Regarding Q1, a roughly 90% majority of respondents agreed in some way that the energy demand of Malaysia still depends on electricity generation from oil and gas, indicating the country's reliance on conventional energy sources is well known. As for Q2, most stakeholders agree that biomass is a sustainable resource to meet the energy security of Malaysia but most of the stakeholders agree mildly rather than strongly. Consequently, stakeholders recognize the promise of biomass overall, however they could harbour concerns over its present role in Malaysia's energy composition.

Regarding Q3, approximately 75% of respondents agree that the bioenergy sector of Malaysia is highly dependent on the oil palm residues, highlighting the palm oil industry's role as a primary biomass resource in Malaysia. However, the other respondents were either uncertain or disagreed, suggesting that the role of other biomass resources and the actual utilization of oil palm residues may not be similarly recognized. Q4 showed relatively higher uncertainty on the energy value of oil palm biomass, suggesting that the stakeholders may not be confident on the consistency and quality of biomass as an energy feedstock. This perception may be related to the differences in moisture content, composition, collection practices and conversion efficiency.

For Q5, about 80% of respondents agreed that the large oil palm plantations produce abundant biomass residues but about 20% remained uncertain. Such uncertainty may be indicative of the differences in residue generation and management practices of the plantations and mills. Equally, Q6 also revealed more uncertainty on the matter of whether the abundant palm oil residues are neglected without proper management, with over 30% of respondents either uncertain or disagreed with the statement. This finding indicates that stakeholders may have different perceptions of current biomass recovery, utilization and waste-management practices around the industry. For Q7, although no respondents strongly disagreed with the statement that Malaysian palm biodiesel is more environmentally friendly, of higher quality than conventional diesel, and comparable with international standards, around 40% were still uncertain. This relatively high level of uncertainty indicates that stakeholders may need stronger evidence regarding the environmental performance, technical quality and international competitiveness of Malaysian palm biodiesel.

Overall, the findings indicate that stakeholders recognize the substantial quantity and strategic importance of oil palm biomass for Malaysia's energy security, yet their confidence is hampered by worries regarding biomass quality, residue utilization, waste management practices and the competitiveness of biodiesel. Such perceptions underscore the need for better

communication of technical and environmental performance data, increased transparency on biomass use, and targeted policies to build stakeholder confidence. These may provide a basis for wider acceptance of biomass-based energy solutions and enhanced integration of oil palm residues in Malaysia's sustainable energy transition. (Aghamohammadi et al., 2016; van Dijk et al., 2024).

Table 1: Survey Questions for Section 1: Oil Palm-Based Biomass Industry in Malaysia

Questions

1. The high energy demand in Malaysia is primarily constrained to electricity generation and from oil and gas
2. The energy generation from biomass sources is sustainable and contributes to the good reputation of energy security in Malaysia.
3. The bio-energy sector in Malaysia is still heavily dependent on the oil palm waste produced.
4. The quality of biomass waste generated from oil palm plantations and mills is much more sustainable than other agricultural wastes due to its high energy value.
5. Large hectares of oil palm plantation generate abundant biomass wastes.
6. The abundant oil palm waste generated is currently neglected at plantation sites and processing mills without proper care.
7. Palm biodiesel produced in Malaysia is more eco-friendly and has high fuel quality compared to conventional diesel and comparable with other countries.

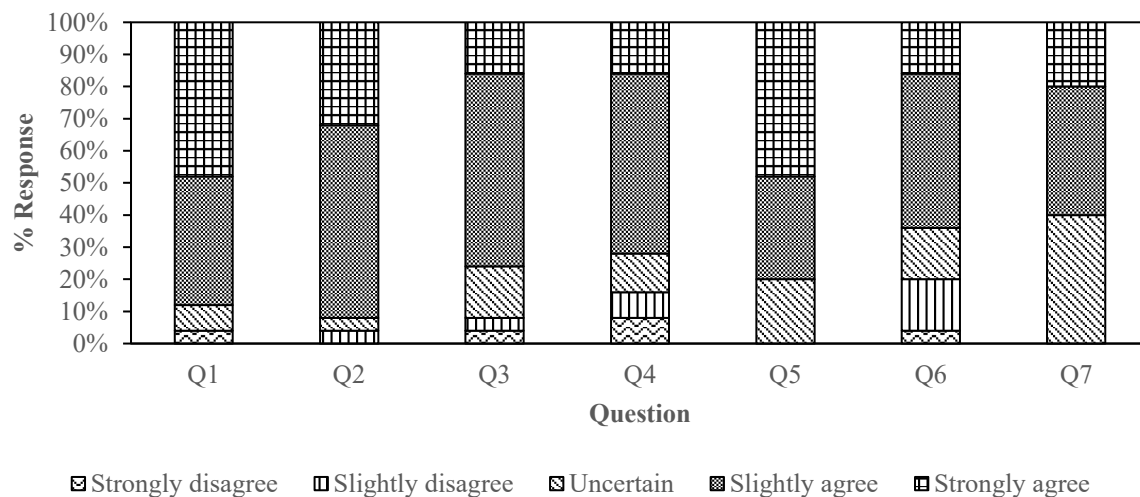


Figure 1: Stacked Bar Chart of Stakeholder Perceptions in Section 1: Oil Palm-Based Biomass Industry in Malaysia.

