

Oil Palm Industry Economic Journal

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CONTENTS

- 1 Evaluation of Replanting Program for Indonesian Oil Palm Smallholders: Case Study of West Aceh Regency, Indonesia
Said Achmad Kabiru Rafiie; Nasya Aulia and Tamitha Intassar Husen
- 11 Research Trends in Palm Oil Mill Effluent (POME) Wastewater Treatment Using Bacteria in Malaysia: A Systematic Review
Nurul Asmak Md Lazim; Zaharah Ibrahim and Nurain Mohd Nazir
- 20 The Impact of Asymmetric Relationship Between Crude Oil and Palm Oil Prices on the Palm Oil Industry
Nur Ain Mohd Hassan; Norlin Khalid; Kalsom Zakaria; Tamat Sarmidi; Azrina Abdullah Al-Hadi; Kamalrudin Mohamed Salleh and Siti Mashani Ahmad



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EVALUATION OF REPLANTING PROGRAM FOR INDONESIAN OIL PALM SMALLHOLDERS: CASE STUDY OF WEST ACEH REGENCY, INDONESIA

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ABSTRACT

Our comprehensive study assessed the People's Palm Oil Replanting Program (PSR), also known as Program Peremajaan Sawit Rakyat, in West Aceh Regency, Indonesia. Employing qualitative research methods, this study conducted an in-depth interviews with various stakeholders, including smallholders, representatives from the Agricultural Department of West Aceh Regency, and members of cooperative palm oil plantation committees. In complementing the primary data, this study incorporated secondary information from authoritative sources such as Statistics Indonesia, The Indonesia Oil Palm Plantations Fund Management Agency (BPDPKS), and relevant publications. Evaluation of this study was framed within the analytical framework that Donald Van Metter and Carl Van Horn developed in 1975. This framework encompassed vital dimensions, including standards and objectives formulation, resource allocation, inter-organisational communication strategies, enforcement mechanisms, implementing agency characteristics, contextual economic, social, and political factors, and program administrators' disposition. Our findings revealed significant implementation challenges, including ineffective inter-organisational communication, a perceived lack of commitment among implementers, and a lack of transparency in resource allocation. These issues raised concerns about the program's overall effectiveness. However, this study also highlighted a positive impact: The PSR contributed to reducing poverty rates in West Aceh Regency, showcasing its potential to enhance local socio-economic conditions.

Keywords: PSR evaluation, poverty reduction, program implementation, socio-economics impact, West Aceh Regency.

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INTRODUCTION

Oil palm stands out as an economically valuable crop compared to other vegetable oils like olive,

sunflower, and corn (Yaşar, 2020). Indonesia's oil palm plantations covered 14.32 million hectares and produced 40.56 million tonnes of palm oil in 2019 (Indonesia Statistic, 2019). These plantations fall into two categories: Large-scale corporate plantations covering 8.51 million hectares and smallholders' plantations spanning 5.81 million hectares, contributing 39% of Indonesia's total palm oil production (Okarda *et al.*, 2018). Smallholders typically achieve lower yields, around 2.4 t/ha, compared to corporate plantations' 4.1 t/ha, possibly due to limited fertiliser application (Woittiez *et al.*, 2018). Also, old oil palm trees are a dilemma faced by Indonesian smallholders. According to the Indonesia Oil Palm Plantations Fund Management Agency (BPDPKS) (2021), 78%

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of smallholder plantations consist of trees that are between 17 and 27 years old. This situation contributes to lower productivity and inefficiency.

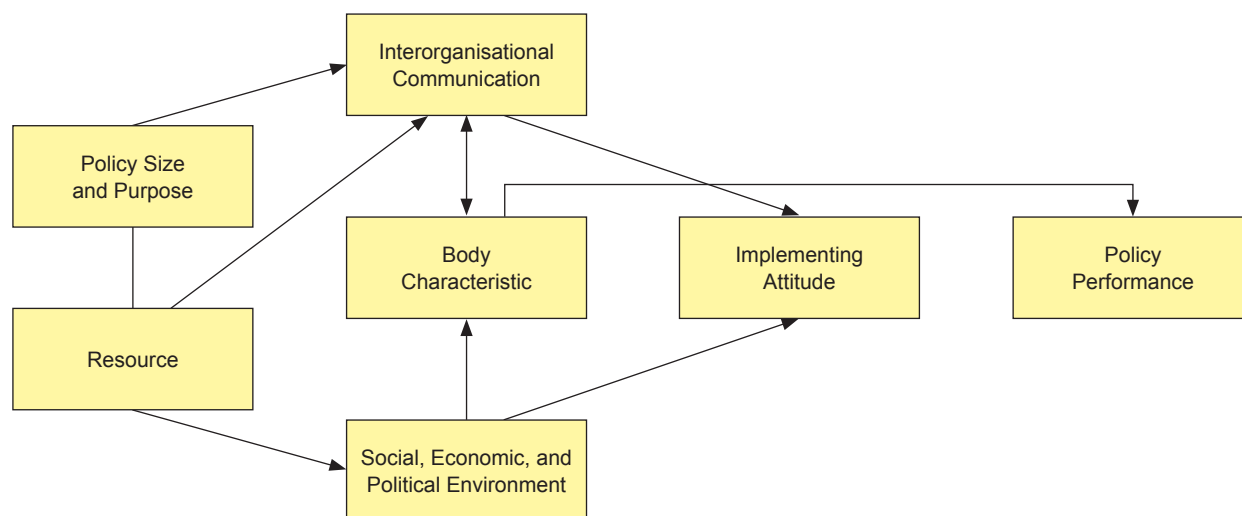
The Indonesian government is helping to increase the productivity of oil palm farmers. To boost smallholders' productivity, the Indonesian government initiated the replantation program (Petri *et al.*, 2023). The replantation program is aimed to reduce poverty level in rural areas and holds the potential to bring both social and economic benefits for the rural areas in Indonesia. The future of Indonesia's oil palm industry relies on smallholders (Saragih, 2017), and replanting aims to ensure its sustainability (Purba, 2019). Permentan No. 18 of 2016 defines replanting as replacing old or unproductive oil palm plants with new ones (Direktoral Jenderal Perkebunan Kementerian Pertanian, 2018). The government's policy seeks to enhance the community's economy by supporting smallholders with funds from self-help, banks, and other sources (Article 4 and Article 2, Permentan No. 18/KB.330/5/2016).

West Aceh Regency has been one of the recipient areas of the oil palm replantation program since 2018. This study is aimed to evaluate the program. "Top-level achievement standards and goals" refer to specific and overarching objectives set by authorities for policy evaluation (Novra *et al.*, 2022). These standards are precise criteria for assessing policy success. At the same time, goals encompass broader, long-term objectives aligned with regional or national development, such as food security, poverty reduction, sustainable land use, and economic and environmental benefits. Evaluation involves using various indicators and metrics, both quantitative and qualitative, to gauge progress and address challenges (Novra *et al.*, 2022).

According to Van Meter and Van Horn (1975), policy implementation success hinges on policy scope and objectives, resource availability, implementing organisation characteristics, inter-organisational communication, implementer disposition, and the broader socio-economic and political context. "Inter-Organisational Communication" involves information exchange between organisations to facilitate collaboration. "Policy Measures and Objectives" specify implementation metrics and goals. "Characteristics of the Implementing Body" refers to the executing organisation's attributes. "Resources" encompass necessary assets. "Attitude towards Implementation" reflects implementer disposition. "Policy Performance" assesses impact and efficiency. Lastly, "Social, Economic, and Political" factors shape policy outcomes, including societal, economic, and political influences (Van Meter and Van Horn, 1975).

Size and Purpose of Policy

The statement "In West Aceh Regency, the local government had proposed 2500 ha in 2021; however, it can be realised 1300 ha in 2019" appears to contain a temporal inconsistency. Assuming that the intended message is that in 2019, the local government successfully replanted 1300 ha of oil palm plantations, while in 2021, they proposed a more ambitious target of 2500 ha, several factors may explain this change. Firstly, policy adjustments could have addressed increasing concerns over environmental sustainability, economic development, or agricultural practices. Secondly, resource availability, funding, or technical capacity may have influenced the ability



Source: Van Meter and Van Horn (1975).

Figure 1. Model approach to the implementation of policies formulated.

to realise the proposed targets. The discrepancy may be due to a typographical error in the years mentioned.

In essence, this discrepancy underscores the dynamic nature of policy implementation, where goals and targets can evolve in response to changing socio-cultural, economic, and environmental conditions and the capacity and resources available for implementation.

Resources

The effectiveness of poverty reduction policies, such as the replantation program, is contingent on resource utilisation. Shortages in essential resources, including financial support, technical expertise, and skilled labour, can impede efficient policy implementation, as evidenced by Johnston *et al.* (2020). A need for more knowledgeable personnel has slowed the replantation process, affecting its quality and pace.

The financial component of the replantation program, overseen by the BPD PKS, plays a vital role in uplifting smallholders' livelihoods. It provides funding for replanting, enabling smallholders to invest in their plantations. Each hectare incurs a cost of 25 million Indonesian Rupiah. However, the efficacy of this financial aid hinges on proficient fund management and accessibility for smallholders.

Empirical evidence underscores the pivotal role of resources in poverty reduction policies. Resource inadequacies, especially financial support, technical know-how, and skilled labor, can impede policy execution. For instance, Johnston *et al.* (2020) highlight how the scarcity of experts has hampered the replantation program, potentially limiting its poverty reduction impact. Moreover, financial support from the BPD PKS holds promise in improving smallholders' livelihoods. Facilitating replanting enables smallholders to enhance yields and income. However, successful implementation relies on efficient fund management and equitable access. Mismanagement or limited access curtail the program's poverty reduction potential. Additionally, the emphasis on sustainable practices aligns with broader policy objectives related to environmental sustainability and economic development. Sustainable practices can bolster long-term economic stability for smallholders while contributing to regional economic and environmental sustainability.

In conclusion, policymakers must holistically address resource requirements for smallholder-focused programs. Besides financial support, facilitating access to technical expertise is critical. Investments in capacity-building and education can mitigate expertise shortages, augmenting the effectiveness of poverty reduction policies. Resource

allocation and utilisation are pivotal in smallholder poverty reduction efforts, necessitating resource gap mitigation for program success and sustainable development impact.

Characteristics of the Implementing Body

Implementing agencies' characteristics significantly impacts policy success, like the replantation program's role in the reduction of poverty especially in rural areas. Effective agencies exhibit expertise, ensuring adept handling of program complexities. Efficiency and accountability in resource management build public trust. Flexibility allows adaptation to changing circumstances. Coordination among institutions, such as fund providers, policymakers, implementers, distributors, and cooperatives, is vital for People's Palm Oil Replanting Program (PSR) alignment. Agencies' objectives should ideally support the PSR's vision, with fund management aiding smallholders. Effective coordination mechanisms, including communication channels and feedback loops, promote synergy among institutions, enhancing the likelihood of achieving PSR goals, particularly poverty reduction and sustainable development.

Communication between Organisations and Executors of Activities

Empirical evidence underscores the crucial role of effective communication in policy implementation, especially within Indonesia's Poverty Reduction Strategy. Given the limited formal education among many Indonesian farmers (Heryanda and Purbadharma, 2021), transparent and accessible communication channels are essential. Research consistently shows that well-executed communication with policy implementers dramatically improves the chances of achieving desired outcomes. Effective communication ensures that individuals understand the policy's standards and objectives, providing a clear path for action. This is particularly critical in poverty reduction efforts, where coordinated actions involving various stakeholders are necessary.

Empirical studies also highlight how communication breakdowns and misconceptions can lead to bottlenecks and inefficiencies in policy execution. When implementers need a comprehensive understanding of the objectives, aligning their actions with the intended goals becomes challenging, potentially resulting in suboptimal outcomes. In the context of the PSR, which aims to reduce poverty and improve the well-being of vulnerable populations, effective communication among policymakers, implementers, and beneficiaries is paramount. It ensures comprehension of policy standards and

objectives and their translation into actions that contribute to poverty reduction. Thus, fostering a culture of transparent and efficient communication within the policy framework is indispensable for achieving the overarching goals of poverty reduction and sustainable development.

Disposition or Attitude of the Executor

Empirical evidence underscores the vital role of policy implementers' disposition in successful policy execution, consistent with findings by Natesan and Marathe (2017). Research consistently demonstrates that the characteristics and attitudes of implementers significantly affect outcomes. Implementers with positive traits are more likely to align with policy objectives as intended by policymakers. Conversely, studies show that when implementers hold contradictory perspectives or dissenting opinions about policymakers and directives, the implementation process becomes complex and less effective. Discord can lead to resistance, delays, or deviations from the intended course, undermining policy outcomes. These findings stress the importance of selecting implementers with the necessary skills and a disposition that aligns with policy goals and policymakers' intentions. Effective policy execution relies on a harmonious, cooperative relationship grounded in mutual understanding and shared objectives supported by empirical research.

Social, Economic and Political Environment

Empirical evidence strongly emphasises the pivotal role played by the social, economic, and political environment in shaping the outcomes of public policy implementation, in line with Quitzow's insights from 2006. Numerous studies have consistently shown that the effectiveness of policies is profoundly influenced by the conditions prevailing in these domains. Economic stability, access to financial resources, and income distribution significantly impact the success of poverty reduction efforts. Similarly, political stability and social cohesion influence the

acceptance and impact of social programs. Policymakers must heed these contextual factors to craft policies aligned with their specific environment, enhancing the prospects of successful implementation. This study is aimed to evaluate the implementation of a replantation program in West Aceh Regency, Indonesia.

METHODOLOGY

This study uses qualitative research methods to evaluate a program implementation. The reason to use qualitative research methods is because it provides detail about social problems. Using an in-depth interview methods is a valuable tool for gaining a comprehensive understanding of PSR's implementation because it helps to answer complex questions, such as how and why efforts to implement may succeed or fail (Hamilton and Finley, 2019). In this study, the method used is qualitative method with a descriptive approach. Qualitative research aims to understand what phenomena are experienced by the subject to be studied, for example, behaviour, perception, motivation, and action holistically, and by way of describing words and language in a context (Moleong, 2006). Therefore, the qualitative approach can be used for a complex social research context.

Primary Data

Primary data was collected from observation and interviews with informants from three different sources identified as targeted respondents for this study as shown in *Table 1*.

This research collects primary data through a mixed-method approach involving observation and interviews with specific informants. Observations entail documenting on-ground activities related to the policy under study, including replantation practices, resource allocation, and implementation challenges. Interviews involve direct conversations with chosen informants, including the head of the Department of Agriculture in West Aceh Regency, a cooperative representative, and four oil palm smallholders.

TABLE 1. RESEARCH INFORMANTS

No.	Informants	Total
1.	Head of Department of Agriculture West Aceh Regency	One person
2.	Cooperative	One person
3.	Oil palm smallholders	Four people

Source: Ardian *et al.* (2018)

The selection of respondents is guided by criteria such as relevance, diversity, expertise, and availability. This ensures that informants have direct knowledge, offer diverse perspectives, possess relevant expertise, and are willing to participate, enhancing the validity and comprehensiveness of the collected data. Employing this comprehensive approach and selective respondent choice aims to gather a rich dataset. This dataset will enable a thorough evaluation of the policy's effectiveness and its impact on various stakeholders. Such a holistic analysis ensures the research captures various perspectives and nuances, providing valuable insights for informed decision-making and potential policy improvements.

Research Location

Arongan Lambalek is a sub-district in West Aceh district, Aceh province. This village is one of the replanting areas chosen by the BPDPKS, and the village received 44 ha of the PSR.

The framework involving government funds through the Ministry of Finance, the Indonesia Oil Palm Plantations Fund Management Agency (BPDPKS), national banks, local agricultural offices, and smallholder farmers is integral to the palm oil sector in Indonesia. Government funds support sector development and sustainability. BPDPKS manages levies and promotes industry competitiveness. National banks facilitate financial transactions and credit. Local agricultural offices oversee compliance and provide guidance. Smallholder farmers are at the heart of palm oil production, responsible for cultivation and adherence to sustainable practices. Together,

they form a comprehensive network supporting the growth and sustainability of the palm oil industry.

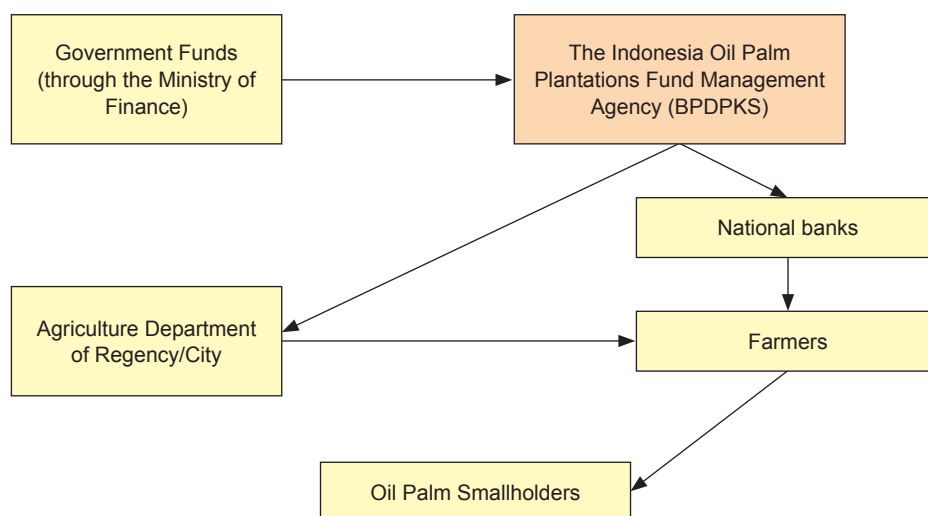
RESULTS AND DISCUSSION

Implementation of the PSR is the government's effort to develop smallholder oil palm plantations by replacing old or unproductive plants with new plants to help the people's economy. The program started in 2016 on the national stage. However, it was only commenced in West Aceh beginning 2018. An in-depth interview with informants has been conducted to gain information regarding the program's implementation to evaluate program implementation by using a model formulated by Van Meter and Van Horn (1975).

Size and Purposes Policy on the PSR

Claims of the PSR success should be approached with a critical perspective, as highlighted by Mr. Mustafa, a local government officer. While the absence of immediate obstacles is positive, more is needed to provide a complete picture of success. A comprehensive evaluation of the PSR should include measuring its impact on poverty reduction, sustainable development, and equitable benefit distribution. Additionally, the effectiveness of socialisation efforts needs assessment to ensure community understanding and engagement.

Furthermore, statistics related to smallholders' farm sizes, program applications, participation rates, production levels, seed certification, and the reach of socialisation efforts are crucial for a data-driven



Source: The Indonesia Oil Palm Plantations Fund Management Agency (BPDPKS) (2020).

Figure 2. The flow of the People's Palm Oil Replanting Program (PSR) fund in West Aceh.

evaluation. Combining qualitative insights with these statistics provides a more informed assessment of the program's impact. A holistic evaluation is necessary to determine the PSR's overall success in West Aceh Regency.

The head of the farmer group who received the palm oil replanting program, Mr. Alwi, on 19 June 2021, said:

"The implementation of this program has been very successful so far; it has been carried out if you look at the oil palm, the palm trunks are large, but if we look further at the implementation process, actually this program has been promoted, and when it was promoted, it was explained how what is the procedure for accepting this palm oil replanting program, but you know for yourself that our people are still unfamiliar and do not trust the program because they are afraid that their land will be taken as the land certificate is one of the conditions for participating in the program."

The assertion that the PSR enhances smallholders' productivity in the West Aceh Regency requires empirical evidence. This evidence should encompass increased production, income, and adopting certified seeds and sustainable practices. Additionally, it is crucial to evaluate the program's long-term sustainability and the equitable distribution of productivity gains. A comprehensive assessment of the PSR's impact on smallholders' productivity demands an examination of these multifaceted factors. According to statistics data, the poverty rate has been decreasing steadily from 2019 to 2021 in West Aceh Regency. The oil palm plantation program has succeeded in increasing community income.

The Resources

The allocation of resources is an integral part of the success of implementing a policy, which includes human and financial resources, as conveyed by the informant, one of the recipients of the palm oil replanting program Van Meter and Van Horn (1975). The interview was conducted to explain the PSR fund the smallholders received.

The same statement was conveyed by the recipient of the program, Mr. Marzuki, on 22 June 2021:

"Beneficiaries like Mr. Abuyed provide concrete evidence of the PSR's positive impact. They receive new plants through replanting funding, boosting plantation sustainability. Mr. Abuyed's statement about proper implementation and

supervision reinforces the program's credibility. Distributing support through cooperatives ensures a structured, transparent process. This local success in Arongan Lambalek illustrates the PSR's effectiveness in empowering smallholders, promoting sustainability, and fostering economic growth in palm oil.

However, there is another opinion expressed by Mr. Abdurahman as the recipient of the program:

"Work began before Ramadan, primarily focusing on land clearance, but only 5 out of 24 ha have been addressed. The village head mentioned efforts to secure additional excavation services but acknowledged a need for tangible progress. Concerns arise as funds have been disbursed to beneficiaries without corresponding progress, prompting a need for a comprehensive investigation into this issue.