Oil Palm Biomass Value Chain (BVC) in Malaysia

The second part of the questionnaire, illustrated in Table 2 and Figure 2, evaluated stakeholders' views on the sustainability and execution of Malaysia's oil palm biomass value chain (BVC). Most respondents (90%) agreed that the oil palm BVC is sustainable, cost effective, eco-friendly and safe (Q1). 70% of the respondents slightly agreed and 20% of the respondents

strongly agreed. It is interesting to note that 80% also expressed concerns over environmental sustainability issues associated with its implementation (Q2), while 40% were undecided or disagreed that the BVC had been fully optimized to maximize performance while minimizing environmental impacts (Q3). About 70% agreed that the BVC generally involves plantation harvesting, biomass processing, storage and transportation (Q4). As for biomass sourcing, 65% agreed that CPO mills primarily rely on FFB from their own plantations, whereas 30% were undecided and 5% strongly disagreed (Q5).

Stakeholders identified several operational constraints within the BVC. Around 75% felt that the limited availability of FFB leads to a reduction of mill processing capacity (Q7), 80% claimed that plantation productivity directly influences the generation of biomass waste (Q8), 80% agreed that the waste generated by the mill requires a significant pre-treatment before conversion (Q9), and 75% admitted that biomass pre-processing requires significant heat and electricity (Q10).

In addition, 80% agreed that the handling of biomass waste requires an increase in transportation and storage capacity. Regarding Q11, 65% agreed that biomass storage cannot be considered fully carbon-neutral due to its cooling and power demand, while 35% were unsure or disagreed. The results show that the Malaysian oil palm BVC is generally perceived as sustainable and resource-efficient by the stakeholders, but important challenges can be identified in feedstock availability, process optimization, pre-treatment, logistics and energy consumption. These emphasized the need to enhance the environmental and operational performance of BVCs (Abogunrin-Olafisoye et al., 2024; Saleh & Hassan, 2024).

Nevertheless, the present study advances the existing knowledge by providing a stakeholder-centric assessment on these challenges in the Malaysian EFEW nexus. The results provide practical evidence to policymakers and industry stakeholders for improving biomass collection and logistics, developing more energy-efficient pre-treatment technologies, optimizing storage systems, and improving resource integration throughout the BVC.

Table 2: Survey Questions for Section 2: Oil Palm Biomass Value Chain (BVC) in Malaysia

Questions
1. The oil palm BVC is sustainable, cost-effective in terms of operation, eco-friendly, and safer.
2. The implementation of oil palm BVC in Malaysia is highly concerned with environmental sustainability in Malaysia.
3. Oil palm BVC in Malaysia has been optimized for maximum performance while minimizing environmental impacts.
4. The BVC in Malaysia's oil palm sector typically involves crop harvesting from plantations, biomass processing, storage, and transportation.
5. Most of the crude palm oil (CPO) refinery mills in Malaysia primarily supply fresh fruit bunches (FFB) harvested from plantations belonging to their company rather than sourcing externally.
6. Limited supply of fresh fruit bunches (FFB) from plantation areas reduces the oil palm processing capacity utilization rate in the processing mill.
7. The productivity of fresh fruit bunches (FFB) in the plantation significantly influences the amount of biomass waste generated.

8. Oil palm wastes produced from processing mills require an intensive pre-treatment process before further conversion process.
9. Pre-processing of biomass in the oil palm industry utilizes large amounts of heat and/or electricity to power their facilities.
10. More transportation and storage space are required to operate the generated waste from processing mills.

Most storage facilities used for storing biomass are not carbon-free as they may require energy for cooling and other inputs for biomass storage.