The incongruity between the established Standard Operating Procedures (SOPs) and the observed realities regarding the PSR eligibility criteria highlights a critical issue in policy implementation. While SOPs are designed to provide clear guidance and criteria for program access, there needs to be a specific and coherent SOP for the PSR raises concerns. Mr. Mustafa, the head of the community of oil palm replanting program in West Aceh, rightfully points out the lack of a dedicated SOP for the replanting initiative, emphasising the Keputusan Direktur Jenderal Perkebunan Nomor: 29/KPTS/Kb.120/2017.

This discrepancy underscores the importance of a comprehensive and well-defined SOP that aligns with the PSR's objectives and ensures consistent and equitable implementation. Even with a clear SOP, yet, there is a risk of misinterpretation, consistent application of eligibility criteria, and potential disparities in program execution. To enhance the program's effectiveness and fairness, policymakers must establish a robust and specific SOP for the PSR, providing a solid foundation for transparent, consistent, and successful implementation. Such clarity in eligibility criteria is essential for ensuring the program reaches its intended beneficiaries and achieves its poverty reduction goals.

The contrasting statements made by Mr. M. Nasir, the cooperative secretary, and Mr. Abuyed, a PSR recipient, regarding the maximum land allocation allowed under the PSR, underscore a significant issue in policy implementation. While Mr. M. Nasir suggests a maximum of 4 ha per family, Mr. Abuyed's account reveals instances where individuals with more extensive land

holdings exploit family cards to access the program, potentially breaching program rules. These inconsistencies signal a potential breach of SOPs and raise concerns about fairness and transparency in program execution. To uphold program integrity and ensure equitable distribution of benefits, robust SOP enforcement mechanisms, and effective oversight are imperative. This ensures that the PSR adheres strictly to its established SOPs, fostering transparency and fairness while advancing its objectives.

Communication between Organisations and Activities Implementer

Communication plays a pivotal role in policy implementation, and its significance becomes evident in the PSR process due to unclear information delivery. This miscommunication between PSR recipients and various stakeholders is discernible from the study. Mr. Mustafa, who oversees the Agriculture Department of West Aceh Regency program, shed light on the distribution process in his interview. He explained,

“The distribution process is facilitated directly to the community. Our cooperatives assist in ensuring the program’s smooth operation, aiming to preempt any on-field challenges. The cooperatives are instrumental, operating under our supervision, with the intent of ensuring seamless program execution.”

This statement underscores the importance of effective communication channels and cooperative involvement in program distribution while maintaining supervision for optimal outcomes.

However, Mr. Abdurahman posed different views as one of the advocates of the PSR as he said:

“The work is already underway, but it seems like it is being blocked in the middle of the road because it has been a long time even until now it is not clear why we have not started the process of logging our land, we have asked the group leader, but it is still the same as there is no definite answer regarding our land.”

A similar assessment was echoed by Mr. Safrizal, a recipient of the PSR fund, who noted that while some progress had been made, land clearing remained incomplete, and the reasons for this were unclear. He suggested that the issue might not be related to fund availability, as the money had already been deposited in their bank accounts. However, a need for more understanding about the program persisted among many villagers in their community.

Examining statistics from the BDPDKS for 2020 revealed that the PSR’s implementation has fallen short of its targets since its inception in 2016. For instance, in 2018, the program achieved only 12 611 ha out of a planned 180 000 ha. Similarly, in 2019, the target was 180 000 ha, but only 90 207 ha were realised. The actual realisation of the PSR was 94 248 ha.

In summary, the assessment of communication in implementing the PSR in Arongan Lambalek District, West Aceh Regency, indicates that the program needs to improve in effective communication, leading to miscommunication in its implementation. *Table 2* illustrates that only 46.9 ha were covered under the PSR in 2020, further underscoring the program’s communication-related issues.

TABLE 2. LIST OF RECIPIENTS OF PSR AT ARONGAN LAMBALEK DISTRICT WEST ACEH REGENCY IN 2020

No.	Name of farmers	Address	Land area (ha)
1	Ariyadi umar	Karak	4
2	Bukhari Jakfar	Peuribu	4
3	Dadang Fahrudin	Karak	4
4	Fikrizal	Karak	4
5	M. Saleh Idris	Keub	3
6	Marzuki The	Peuribu	4
7	Rahmad Hidayat	Karak	4
8	Rahmad Taufik	Karak	4
9	Razali Z	Arongan	3.7
10	Said Alwi	Peulanteu LB	4
11	Sulaiman Z	Peulanteu LB	0.6
12	Syarifuddin P	Peuribu	3.6

Source: Agriculture Department of Aceh Province (2020).

Disposition or Attitude of Executor

According to the decree from the Director for Plant Ministry of Agriculture No: 29/KPTS/KB.120/3/2017, cooperatives have a responsible action for replanting. Based on the disposition aspect interview, the PSR implementation did not go hand in hand because there were differences in the implementation and entry processes. As stated by Mr. M. Nasir, secretary of the Mandiri Jaya Beusare Cooperative, who works for land clearing until the replanting process or executor:

“Once the registration process is completed, we forward the list of applicants for replanting to the Department, followed by verification and land suitability assessments by relevant agencies. If the land is deemed suitable, we facilitate the creation of a bank account for the farmer. Once the funds are transferred, we initiate the replanting process, handling it comprehensively. Farmers receiving the program only need to oversee our work.”.

However, Mr. Safrizal as one of the program recipients, said:

“The progress of the work remains stagnant and has yet to advance beyond the initial logging phase. Additionally, he expressed concern about being excluded from the program if the initial work still needs to be completed. This situation significantly contrasts with what was conveyed during the program’s socialisation phase, indicating a substantial discrepancy between its promises and current status”.

Social, Economic and Political Environment

Policy implementation is also influenced by the social, economic, and political environment (Van Meter and Van Horn, 1975). Fundamentally, the impact of economic and political conditions on public policy has been the focus of attention over

the past decade. People comparing state politics and public policy are particularly interested in identifying the impact of economic, social, and political conditions on public policy, the focus of much attention during the last decade.

The national benchmark for poverty rates varies between countries, is determined by government authorities, and is typically based on income thresholds necessary to meet basic needs. Poverty rates are the percentage of people living below the national poverty line.

The objectives and benchmarks of a Poverty Reduction Strategy are contingent on government or implementing agency goals. PSR aims to diminish poverty and enhance well-being. Benchmarks may encompass targets for income, access to education, healthcare, employment opportunities, and other poverty-related factors.

Whether a reduction of less than 1% is acceptable relies on factors like the initial poverty rate, PSR duration, and policy context. A minor reduction could sometimes signify significant progress, particularly with a low baseline poverty rate. Acceptability hinges on the specific circumstances and PSR’s broader objectives.

Table 3 indicates a declining poverty rate in West Aceh Regency, albeit higher than in Aceh Province and the national level. In 2021, it shows that declining of poverty in West Aceh Regency. This suggests the PSR’s role in reducing regional poverty, although it may still need to fully bridge social and environmental well-being gaps in oil palm-growing villages (Santika *et al.*, 2019).

CONCLUSION

The article concludes with several recommendations for the evaluation of the PSR program in West Aceh Regency. The program has begun in 2018 in Arogan Lambalek village. It received 44 ha of replantation. PSR is a government initiative to enhance the productivity of ageing or unproductive oil palm plantations in Indonesia. It was created in response to the low productivity of smallholders’ palm oil plantations, which adversely affected their income.

TABLE 3. PERCENTAGE OF POVERTY RATE IN INDONESIA, ACEH PROVINCE, AND WEST ACEH REGENCY

Year	Indonesia	Aceh Province	Aceh Barat Regency
2018	9.82	15.97	19.31
2019	9.41	15.32	18.79
2020	9.78	15.99	18.34
2021	10.14	15.33	15.33

Source: Indonesian Statistic Agency (2022).

Drawing upon the policy implementation framework outlined by Van Meter and Van Horn (1975), our evaluation of the PSR's implementation in the Arokan Lambalek district of West Aceh in 2018 revealed several challenges. These challenges included a need for more transparency in resource allocation, ineffective communication by implementers, and a perceived lack of commitment among program executors.

However, it is essential to note that our study did not provide clear evidence or arguments indicating the program's success in Aceh Barat Regency, particularly in poverty reduction. The findings did not substantiate the program's impact on poverty rates in the region, suggesting the need for further analysis and data to assess its effectiveness.

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RESEARCH TRENDS IN PALM OIL MILL EFFLUENT (POME) WASTEWATER TREATMENT USING BACTERIA IN MALAYSIA: A SYSTEMATIC REVIEW

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ABSTRACT

The development of POME wastewater treatment using the appropriate bacteria and biological treatment will result in a certain level of management and laboratory abilities that can affect the treatment's overall effectiveness. POME wastewater treatment requires effective microbes to adapt to shifting possibilities and demands. However, little is known about how is the treatment defined, workings, and its biological approaches with POME wastewater treatment, both on a pilot and larger scale. Not to add, an explanation of wastewater treatment from an economic standpoint as well. This study aims to review POME treatment trends and the relationship between bacteria and treatment, as well as how the biological influences treatment. A descriptive content analysis approach was used to go through 2054 reviews, conceptual, empirical, and commentary pieces that were published in journals from Scopus and Web of Science. Every pertinent piece of information was taken out of each article and examined. Excel software was used to analyse the data that was taken from the publications. Economic view also included. Results revealed that, after removing extraneous material from 2054 articles, only three publications specifically addressed bacterium species and Malaysian scholars. Parabacteroides, Bellilinea, Levilinea, Smithella, Prolixibacter, and numerous other bacteria are among those mentioned in the publications. Some improvements have been observed before and after treatment, and the presence of bacteria did have a significant influence on the chemical reaction, which is evidence of POME treatment. To sum up, the paper will contribute to the global knowledge base and recent efforts to improve the current situation (too long HRT), particularly for new research with perspective approaches (biological treatment) to the field.

Keywords: bacteria, POME, treatment, trends, wastewater.

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INTRODUCTION

According to calculations made during the milling process based on 2.5 m³ of raw Palm Oil

Mill Effluent (POME) generated, a total of 43.29 million m³ of raw POME were created annually from a significant amount of water used in the processing (MPOB, 2016; Zainal *et al.*, 2017). Wu *et al.* (2009) reported that to process 1.0 t of crude palm oil (CPO), it would require 5.0 to 7.5 t of water, with the remaining 50% of this water ending up as wastewater effluent. It is reported that in 2023 itself, Malaysia's total CPO production reached 18.55 million tonnes, 0.53% higher than a year ago (Palm Oil Analytics, 2024). As a result, the amount of water required in the process keeps increasing. Raw POME is an additional useful biomass source. It is a thick, brownish liquid effluent with high organic content and significant

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solid content that has the indirect potential to contaminate the environment, especially the atmosphere and waterways. Raw POME is an acidic effluent with a very low pH of 3.5 to 4.2, high chemical and biological oxygen demands (COD and BOD), and high total suspended solids (TSS) of 51 000, 25 000, and 18 000 mg/L, respectively (Zainal *et al.*, 2017). It required mill operators to pay a high fee, and handling the waste was very challenging (Madaki and Seng, 2013). Therefore, the Department of Environment (DOE), Malaysia, adopted the Environmental Quality Act (EQA) 1974 and set regulatory limits for the discharge of POME into the environment in order to control and reduce the impact of pollution on the environment (Mohamad *et al.*, 2021).