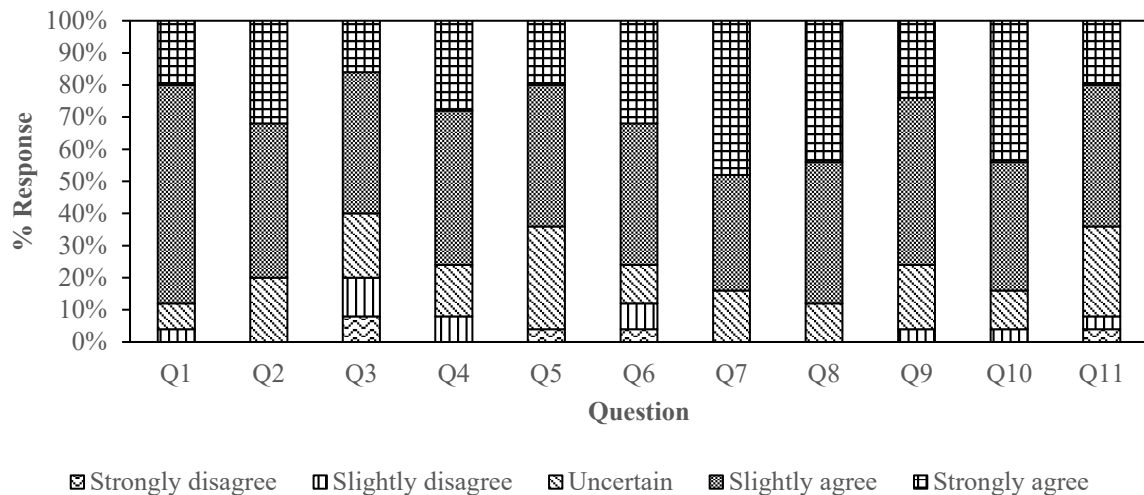


Figure 2: Stacked Bar Chart of Stakeholder Perceptions in Section 2: Oil Palm Biomass Value Chain (BVC) in Malaysia

Challenges of Oil Palm Biomass Value Chain (BVC) Implementation

The third part of the questionnaire, presented in Table 3 and Figure 3, examined stakeholders' perceptions of the challenges associated with implementing the oil palm biomass value chain (BVC) in Malaysia. Findings indicate that implementation remains constrained by feedstock uncertainty, infrastructure requirements, financing limitations, technological dependence, and policy instability.

Approximately 95% agreed that weather conditions and fertilizer quality are strong factors affecting oil palm productivity and thus contribute to uncertainty in biomass feedstock availability (Q2). Similarly, the majority of the respondents agreed that the variations in biomass quality can impact the conversion efficiency and the quality of the product (Q3), while a small percentage of the respondents remained unsure or slightly disagree. All the respondents (100%) agreed in Q4 that variations in the demand of resources directly impact the market prices. Infrastructure and financial constraints were also identified as a serious barrier.

In Q5, approximately 90% of the respondents agreed that better logistics and transportation infrastructure is required for efficient biomass distribution, but high initial investments in infrastructure, technology and processing facilities remain major barriers. Stakeholders noted in Q6–Q8 that limited investment in advanced technologies, lack of financial support and insufficient expertise in biomass financing are factors that increase operational costs and limit project development.

Furthermore, most respondents agreed in Q9 that stronger public–private collaboration is needed to share investment risks and attract more financing to the biomass sector. However, uncertainty and disagreement increased to approximately 30% for Q10–Q11, regarding whether insufficient green technological advancement in processing plants is a hindrance to sector development and whether biomass conversion technologies are still overly dependent on imported technologies. Despite this variation, about 90% of respondents agreed in Q12 that limited availability of green technologies and insufficient investment in technological innovation could reduce business profitability. Policy-related challenges were also prominent. In Q13–Q14, stakeholders identified inadequate and unclear environmental policies, together with frequent policy changes, as important sources of uncertainty that may discourage long-term investment in the biomass sector.

Overall, the findings reveal that the implementation of the oil palm BVC is not only determined by technical and environmental factors but also by financial, technological, market and institutional conditions. These findings align with earlier research that emphasizes the importance of eliminating technological, financial, and policy obstacles to foster biomass-based growth. (Chowdhury et al., 2025). More importantly, the stakeholder responses provide empirical evidence of the interconnected barriers that should be considered within the Malaysian EFEW nexus. Overcoming these barriers thru technological innovation, accessible financing mechanisms, stronger public–private partnerships, improved logistics and stable policy frameworks could alleviate investment risks and bolster the competitiveness and enduring viability of Malaysia’s oil palm BVC.

Table 3: Survey Questions for Section 3: Challenges of Oil Palm Biomass Value Chain (BVC) Implementation

Questions
1. To what extent do you agree that the implementation of oil palm BVC is challenging for environmental sustainability and economic growth in Malaysia?
2. The weather pattern and fertilizer quality used in the plantation area influenced the oil palm crop productivity which leads to the uncertainty in feedstock supply.
3. Variability in biomass quality can greatly affected the biomass conversion efficiency and product quality.
4. The fluctuation rate in the resources demand affected their marketing price.
5. Improved logistics and transportation infrastructure facilitate efficient biomass distribution, while minimizing the environmental impacts.
6. Significant initial investment in infrastructure, technology, and processing facilities can be a major barrier.
7. The limited investment in advanced technology within the biomass industry is a significant barrier to further implementing the oil palm BVC in Malaysia.
8. Inadequate financial services and the incompetency of expertise in financing biomass projects can increase operational costs and hinder project development.
9. Mutual collaboration between public and private sectors helps share financial risks and attract more investment in biomass sector.
10. The lack of green technological advancement in biomass processing plants hinders the biomass industrial development.
11. The technology used in biomass conversion in Malaysia is mainly imported from foreign countries.

12. The insufficient of green technology availability and investment for new technology may affects the business profitability.
13. Insufficient and unclear environmental policy can decelerate the progress of the biomass industry in Malaysia.
14. Frequent changes or lack of clarity in government policies can create uncertainty, deterring investment in biomass industrial sector.

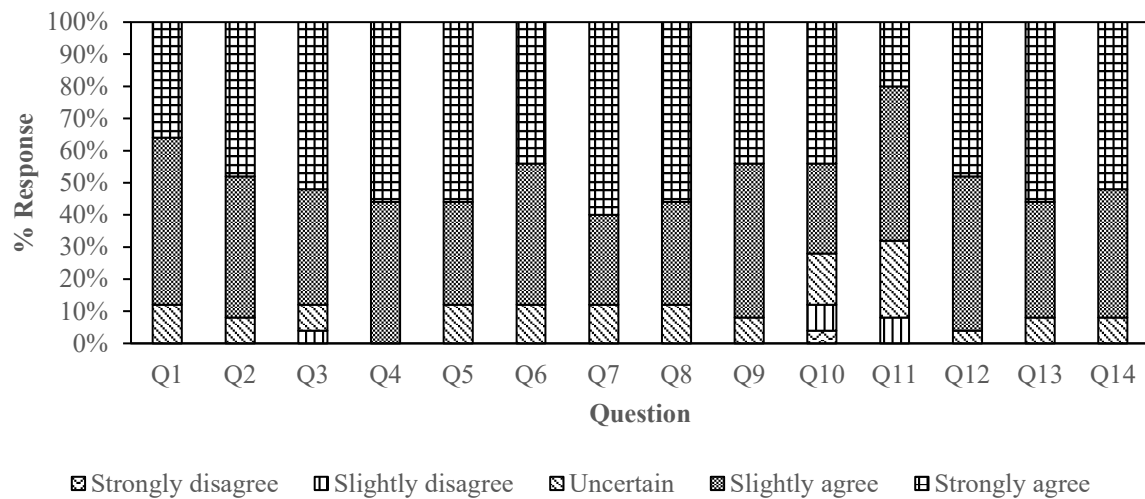


Figure 3: Stacked Bar Chart of Stakeholder Perceptions in Section 3: Challenges of Oil Palm Biomass Value Chain (BVC) Implementation

The Interrelationship between Oil Palm Biomass Value Chain (BVC) with Environment-Food-Energy-Water (EFEW) Nexus

The fourth part of the questionnaire shown in Table 4 and Figure 4 was used to assess the interrelationship of the oil palm biomass value chain (BVC) and the energy–food–environment–water (EFEW) nexus in Malaysia. The results show that the stakeholders are aware of the environmental advantages of the BVC in general, as well as the possible trade-offs related to land use, water use, transportation, and carbon emissions.

All respondents (100%) agreed in Q1 that the implementation of the oil palm BVC positively contributes to environmental sustainability. However, 10% were uncertain in Q2 about whether BVC effectiveness is highly dependent on EFEW resources to achieve sustainable value creation. More uncertainty and disagreement, about 20%, were found in Q3 regarding the wider environmental and resource implications of oil palm expansion and biomass utilization. In Q4–Q6, stakeholders discussed several interconnected issues, including the effects of global demand on land-use change, competition between the production of biomass and food, fertilizer and waste leaching that could potentially lead to water contamination, and the excessive water consumption in plantations and mills. These findings demonstrate the interdependence of BVC with food and water resources, illustrating the potential resource opportunities and environmental trade-offs that can be associated with biomass development.