Ponding systems are a common industrial POME treatment approach; however, they have an economic disadvantage due to their requirement for vast land area (30-45 acres) and long hydraulic retention time (HRT) (100-160 days). Here, it is necessary to develop low-cost materials and make use of materials that are already available so that they can be used more profitably on an industrial scale. Research interest in the alternative production strategy to partially replace the outdated open-ponding system has increased as a result of the aforementioned issues. Particularly for the biological therapy of POME in the presence of microbial cultures such as bacteria, fungus, yeast, microalgae, and others, which have been the focus of numerous recent studies (Mohamad *et al.*, 2021).

A systematic review is an examination of a well-defined research issue that uses specific and systematic procedures to find, evaluate, and critically assess pertinent studies, as well as gather and process data from the studies that are part of the review. The results of the included studies may or may not be analysed and summarised using statistical techniques (meta-analysis). Meta-analysis is the use of statistical methods in a systematic review to combine the findings of the included research (Moher *et al.*, 2009).

For this study, three primary components comprise the conceptual framework that the authors developed: Methodology, conceptual model, and topical foci. The primary themes or subjects covered in the examined papers are referred to as topical focuses. The authors first determined which subjects—such as organisms, biological treatment, *etc.* frequently appear in other recent studies on POME treatment before compiling a list of such subjects. The list of topics was completed at the end of the analysis by iteratively adding more as needed. The second part of the authors' framework focuses on the conceptual models used in the studies that are being examined. A methodology component, which deals with the tools and techniques used in methodological research, wraps up the authors'

conceptual framework. This dimension includes both the cultural type (single or mixed) and the strategy.

This study sought to answer the following research questions by synthesising and reviewing the empirical literature on bacteria and biological trends related to POME wastewater treatment in Malaysia;

- RQ1. What are the trends in POME wastewater treatment in Malaysia using bacteria species?
- RQ2. What is the relationship between the trends and POME wastewater treatment?
- RQ3. How is the influence of these trends on POME wastewater treatment in Malaysia?

THE ECONOMICS OF BIOLOGICAL TREATMENT METHOD

In tropical nations, particularly those in Southeast Asia, the palm oil industry has emerged as the primary driver of economic growth. Recent years have seen an increase in palm oil production worldwide, which reached 72 million tonnes in 2018 from roughly 68 million tonnes in 2017. With 84.0% of global production at that time, Indonesia and Malaysia were the world's top exporters of palm oil. From 24.88 million tonnes in 2018 to 27.88 million tonnes in 2019, the total amount of oil palm products exported from Malaysia climbed by 12.1%. However, it was said that the drop in global trade prices resulted in a 4.0% fall in overall export earnings to RM64.84 billion (Kristanti *et al.*, 2021).

The biological treatment method that has been available in Malaysia for the past 20 years to cure POME consists of facultative, anaerobic, and aerobic pond systems. The majority of palm oil mills have used anaerobic digestion as their main method of treating POME. For treatment, more than 85% of Malaysian palm oil mills have chosen to use ponding systems; the remaining mills have chosen to use open digesting tanks. These techniques, which call for lengthy retention periods and extensive treatment areas, are recognised as traditional POME remediation techniques (Abdurahman *et al.*, 2013).

The evaporation method, membrane treatment systems, and aerobic treatment are the currently available alternatives for treating POME. Anaerobic digestion has a bigger benefit over the other alternative methods in terms of energy need for POME treatment operation since it does not require energy for aeration (Haris, 2006; Soo *et al.*, 2022; Vijayaraghavan *et al.*, 2007) (Table 1). Moreover, methane gas (CH₄), a value-added byproduct of digestion that the mill can use to increase Certified Emission Reduction (CER) revenue, is produced

by the anaerobic POME treatment. For instance, a palm oil mill processing 30 t of FFB/hr quoted a capital cost of RM750 000 for an open digesting tank for POME treatment without land application. The system's estimated in 2006 capital cost is USD370 272, according to the Chemical Engineering Plant Cost Index. This is clearly more advantageous than other treatment methods in terms of capital cost when compared to the membrane system's cost for POME treatment at RM3 950 000 for a palm oil mill processing 36 t of FFB/hr (Abdurahman *et al.*, 2013).

Anaerobic treatment has two drawbacks: A lengthy retention period and a lengthy start-up period. While the lengthy start-up period can be reduced by using granulated seed sludge, using seed sludge from the same process, or keeping the high-rate anaerobic bioreactor at a suitable pH and temperature for the growth of bacterial consortia, the issue of long retention times can be resolved by using these bioreactors (Abdurahman *et al.*, 2013).

METHODOLOGY

This work complies with the recommendations for conducting systematic reviews. First, a systematic review study is used to identify the main areas of interest, research questions, and objectives using this framework. The next stage is to find, pick, assess, and examine pertinent publications using a conceptual point of view. The sources of the data are then discussed, along with the procedures used for analysis and synthesis. Finally, it discusses the implications, limitations, and conclusions.

Data Collection and Analysis

Identification of sources. For this section, the authors chose to use the Web of Science (WoS) database and Scopus to access the publication. The evaluation period is not limited, although the authors concentrated on studies published between 2019 and 2023, which is five years later. The following search term was chosen because it yielded the most representative data set out of all the ones they attempted searching for in the Scopus and WoS databases:

Scopus:

- i) TITLE-ABS-KEY(palm oil mill effluent AND treatment)
- ii) TITLE-ABS-KEY (palm AND oil AND mill AND effluent AND treatment) AND PUBYEAR > 2018 AND PUBYEAR < 2024 AND (LIMIT-TO (SUBJAREA, "ENVI")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (EXACTKEYWORD, "Palm Oil Mill Effluents"))OR LIMIT-TO (EXACTKEYWORD, "Wastewater Treatment")) AND (LIMIT-TO (AFFILCOUNTRY, "Malaysia"))

WoS:

- i) ALL = (palm oil mill effluent AND treatment)
- ii) Results for palm oil mill effluent AND treatment (All Fields) and Review Article (Document Types) and 2023 or 2022 or 2021 or 2020 or 2019 (Publication Years) and Review Article (Document Types) and English (Languages) and Environmental Sciences Ecology (Research Areas)

TABLE 1. ADVANTAGES AND DISADVANTAGES OF VARIOUS TREATMENTS

Treatment	Efficiency	Advantages	Disadvantages
Evaporation method	85.00%	The process' solid concentrate can be used as a feedstock for the production of fertiliser.	High usage of energy.
Membrane treatment systems	99.03%	Reduced space needed for membrane treatment plants, constant and high-quality water quality after treatment, and the ability to disinfect treated water.	Membrane fouling, short membrane life, and high cost in comparison to traditional treatment.
Aerobic treatment	57.00%, 45.00%, 38.00%, 30.00% and 27.00%	Retention period shorter and more efficient for managing harmful wastes.	Because aerobic sludge requires more energy (aeration) and inactivates pathogens more slowly than anaerobic sludge, it is not appropriate for use on land.
Anaerobic digestion	93.90%	Reduced energy needs (no aeration), the production of methane gas as a valuable byproduct, and the possibility of using the process's created sludge for land uses. Does not require energy for aeration. Cheap.	Long retention period and huge space needed slowly start traditional digesters (granulating reactors).

There were 881 research and review articles in WoS and 1173 in Scopus as a result of this search. The authors filtered and examined every article to remove those that did not fit the field. The data set did not include the out-of-scope articles that focused largely on a range of other disciplines, like engineering, chemical engineering, and many others. Articles pertaining to environmental sciences are the only ones chosen. As a result, there were 114 articles altogether in the data set that was derived from the WoS (22) and Scopus (92) databases. The authors then went through each article's title and abstract to find those that were co-authored or written by Malaysian academics within the same time frame. Using this method, 3 (Scopus) and 5 (WoS) articles were found. For these 8 publications, inclusion and exclusion criteria were used. The inclusion criteria set by the authors are founded on studies conducted by Malaysian scholars, studies of Malaysian organisations, and studies with bacteria for treatments. Research on other nations, research on other microorganisms, and research on other materials outside the scope of biological treatment are the exclusion criteria. Three articles in total that were closely related to bacteria, POME, and studies conducted in Malaysia were included in the review after merging the two data sets and eliminating any overlapping ones (Figure 1).

Data extraction. This stage involved extracting from each publication the data pertinent to the authors' study questions (3 articles). A spreadsheet was used to compile the extracted data. For instance, in the "research with bacteria" column, single bacteria as 1, double bacteria as 2, and mixed bacteria were scored as 3. After going over each article's content, the authors created different lists of codes. After that, the two lists were compared, and the differences were talked about. In cases where there was a disagreement, the best category for each article was chosen before data analysis by taking into account the views of subject-matter experts.

Data analysis. The data analysis procedure used Excel. Every research question was addressed in light of every discovery. To find trends and patterns of knowledge production for the relevant research from this developing region, a review of data analysis was carried out. The objective was to expedite the process of formulating suggestions for novice investigators who possess the suitable generation and historical context. Despite the fact that this study was restricted to research conducted in Malaysia, we compared it to other recent evaluations of relevant literature from across the world.