Stakeholders also identified opportunities for resource recovery. In Q7, the use of palm oil mill effluent (POME) for biogas production was identified as a potential way to reduce waste and water pollution while recovering energy from a biomass residue. However, transportation

concerns were still apparent. In Q8, about 35% of respondents either disagreed or were uncertain that transportation routes between facilities are sufficiently optimized to reduce greenhouse gas (GHG) emissions and the overall carbon footprint. Q9 results suggest that approximately 70% agreed that the large volume and perishable nature of biomass increase transportation requirements, and may subsequently worsen environmental impacts, however, some respondents were unsure. The findings align with earlier research that has emphasized the environmental and resource management consequences linked to oil palm cultivation and biomass usage (Naidu & Moorthy, 2021).

The responses from the stakeholders also highlight the need to consider land, water, energy and environmental impacts together instead of looking at biomass utilization in isolation. Thus, strategies such as POME-to-biogas conversion, better transportation planning, resource-efficient processing, and integrated land and water management could improve the sustainability of Malaysia's oil palm BVC. These measures provide practical guidance to policymakers and industry actors to balance the use of biomass with environmental protection and resource security.

Table 4: Survey Questions for Section 4: The Interrelationship between Oil Palm Biomass Value Chain (BVC) with Environment-Food-Energy-Water (EFEW) Nexus

Questions
1. The implementation of oil palm BVC in Malaysia positively impacts the environmental sustainability in Malaysia.
2. The effectiveness of BVC in the oil palm sector is highly dependent on the impacts of EFEW resources to ensure that sustainable value creation is achieved ultimately.
3. High global demand for oil palm supply led to more land usage and expansion for plantations.
4. The biomass cultivation led to high competition over food crops for land.
5. It is common that fertilizers used in the plantation area and oil palm wastes from processing mills are leached into the soil, resulting in water pollution.
6. Water as scarce resource has been extensively utilized in water supply for crop plantation and as steam in the processing plants, leading to significant water discharge and soil penetration.
7. Utilizing palm oil mill effluent (POME) for biogas production presents an opportunity to mitigate water pollution.
8. Current transportation routes distance between facilities in BVCs are optimized to reduce greenhouse gas (GHG) emissions, resulting in the reduction of carbon footprint.
9. The nature of biomass materials that are usually produced in high volume and deteriorate further increases transportation needs that lead to environmental damage.

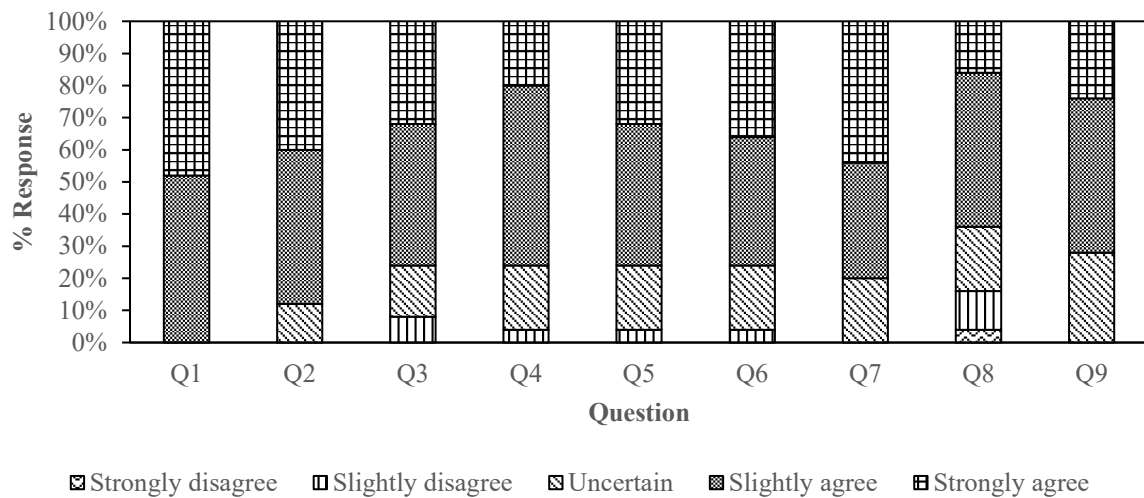


Figure 4: Stacked Bar Chart of Stakeholder Perceptions in Section 4: The Interrelationship between Oil Palm Biomass Value Chain (BVC) with Environment-Food-Energy-Water (EFEW) Nexus

Role of Government Sector in the Implementation of Malaysian Oil Palm Biomass Value Chain (BVC)

The fifth part of the questionnaire, presented in Table 5 and Figure 5, examined stakeholders' perceptions of the government sector's role in implementing Malaysia's oil palm biomass value chain (BVC). The findings indicate that stakeholders generally recognize the government's role in monitoring BVC activities, promoting environmental sustainability, and establishing policy frameworks. However, concerns remain regarding capacity building, regulatory effectiveness, and financial support, particularly for smallholders.

In Q1, approximately 70% of respondents agreed that government agencies are committed to monitoring existing BVC activities and prioritizing environmental sustainability, while the remaining respondents were either uncertain or disagreed. This perception was stronger in Q2, with approximately 90% agreeing that government performance should be assessed based on its ability to balance socio-economic development with the minimization of environmental impacts. Nevertheless, approximately 60% of respondents in Q3 were either uncertain or slightly disagreed that existing government training programs are adequate to support sustainable BVC practices. This suggests that, although government commitment is generally recognized, stakeholders perceive a need for stronger capacity-building and knowledge-transfer initiatives.

Concerns were also evident regarding regulatory and market competitiveness. In Q4, approximately 45% of respondents disagreed that current government regulations sufficiently support Malaysia's competitiveness in the global biomass market. For Q5, approximately 70% agreed that the National Biomass Action Plan 2023–2030 provides an effective outline for promoting sustainable biomass practices, although 30% remained uncertain or slightly disagreed. In Q6, approximately 65% of stakeholders were either uncertain or disagreed that the government provides substantial incentives and financial support to smallholders to encourage greater investment in biomass-based products. This finding highlights a potential gap between policy development and the accessibility or effectiveness of implementation mechanisms at the stakeholder level.

Overall, the findings suggest that stakeholders acknowledge the government's importance in establishing a supportive policy environment for Malaysia's oil palm BVC, but perceive limitations in training, regulatory effectiveness, market competitiveness, and financial assistance. These findings highlight the need to strengthen the implementation dimension of biomass policies rather than focusing solely on policy formulation (Putri et al., 2022). Greater investment in stakeholder capacity building, clearer and more consistent regulations, targeted financial incentives, and improved support for smallholders could enhance participation across the BVC and strengthen Malaysia's competitiveness in the biomass sector. Such measures would also support a more inclusive energy transition by enabling smaller producers to participate in biomass-based value creation while advancing the sustainability objectives of Malaysia's biomass development agenda.

Table 5: Survey Questions for Section 5: Role of Government Sector in the Implementation of Malaysian Oil Palm Biomass Value Chain (BVC)

Questions
1. Government agencies are committed to monitoring all existing oil palm BVC activities and place a high priority on environmental sustainability.
2. The success of the government sector is measured by its ability to balance socio-economic development with minimizing environmental impacts.
3. Training provided by the government sector is sufficient to ensure sustainable practices in the implementation of the BVC in Malaysia.
4. The government regulations in oil palm biomass sectors showed positive competition level towards global market.
5. The existing policies and regulatory frameworks established by the Malaysian government (The National Biomass Action Plan 2023-2030) is highly effective in promoting sustainable practices in the oil palm sector.
6. The government has provided substantial incentives and financial support to smallholders to promote increased investment in biomass-based products.

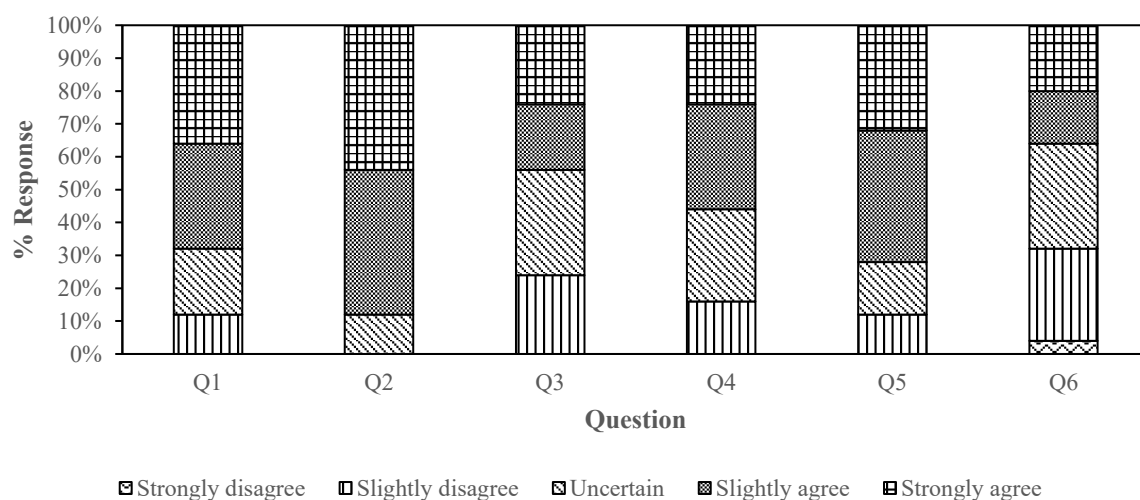


Figure 5: Stacked Bar Chart of Stakeholder Perceptions in Section 5: Role of Government Sector in the Implementation of Malaysian Oil Palm Biomass Value Chain (BVC)

Role of Private Sector in the Implementation of Malaysian Oil Palm Biomass Value Chain (BVC)

The last part of the questionnaire, as shown in Table 6 and Figure 6, looked at stakeholders' perception of the private sector's role in implementing the BVC of Malaysia's oil palm biomass. The results showed that stakeholders generally recognize the contribution of the private sector to technology development, financing, and capacity building. However, issues related to investment priorities, dependency on foreign capital, and maintaining a balance between profitability and sustainability remain.