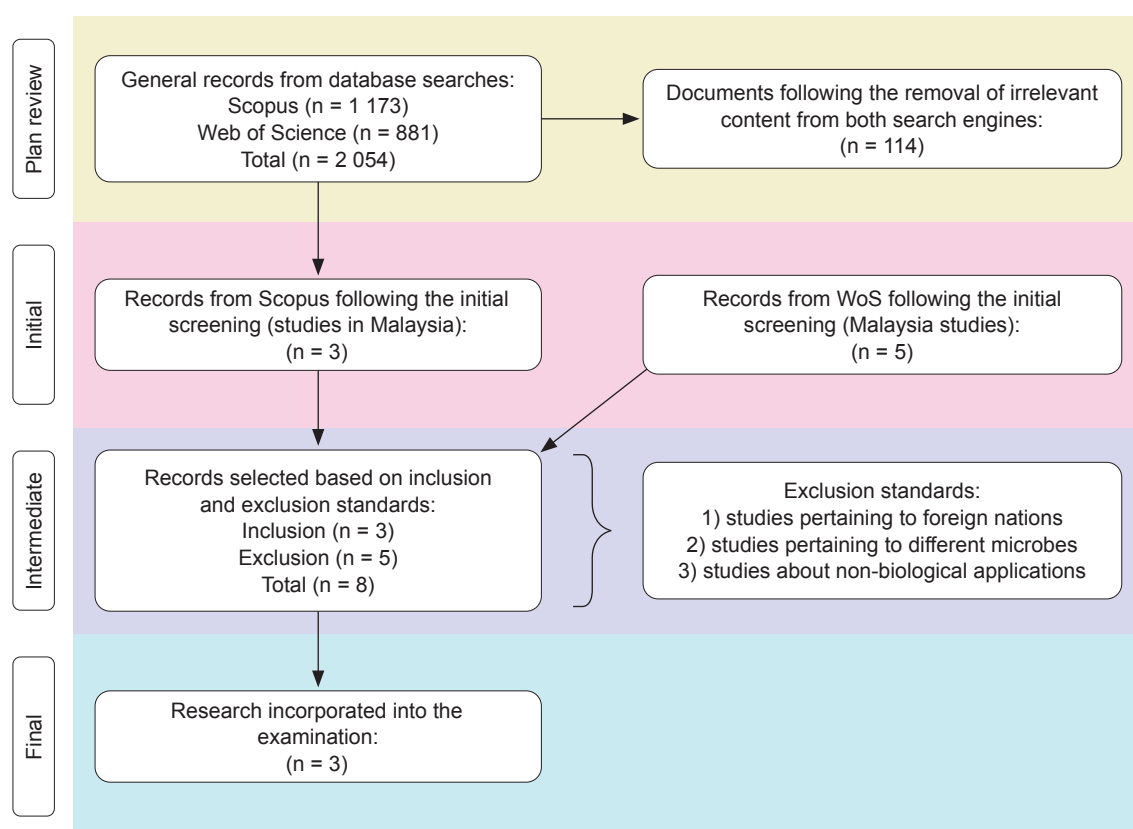


Figure 1. Research flow in this study.

RESULTS AND DISCUSSION

From the authors findings, only three articles from both Scopus and WoS are reported and mentioned specifically on bacteria species and POME treatment, especially from Malaysia's scholars. Others are explained about POME treatment using bacteria or microorganisms in general. Therefore, the authors only explained the research trends of bacteria species in POME treatment based on three articles and only responded to their research question. Otherwise, the authors will discuss and add on additional information when necessary to support the findings. The authors believe the updated POME treatment research trends, specifically with bacteria species, can offer beneficial information for future research improvement.

In response to the authors research questions, the review found that:

- RQ1. What are the research trends of POME wastewater treatment in Malaysia using bacteria species?

After excluding unrelated papers (based on publication type, language, field, year, etc.), the search yielded 2054 articles that examined POME wastewater treatment utilising bacteria trends in Malaysia. The total number of articles was then reduced to 114. Following a preliminary screening, eight papers were compared to the inclusion/exclusion criteria that the authors could obtain from the abstract and title. Three empirical research studies were left, and these three studies served as the main subject of this review. Nevertheless, the authors choose to talk about these three papers that particularly addressed the species of bacteria used in POME treatment in Malaysia after carefully examining all the article's detailed material (Table 2).

From Table 2, it can be seen the bacteria trends in POME wastewater treatment in Malaysia as reported in 2022 are *Parabacteroides*, *Bellilinea*, *Levilinea*, *Smithella* and *Prolixibacter*; *Nitriliruptor*, *Delftia*,

Filomicrobium, *Steroidobacter* and *Ohtaekwangia*; *Steroidobacter*, *Nitriliruptor*, *Anaeromyxobacter*, *Filomicrobium* and *Filomicrobium*; *Devosia yakushimensis* and *Desemzia incerta*; *Planococcus rifietoensis* that were found in POME anaerobic sludge. Meanwhile, in 2020, the bacteria trends are *Bacillus velezensis*, *Pseudomonas aeruginosa* (strain IASST201), *Achromobacter xylosoxidans*, *Streptomyces* sp. *Gansen* and *Cellulomonas* sp. *Okoh* have been used together with biofloculant. In the same year of 2020, *B. subtilis* mixed with *Methanosarcinales* and *Methanobacteriales* and combined with bio-augmentation to treat POME wastewater were also reported for the treatment (Table 2). All studies used mixed culture approach to treat POME wastewater (pilot scale).

To summarise, from these three articles, the authors found that the research trends specifically mentioned on bacteria species in POME wastewater treatment whether in the mixed or single culture form, in pilot scale, within review and research articles, direct treat or changing the waste to beneficial form are *Parabacteroides*, *Bellilinea*, *Levilinea*, *Smithella*, *Prolixibacter*, *Nitriliruptor*, *Delftia*, *Filomicrobium*, *Steroidobacter*, *Ohtaekwangia*, *Steroidobacter*, *Nitriliruptor*, *Anaeromyxobacter*, *Filomicrobium*, *Filomicrobium*, *D. yakushimensis*, *D. incerta*, *P. rifietoensis*, *B. velezensis*, *P. aeruginosa* (strain IASST201), *A. xylosoxidans*, *Streptomyces* sp. *Gansen* and *Cellulomonas* sp. *Okoh*, *B. subtilis* mixed with *Methanosarcinales* and *Methanobacteriales* and combined with bio-augmentation (from year 2020-2022).

- RQ2. What is relationship between the research trends and POME wastewater treatment?

In Malaysia, POME anaerobic sludge is easily accessible and comes in big quantities. The production of palm oil generates a large amount of POME waste, which is then treated by anaerobic digestion to produce POME anaerobic sludge.

TABLE 2. CURRENT POME TREATMENT RESEARCH TRENDS IN MALAYSIA

Bacteria species	Method approaches	References
<i>Parabacteroides</i> , <i>Bellilinea</i> , <i>Levilinea</i> , <i>Smithella</i> and <i>Prolixibacter</i> (in POME) <i>Nitriliruptor</i> , <i>Delftia</i> , <i>Filomicrobium</i> , <i>Steroidobacter</i> and <i>Ohtaekwangia</i> (surface compost) <i>Steroidobacter</i> , <i>Nitriliruptor</i> , <i>Anaeromyxobacter</i> , <i>Filomicrobium</i> and <i>Filomicrobium</i> (inside compost) <i>Devosia yakushimensis</i> and <i>Desemzia incerta</i> (thermophilic stage), <i>Planococcus rifietoensis</i> (co-composting)	Mechanical rotary drum reactor, POME anaerobic sludge	Sabiani and Awang (2022)
<i>Bacillus velezensis</i> <i>Pseudomonas aeruginosa</i> (strain IASST201) <i>Achromobacter xylosoxidans</i> <i>Streptomyces</i> sp. <i>Gansen</i> and <i>Cellulomonas</i> sp. <i>Okoh</i>	Biofloculant	Hassimi et al. (2020)
<i>Bacillus subtilis</i> and <i>Methanosarcinales</i> and <i>Methanobacteriales</i>	Bio-augmentation	Chin et al. (2020)

POME is an excellent microbial seed for composting since it is thicker anaerobic sludge. The study found that knowing the functions of different microorganisms, like bacteria and fungus in EFB-POME compost is essential for evaluating the efficacy of composting and producing high-quality compost (Sabiani and Awang, 2022). It demonstrates that treating POME wastewater with bacteria alone would not be effective. Nonetheless, attempts have been made to mix and combine various methods and species. From here, progress in the course of treatment can be shown (Table 3).

In their review, Sabiani and Awang (2022) stated that the ideal and suggested pH value for the finished compost is the decline of the pH profile. After 111 days, the carbon/nitrogen (C/N) ratio was 10.29, indicating that the compost had reached maturity and was ready to be used as an organic fertiliser in farming. Furthermore, no heavy metal elements were found, indicating that the compost was of excellent quality. This state is highly useful for tracking the maturity of the compost and the advancement of co-composting since it illustrates how the bacterial population shifts throughout the process, influencing physicochemical parameters like moisture content, temperature, and oxygen concentration.

In contrast, extracellular biopolymers secreted by microorganisms: Fungi, algae, yeast, and bacteria are known as biofloculants. Specific media are used as feedstocks for fermentation in most biofloculant production processes. An effective feedstock for the production of biofloculants could be high-nutrient palm oil mill effluent (POME) (Hassimi *et al.*, 2020).

Additionally, it was noted that the biofloculants' hydroxyl and carboxyl groups constitute important chemical functional groups for flocculation since they strongly bind to particles and other chemical contaminants. Furthermore, the biofloculants generated in POME demonstrated

a robust stretching vibration in contrast to those derived from sago mill effluent (SME) and synthetic media, which demonstrated the least amount of stretching. A study revealed that xylose and deoxy-rhamnose sugar were present in the biofloculant made by *P. aeruginosa* (strain IASST201). A biofloculant that was partially purified and generated from a strain of *A. xylosoxidans* revealed the presence of either glucose or galactose at 160.84 m/z. Additionally, the study discovered a range of distributions in the molecular weights of the chemicals in a biofloculant made by *Streptomyces* sp. Gansen and *Cellulomonas* sp. Okoh grown in synthetic medium using mass spectrometry analysis (Hassimi *et al.*, 2020).

The employment of particular microorganisms to increase the desired microbial population while also speeding up the breakdown process and producing more methane is known as bio-augmentation. To help break down empty fruit bunch (EFB) and POME, mixed methanogens and *B. subtilis* were employed. *Methanosarcinales* proliferate in garbage by catabolising methyl molecules or converting acetate to methane and carbon dioxide. However, methanobacterial organisms convert hydrogen and carbon dioxide into methane gas (Chin *et al.*, 2020).

Taking into account the study by Nuid *et al.* (2023), the use of bio-augmentation synergistic with biogranulation using a lab-scale sequencing batch reactor (SBR) system under alternating anaerobic and aerobic conditions, there is excellent settleability with improved treatment efficiency after 60 days of being bioaugmented with the *Serratia marcescens* SA30 strain and the flocculent biomass transformed into biogranules. This finding showed that the proposed technique can enhance the biodegradation of oil and grease (O&G) and is capable of treating real AD-POME in the future (Nuid *et al.*, 2023).