In Q1, around 60% of respondents agreed that the private sector has invested in advanced technologies, research and development (R&D) to increase operational efficiency and sustainability while considering the environmental impacts. Likewise, in Q2, 60% of respondents agreed that private-sector stakeholders provide incentives, financial support and operational training to support biomass industry development, but some respondents were unsure or slightly disagreed. The findings suggest that the private sector is perceived as crucial in providing the technology and financial assets necessary for BVC advancement. The priorities for funding and investment exhibited greater diversity.

The responses for Q3 were mixed, with about 45% of the participants agreeing that private sector capital is primarily foreign investment and some unsure or disagreeing. The responses for Q4 were also mixed, 40% agree that private agencies are more concerned with land development than investing in new technologies, 30% were unsure and 30% disagreed. This suggests a mixed stakeholder perception on the extent to which private investment is being directed toward technological development versus growth of physical production capacity. For Q5, just over 60% of respondents agree, around 30% respondents are undecided and just under 10% disagree that the private sector is more profit driven than sustainability driven in the BVC. This highlights potential conflict of interest in the private sector. Similar concerns have been raised in studies of oil palm development and its investment and land-use dynamics (Cifuentes-Espinosa et al., 2023).

The findings show that stakeholders see the private sector as a major contributor to technological innovation, investment and skills development in Malaysia's oil palm BVC. Profit driven decision making, reliance on foreign investment and investment priorities raise issues of the need for greater alignment of commercial and sustainability objectives. Greater private sector accountability, sustainability-based investment criteria and collaboration with government and research institutions could encourage investment in cleaner technologies and higher value biomass applications. These may improve the long-term competitiveness and environmental performance of Malaysia's biomass sector.

Table 6: Survey Questions for Section 6: Role of Private Sector in the Implementation of Malaysian Oil Palm Biomass Value Chain (BVC)

Questions

1. The private sector highly invested in the new advance technology for R&D purpose to enhance the efficiency and sustainability of oil palm BVC while concerning the environmental impacts.
2. The private sector also helps in providing adequate incentives and financial support for biomass industrial development and in operational training.

3. The capital source of private financing mostly comes from foreign investment.
4. Private agencies mainly invested for new land development instead of new technology.
5. The private sector tends to **prioritize profit-making over the sustainability of the BVC.**

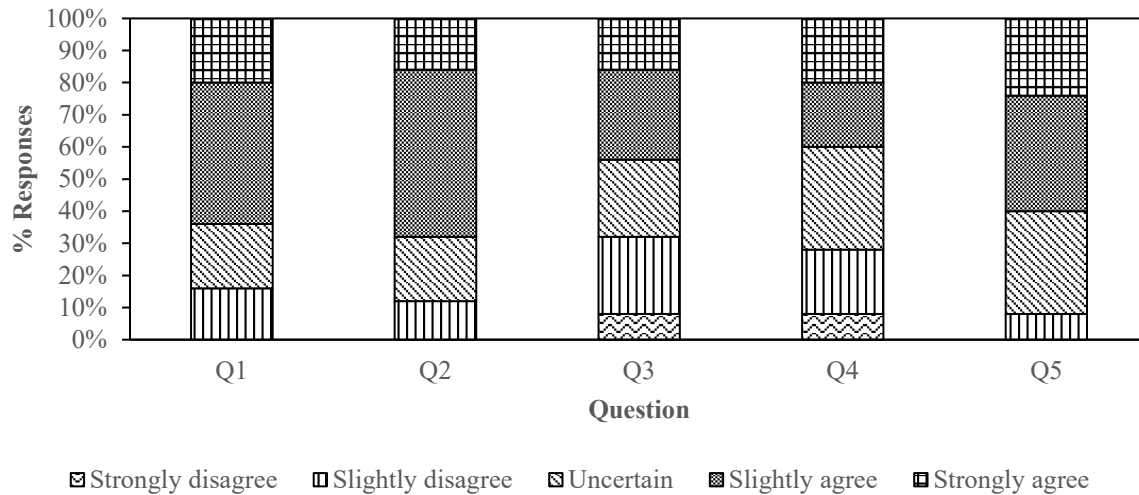


Figure 6: Stacked Bar Chart of Stakeholder Perceptions in Section 6: Role of Private Sector in the Implementation of Malaysian Oil Palm Biomass Value Chain (BVC)