TABLE 3. RESULTS FROM BACTERIA TREATMENT AND METHOD APPROACHES

Bacteria species	Method approaches	Results	References
<i>Parabacteroides</i> , <i>Bellilinea</i> , <i>Levilinea</i> , <i>Smithella</i> , and <i>Prolixibacter</i> <i>Nitriliruptor</i> , <i>Delftia</i> , <i>Filomicrobium</i> , <i>Steroidobacter</i> , and <i>Ohtaekwangia</i> <i>Steroidobacter</i> , <i>Nitriliruptor</i> , <i>Anaeromyxobacter</i> , <i>Filomicrobium</i> , and <i>Filomicrobium</i> <i>Devosia yakushimensis</i> and <i>Desemzia incerta</i> , <i>Planococcus rifietoensis</i>	Mechanical rotary drum reactor, POME anaerobic sludge	pH profile decline to 7.59, the C/N ratio was 10.29, extremely low amounts of heavy metals, changes in physicochemical properties	Sabiani and Awang (2022)
<i>Bacillus velezensis</i> <i>Pseudomonas aeruginosa</i> (strain IASST201) <i>Achromobacter xylosoxidans</i> <i>Streptomyces</i> sp. Gansen and <i>Cellulomonas</i> sp. Okoh	Biofloculant	Biofloculant yield (2.03 g/L) at a temperature of 40°C	Hassimi <i>et al.</i> (2020)
<i>Bacillus subtilis</i> and <i>Methanosarcinales</i> and <i>Methanobacteriales</i>	Bio-augmentation	75% reduction in methane production	Chin <i>et al.</i> (2020)

In short, the relationship between the bacteria research trends and POME wastewater treatment is that the bacteria have improved the quality of waste significantly after the treatment. This can be confirmed with the comparison results between before and after treatment, in particular the pH profile of wastewater, the C/N ratio obtained, extremely low amounts of heavy metals left from waste, changes in physicochemical properties, and a 75% reduction in methane production (carcinogenic compounds). At the same time, the treatment can also produce beneficial products such as bio-flocculant.

- RQ3. *How is the influence of these research trends towards POME wastewater treatment in Malaysia?*

The mixture culture of bacteria species for POME wastewater treatment has been identified together with method approaches. From these findings, we can predict how the treatment works and how effectively the bacteria have been utilised in wastewater treatment. The POME anaerobic sludge's COD concentrations, total solids, volatile solids, and water content were 57.77%, 8.43%, 68.30% and 91.50% mg/L, respectively. Thickened POME anaerobic sludge is an ideal microbial seed for the composting process since it is high in nutrients, including potassium (6.5%), phosphorus (1.3%), and nitrogen (4.7%), as well as native microorganisms. When thickened POME sludge is applied during the composting process, the amount of compost produced can be increased while the composting period is shortened. Some of these bacteria used the waste as their nutrient and energy sources, and on the other side, the bacteria converted their foods into something beneficial to humans, for example, gas, fuel, and many others (Sabiani and Awang, 2022).

Since POME includes a lot of cellulose (Bakar *et al.*, 2020), adding cellulolytic *B. subtilis* will help to produce the enzyme cellulase, which can break down cellulose into simpler sugars. In contrast, a class of bacteria known as methanogens uses acetate as a food source and uses anaerobic environments to create carbon dioxide and methane. Consequently, including methanogen species into the substrates will quicken the rate and production of methane gas (Chin *et al.*, 2020).

With the economy fluctuating globally nowadays, it is important to see the cost of operating, procedures for operation, and efficient methods applied to the whole treatment process. This will influence the decision to use which research trends to treat the waste.

However, it is reported that methanogenesis reactions in POME can produce approximately more than 0.8 L of biogas per gram with methane

concentrations above 50%. Numerous research projects have been undertaken in an effort to maximise the profitability of POME biogas generation. The economic viability of various bioreactor layouts that have been investigated to maximise biogas output is unknown. Numerous technological approaches have also been investigated to maximise the production of biogas from POME particularly those that help boost the production of biogas using co-substrates and POME pretreatment methods. A study on the techno-economics of using biogas from POME as compressed natural gas (Bio-CNG) was also conducted in Malaysia. The results indicated that the system that uses membrane separation technology for biogas purification has the shortest payback period value and is the most cost-effective as a result. These studies demonstrate the growing diversity in biogas generating technology from POME. It offers a wide range of substitute technological choices to maximise biogas output from POME and make it sustainable and economically appealing. However, there is still need for more research into these techno-economic elements due to the complexity of the problems surrounding POME processing for sustainable environmental practices and renewable energy. Just a few numbers of research on the techno-economic aspects of the aforementioned renewable energy utilisation systems have examined the use of POME for the production of biogas, which is then used to generate electricity (Sodri and Septriana, 2022).

In addition, it is reported that the potential for POME biogas collection to produce energy with an annual revenue of RM3.8 million for a palm oil mill (POM) with a production capacity of 60 t/hr and it was mentioned a number of obstacles to the biogas system's dissemination in Malaysian POMs. The most recent review of the benefits and drawbacks of POME biogas collection and utilisation, including the most recent Malaysian policies, was recently completed by Loh *et al.* (2017) and Yap *et al.* (2021). POME biohydrogen production, particularly yield from the treatment can be used as carbon source through dark fermentation process and has potential to be bioenergy and act as alternative renewable energy source (Arisht *et al.*, 2022). Although numerous articles have been written about the benefits, challenges, and opportunities of using POME-based biogas in Malaysia and assisting with the installation of biogas facilities at POMs, no paper has addressed the advantages of removing POME from the design of an integrated palm oil complex as an alternate strategy to lower the palm oil sector's GHG output. Reducing POME production in POMs actually has a lot of potential to improve the palm oil industry's sustainability and profitability. For mill owners to have options, a comparison of POME eradication and utilisation from several angles particularly those related to the economy and

environment is necessary whom biogas capturing is of no importance to. One way to address the knowledge gaps in industrial symbiosis attempts in the palm oil industry is to analyse potential process integrations within the palm oil supply chain (Tan and Lim, 2019).

In a nutshell, the influence of these research trends on POME wastewater treatment in Malaysia is the result of treatment and economic growth. Discharging wastewater on public land may cause unpleasant effects on the environment as well as human well-being. However, treating the waste with suggested bacteria species together with other integrated technology might have the potential to produce the best results as the bacteria can use chemical compounds from waste as their energy and food. Taking together the resultant of wastewater after treatment with their impact on the economy, especially in Malaysia, the beneficial product, for example, methane gas, somehow has the potential to limit Malaysia's reliance on renewable resources while also having a good impact on the economy.

Limitation. Two major limitations apply to the review that this study presents. Despite having a large number of articles under review, there is a dearth of research on the subject matter published in Scopus and WoS according to keyword searches. Research on the topic is currently ongoing, and more research is necessary to gain a deeper knowledge of it. Secondly, papers from proceedings, books, conferences, theses, and dissertations are not included in the study; only articles.

CONCLUSION

Our approach to study on research trends particularly in subsequent year for treating the discharged waste is greatly influenced by the utilisation of bacteria and biological treatment, which is an intriguing technique in today's treatment research trends. How much its utilisation can improve things in a lab-scale setting for large-scale endeavours. Because it enables the bacteria to be more agentically and behaviourally engaged with the waste and treatment, our work suggests that using bacteria and biological treatment as a handy tool has a huge potential to improve treatment and performance. In this study, three articles were firmed to report on POME treatment using bacteria. The significant effect and relationship between both bacteria and POME treatment has been discussed in the manuscript. This research indicates that the benefits of treatment may be achieved by successfully integrating bacteria and biological treatment potentially on a larger scale. Though the success of such integration depends

on a variety of factors, such as the treatment's perspective on the use of mixture culture, there are some limitations to the integration of bacteria and biological treatment in particular waste concentrations. Therefore, in light of this, scholars and decision-makers would want to conduct a thorough investigation of the efficacy of combining biological treatment with bacteria as a component of regular treatment of particular wastewater. This means that more research should be done by broadening the sources from which articles are obtained, for instance by focusing on a particular publisher's study, extracting information from conferences, proceedings, books and theses, as well as relating to industry policies about biological treatment. Certain biological treatments also result from straightforward strategies and interactions with various wastes, not just relying on one study.

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THE IMPACT OF ASYMMETRIC RELATIONSHIP BETWEEN CRUDE OIL AND PALM OIL PRICES ON THE PALM OIL INDUSTRY

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ABSTRACT

The implementation of the palm biodiesel blend mandate in Malaysia has created new demand for palm oil, thus making the prices of both crude oil and palm oil move in tandem. Generally, the increase in demand for biodiesel products has resulted in a reduced supply of palm oil, which in turn has increased the price of crude palm oil (CPO) in the world market. However, the unpredictability of price movement which is highly influenced by the market situation and sentiment sometimes makes the relationship between both prices loosen. The motivation of this study is to analyse the relationship between Brent crude oil (BCO) and CPO using a non-linear autoregressive model (NARDL) for the period 2010-2019. By applying the Brock Dechert and Scheinkman (BDS), this study indicated the presence of the non-linearity relationship between BCO and CPO price. The bound tests with NARDL specification confirmed the asymmetric association between CPO price movements and their relation to positive and negative changes in BCO price. The estimated NARDL model confirmed the existence of an asymmetric relationship in the changes in CPO prices. This study found that in the long run, there is a significant relationship between the increase in BCO prices and CPO prices while no significant relationship between the decrease in BCO prices to CPO prices in the long run. In the short run, only the changes in BCO prices positively affect palm oil price inflation. The findings of this study are imperative to the industry players especially to the biofuel producers and exporters since changes in CPO price will directly affect their profitability and cost of production.

Keywords: asymmetry, crude oil prices, palm oil prices, NARDL.

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INTRODUCTION

Vegetable oils are plant-based oils. The consumption of vegetable oils can be divided into two categories which are edible oil for food and non-edible oil for non-food applications. In 2020, almost 132 of the total 235 million tonnes of vegetable oils produced in the world correspond to palm and soybean oils (Oil World, 2021). Malaysia is one of the major

producers of world vegetable oil, namely crude palm oil (CPO). Vegetable oil prices move closely due to the substitutions of its applications with one another. Apart from that, a number of researchers have reported the correlation between vegetable oil prices and crude oil prices (Alam *et al.*, 2019; Campiche *et al.*, 2007; Cheng and Cao, 2019; Hanif *et al.*, 2021; Karakotsios *et al.*, 2021; Mokni and Youssef, 2020; Oluseun, 2021; Pal and Mitra, 2018; Priyati and Tyers, 2016). The usage of vegetable oil for biodiesel implementation mandate is one of the factors driving the relationship between vegetable oil prices and crude oil prices. Palm oil price is determined by the forces of supply and demand of vegetable oils thus making the producers an important role as price takers. Being a price taker is causing the CPO price volatile and uncertain.

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The main producers of biodiesel are the European Union, United States, Indonesia and Brazil, which represent 80% of world biodiesel production in 2022. Palm oil has great potential in producing biodiesel. Apart from the environmental and renewable benefits, palm oil-based biodiesel oil is more economically competitive than fossil fuels and other vegetable oil-based biofuels. However, it should be noted that the biodiesel mandate has been largely supported by government subsidies. This is necessary because the price of biodiesel is generally higher than the price of diesel oil.

This mandate would not happen without government intervention. It should be emphasized that government interventions have different effects in influencing the price of palm oil and other vegetable oils, whether they are positive, negative or have no effect at all. In other words, the uncertainty of this kind of situation increases the probability of non-linear relationships between markets especially as the study observed that the price of vegetable oil shows a significant increase in recent years.

The biodiesel policy has implications for the price of palm oil. For example, the level of biodiesel production in Indonesia has a direct effect on the global market of palm oil and vegetable oil prices. It is well known that Indonesia is the world's leading producer and exporter of palm oil, and palm oil is the vegetable oil most consumed by the world's population. Therefore, the biodiesel policy set by the Indonesian government to support the local biodiesel industry has put pressure on the availability of palm oil supply in the global market and subsequently affects the price of palm oil and other vegetable oils.

Figure 1 shows the evolution of the biodiesel implementation for the transport sector in Indonesia which is regulated by the Ministry of Energy and

Mineral Resources (MEMR). The biodiesel industry in Indonesia started in 2008 with a B1 blending mandate (content of 1% palm-based biofuel, 99% petroleum oil), followed by B2.5 in 2010 until 2014. However, this mandate changed in 2013 with a higher blend target which was B10 in 2013 compared to the initial target of B2.5 and increased to B20 starting in 2015. However, the bio-fuel blending target in 2015 was lowered from B20 to B15 due to the sudden drop in crude oil prices resulting in a significant increase in the gap between the two prices further threatening the competitiveness of the biodiesel industry in Indonesia. Currently, Indonesia has implemented the B35 blending mandate.

As mentioned before, there have been a number of researchers who have sought to determine the relationship between crude oil prices and vegetable oil prices. However, there are only a few studies concerning the volatility movement factor (Chowdhury *et al.*, 2021; Ibrahim, 2015; Olasunkanmi and Oladele, 2018). This has given a different view and interpretation of the relationship between crude oil and agricultural commodity prices, particularly palm oil prices. In short, this paper has studied the relationship between Brent crude oil prices and palm oil prices. At the same time, this study will also explain the important role of biodiesel in the price movement.

Oils and fats are extracted either from plants or animals or fish oil. According to Oil World, there are 17 types of oils and fats in the world market. Palm oil, soybean oil, sunflower oil and rapeseed oil are the most consumed and mainly traded oils and fats in the international market. Figure 2 shows the trend of consumption of oils and fats in the world is increasing as the population increases year on year basis. Besides, the world consumption of oils and fats has remarkably increased by only 1.0 million tonnes in 2000 to 2.5 million tonnes in 2023. In other

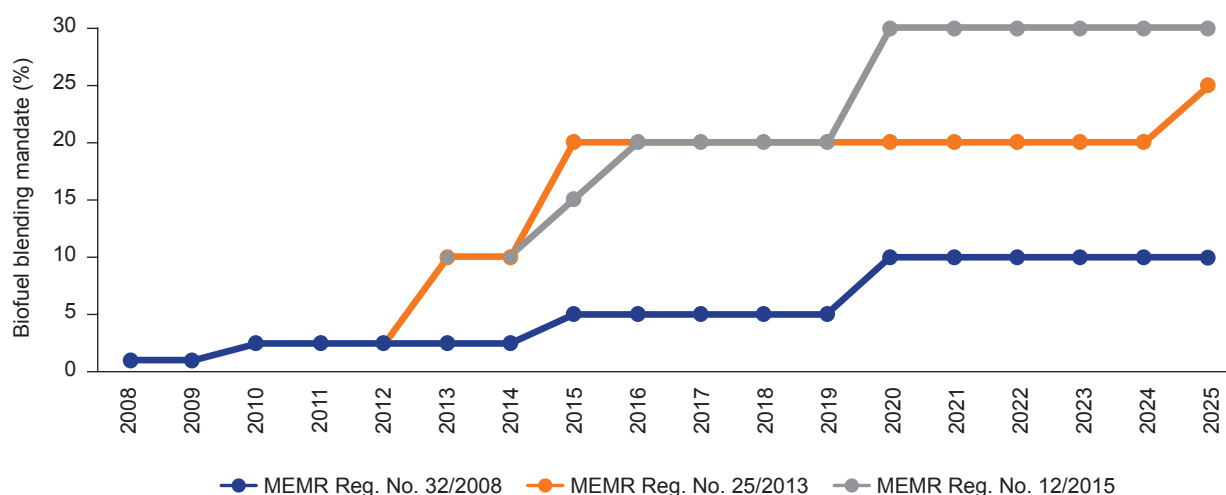


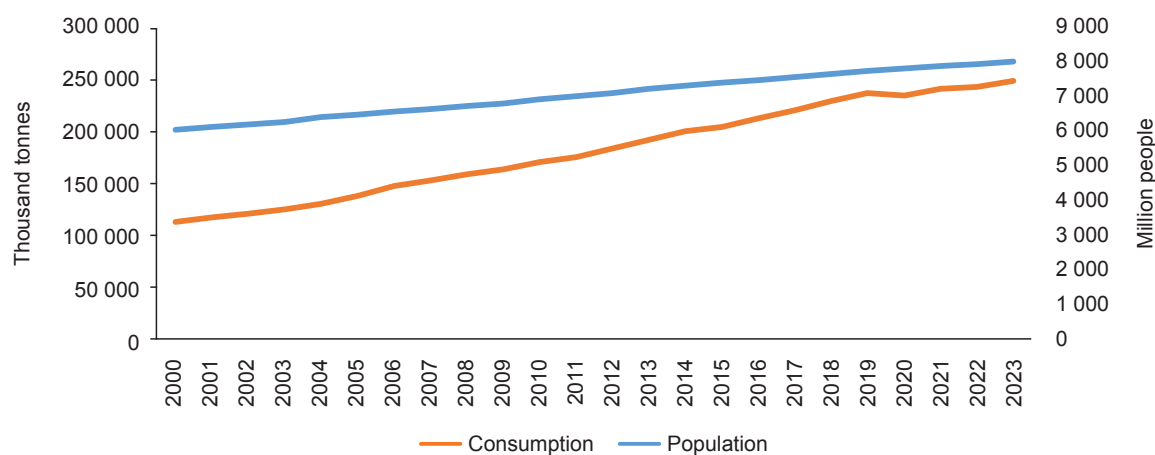
Figure 1. Biodiesel blending mandate for transportation sector in Indonesia.

words, the oils and fats consumption by one person in this world is twice as high in 2023 as compared to in 2000. The increasing trend especially for the four major oils is in line with the increasing number of world population. Thus, with the expectation that the world population will continue to increase exponentially, demand for these major oils is expected to continue to increase substantially in the future.

Figure 3 shows the breakdown of vegetable oil production in 2023 as compared to 2010. In 2023, 90.0% of the world's total vegetable oil production of 254 million tonnes are produced by the four main vegetable oils where palm oil (PO) is the main contributor (32.0%) followed by soybean oil or SBO (23.0%), rapeseed oil or RSO (12.0%) and sunflower

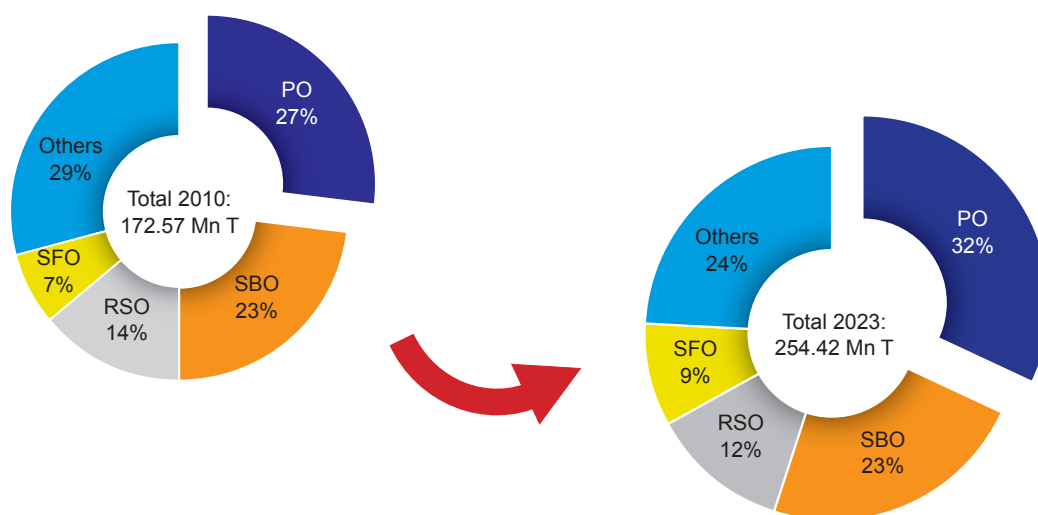
oil or SFO (9.0%). Palm oil has become the leading vegetable oil, surpassing the production of soybean oil since 2003. Palm oil production has increased by 47.4% from year 2010-2023.

Malaysia's CPO industry is an export-oriented industry with at least 80% of palm oil exported compared to local consumption of only less than 20% (Figure 4). For 2022, the export of palm oil and other palm-based products has increased by 0.44 million tonnes or 1.8% to 24.72 million tonnes compared to 24.28 million tonnes in 2021. The five (5) main export markets for Malaysian palm oil are India, China, the European Union, Türkiye and Kenya, with a total export of 7.72 million tonnes or 49.1% of Malaysia's total palm oil exports (MPOB, unpublished data).



Source: World Bank (2024); MPOB (Unpublished data).

Figure 2. Oils and fats consumption vs. world population 2000-2023.



Source: MPOB (2021).

Figure 3. World production of 17 oils and fats, 2010 vs 2023.