Critical Discussion of Stakeholder Perspectives

The results obtained from the six sections of the questionnaire show that stakeholders are aware of the possibility of sustainability in the oil palm biomass value chain (BVC) in Malaysia, but they also see significant barriers preventing its effective implementation. Sections 1 and 2 show a high degree of confidence in the BVC's potential for sustainability and resource efficiency, while uncertainty regarding the points of optimization suggests that biomass availability does not necessarily imply its efficient use. This is an important point, as the processes of biomass collection, pre-processing, transportation, and storage can impose energy, financial, and environmental burdens. Previous studies also identify technical, logistical, and financial constraints as barriers to the commercialization of Malaysia's biomass resources (Zahraee et al., 2019)

In Section 3, it was apparent that BVC performance is affected by feedstock variability, infrastructure requirements, financial constraints, and technological readiness. Availability of biomass is affected by weather conditions and productivity of plantations. Differences in biomass quality may affect conversion efficiency and product quality. High capital requirements and limited access to financing may also limit technological upgrading, especially by smaller stakeholders. These results imply that biomass utilization improvement requires the coordinated development of feedstock management, logistics, technology and financing, and not only focusing on conversion efficiency (Tapia et al., 2019).

The results of Section 4 emphasize the significance of assessing the BVC through the lens of the energy-food-environment-water (EFEW) nexus. Although stakeholders perceive the use of biomass as strongly associated with environmental sustainability, trade-offs are reflected in concerns about land competition, water pollution, resource consumption and transportation emissions. The conversion of POME to biogas has great potential for synergies between waste

management, water protection and renewable energy generation. However, the transport needs of bulky and perishable biomass could offset some of the environmental benefits if logistics are not well optimized. This reinforces the need for integrated BVC planning in which resource use and environmental impacts are considered simultaneously (Ghani et al., 2019).

Sections 5 and 6 highlight complementary institutional and market related challenges. Stakeholders generally recognize the role of the government in policy development and sustainability monitoring but express concerns about training, regulatory effectiveness and financial incentives especially for smallholders. Similarly, the private sector is seen to contribute to technology, financing and training but profit-oriented investment and uncertainty on investment priorities remain concerns. These findings suggest a gap between policy intents, investment decisions and practical implementation. Stronger public–private collaboration, targeted financial incentives, capacity building, and stable policy frameworks could therefore improve investment confidence and accelerate BVC development (Miettinen et al., 2016).

Overall, the six sections demonstrate that the key challenge is not the availability of oil palm biomass but the ability to integrate feedstock supply, technology, logistics, finance, policy, and environmental management into an efficient and sustainable system. The stakeholder-focused assessment therefore provides practical evidence for strengthening Malaysia's BVC within the EFEW nexus. Future strategies ought to focus on resource-efficient processing, enhanced logistics, green financing, domestic technological innovation, smallholder inclusion, and steady policy support. These actions could enhance the competitiveness and sustainability of the biomass sector and support Malaysia's renewable energy transition and SDGs 7, 9, 12, and 13 (James Rubinsin et al., 2021).

Conclusion

The oil palm biomass value chain (BVC) in Malaysia has significant potential to contribute to sustainable energy development, circular bioeconomy goals and the country's low-carbon transition. However, the findings from stakeholders indicate that its large-scale deployment is still hampered by feedstock variability, transportation and infrastructure, technology dependence, financing gaps and policy uncertainty. Environmental concerns related to land use, water use and logistics further highlight the need to assess biomass development thru an integrated Energy–Food–Environment–Water (EFEW) nexus lens. Managing these obstacles requires improved policy coherence, targeted financial incentives, capacity building and enhanced institutional coordination. Increased collaboration among government agencies, private actors, research institutions and smallholders is also critical to accelerate the development of green technology, improve biomass logistics and conversion efficiency and promote more inclusive participation across the BVC. Clear regulations and long-term investment mechanisms are needed to support the effective implementation of the National Biomass Action Plan 2023–2030. Overall, the study shows that the potential of Malaysia's biomass alone is insufficient to ensure a sustainable and competitive BVC. A coordinated approach of technological innovation, policy support, stakeholder collaboration and resource efficiency is needed to enhance the sector's contribution to energy security, circular bioeconomy development and the Sustainable Development Goals (SDGs).

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