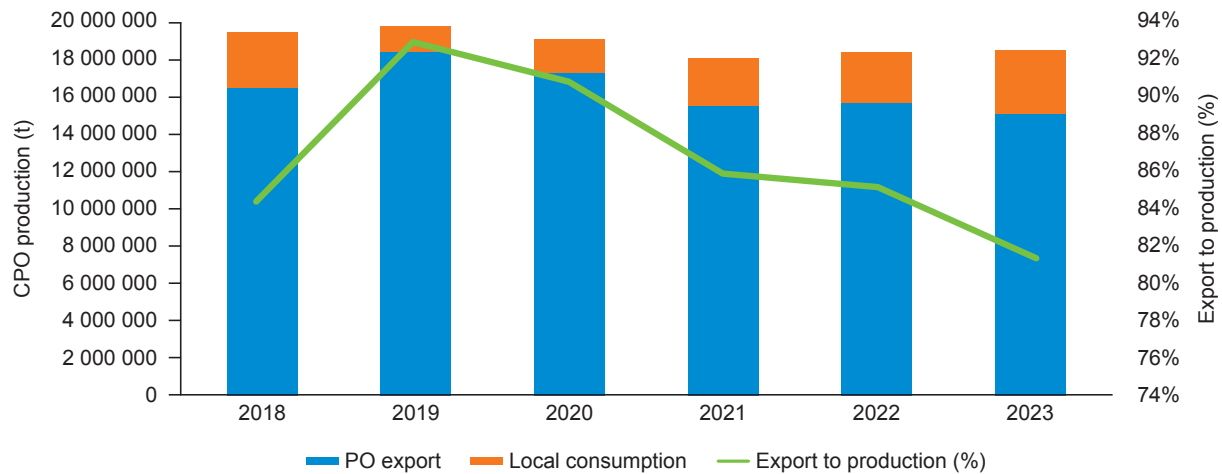


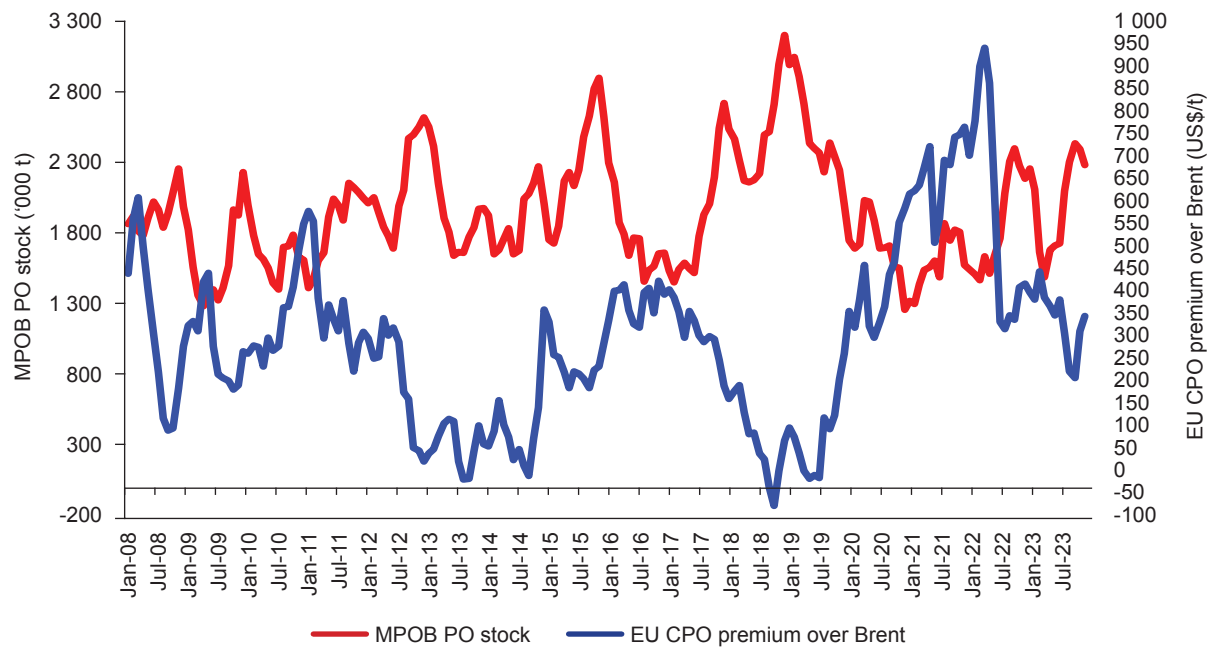
Figure 4. Export and local consumption of Malaysian palm oil.

The local demand for vegetable oils cannot be met due to the rapid increase in population thus most countries rely on trading activities. Changes in demand are also influenced by economic and political uncertainties as well as changes in the structure of import and export taxes. An increase (decrease) in demand will cause prices to increase (decrease). In addition, production, imports and net supply are important elements in determining supply. Production, imports and net supply are negatively affected by palm oil prices. High supply availability of palm oil and other vegetable oils in the market will influence a low palm oil price.

Furthermore, vegetable oil prices are also closely related to the world's crude oil prices. The argument on the relationship between vegetable oil price and the world crude oil price became stronger when the biodiesel programme was introduced in March 2006 voluntarily (Abdullah *et al.*, 2009). Since then, most of the time the movement of crude oil and other major vegetable oil prices are almost similar thus attracting the interest of researchers to understand the real relationship of these prices. There are a lot of arguments regarding the relationship between crude oil prices and major vegetable oil prices, which have led to many studies conducted on these topics. Figure 5 below shows the relationship between the world's crude oil price and the Malaysian final stocks (closing stocks) of palm oil. The increase in world crude oil prices will be closely followed by vegetable oil prices, especially palm oil and soybean oil prices. However, the price of palm oil is found to be more competitive than that of other vegetable oils. As a result, palm oil consumption and trade were found to be higher, thus resulting in the final stocks of the oil being reduced as compared to the consumption and trade of other vegetable oils due to uncompetitive prices and *vice versa*.

There have been a number of longitudinal studies involving the relationship between crude oil and vegetable oil prices that have been reported, for instance, the study by Yu *et al.* (2006) stated that shocks in crude oil prices have a significant influence on the variation of edible oil prices. Campiche *et al.* (2007) examined the co-variability between crude oil prices and corn, sorghum, sugar, soybean, soybean oil, and palm oil prices in which the study found that soybean prices seem to be more closely correlated to crude oil prices rather than corn prices. Correspondingly, Wei and Chen (2016) also found that the changes in vegetable oil prices are significantly influenced by the changes in crude oil prices. Besides that, Songsiangchai *et al.* (2018) found that there is evidence for a causal relationship that runs from the world's crude oil price to the Thai CPO price, but not *vice versa*. Furthermore, Zafeiriou *et al.* (2018) which focused on the relationship between agriculture commodities and crude oil prices confirmed that crude oil prices affect the prices of agricultural products that are used in the production of biodiesel, as well as of ethanol, validating the interaction of energy and agricultural commodity markets. In general, most of the studies have indicated that there is a relationship between crude oil and vegetable oil prices.

Ayatollah *et al.* (2017) have explained that the use of palm methyl ester as a raw ingredient for palm-based biodiesel has resulted in world crude oil prices influencing CPO prices. The strength of the relationship between these two oils depends on the world market situation. Strong ties occur when the world crude oil prices are at a high level. Thus, biodiesel products are more competitive in the international market. However, the increase in demand for biodiesel products has resulted in a reduced supply of palm oil, which in turn has increased the price of CPO in the world market. In addition, the relationship between these two



Source: MPOB (Unpublished data).

Figure 5. Price of CPO and BCO vs. Palm Oil Stocks.

oils can be seen when the world crude oil prices are at low levels. This makes biodiesel products less competitive in the market as a result of the much cheaper diesel prices. Santeramo and Searle (2019) have agreed that a significant increase in the use of vegetable oils in biodiesel products has increased the demand for vegetable oils, and in turn, resulted in the increase in vegetable oil prices. Soybean oil and palm oil are substitutes or complementary oils. Changes in the demand for soybean oil for biofuel production have also resulted in changes in palm oil stocks. Subsequently, changes in the price of palm oil have also occurred in tandem. The implementation of the biodiesel programme has not only affected vegetable oil prices but has also influenced the food sector, for instance, Kochaphum *et al.* (2013) found that the implementation of the biodiesel programme from one angle has provided positive benefits to the vegetable oils industry. Nevertheless, the programme has encouraged farmers to prioritise the biofuel purpose rather than for food with the increased oil production indicating reduced local food production. Before this, Peri and Baldi (2010) also discussed the issue of the relationship between the vegetable oils market and biofuel policy, in which the surge in fuel prices increases the demand for biofuel, which subsequently decreases the supply and inventory of food. Besides, there was the depreciation of the USD Dollar that has led to a spike in the price of food. Even though biofuel improves the welfare of gasoline consumers and

food producers, it has a significant negative effect on food consumers. Correspondingly, several studies have also found a similar indirect effect of the increasing fuel price on food prices through the demand for biofuel (Bentivoglio *et al.*, 2016; Ciaian, 2011; To and Grafton, 2015; Zhang *et al.*, 2010). Chungchild *et al.* (2012) have examined the factors influencing CPO pricing using the extreme value approach. The study showed that the growth rate of CPO and soybean oil prices have very extreme dependence. However, the growth rate between CPO and the world crude oil prices showed a weak interdependence or extreme non-dependence on each other. In contrast, the study by Shri *et al.* (2009) focused on the indirect effects between the biodiesel programme and the performance of the Malaysian palm oil trade. The study showed that biodiesel programmes indirectly have a significant impact on CPO prices.

Principally, the world crude oil prices are now one of the key elements in the CPO price equation of the impact of the biodiesel programme chain. Other than the demand and supply factors, the rise in CPO price movements is also influenced by market sentiments or price speculation. This factor can have a drastic impact on the price of CPO in a short period as compared to the basic factors of demand and supply. Besides that, the weather also influences the supply of palm oil, such as extreme *El Nino* and *La Nina* conditions, which bring extreme heat or excessive rainfall that also disrupts the supply, which in turn drives up prices of CPO.

MATERIALS AND METHODS

This section focuses on the framework of the study and the methodology of the data. A quarterly data set was collected from 2010 to 2022 to achieve the objective of the study. The data was sourced from the Monthly Oil World Reports 2010 to 2023. Variables used in the study were divided into three (3) elements, namely price, supply and demand elements. The data series were then transformed into natural logarithms. The technique used in this study was the Non-Linear Autoregressive Distributed Lag (NARDL) model. The functional framework of the study is as Equation (1):

$$CPO = f(\text{price, supply, demand}) \quad (1)$$

CPO is the price of crude palm oil (CPO) traded internationally in USD per tonne. Meanwhile, the price element consists of Brent crude oil (BCO) price and soybean oil (SBO) price. The first implementation of the biodiesel programme back in June 2011 was B5 which consisted of 5% local refined, bleached and deodorised palm olein blended with 95% petrol diesel (Lim and Teong, 2010). In December 2014, the Government moved forward to implement the B7 programme. Then, in 2019 the B10 palm oil biofuel programme was implemented. Malaysia plans to implement the B20 palm oil biofuel programme by the end of 2022. Thus, this study will take into account these three programmes into the model to identify whether the BCO prices affected CPO prices in the same movement or not.

Supply-side elements that are believed to affect the price significantly are palm oil production (PROD) and palm oil closing stocks (POSTK). Finally, the demand elements consist of palm oil export (EXP) and soybean oil closing stocks (SBOSTK). The empirical framework of this study can be articulated as Equation (2):

$$CPO_t = \beta_0 + \beta_1 BCO_t + \beta_2 SBO_t + \beta_3 PROD_t + \beta_4 EXP_t + \beta_5 POSTK_t + \beta_6 SBOSTK_t + \varepsilon_t \quad (2)$$

Based on Equation (2), the BCO price is expected to influence the CPO price positively. In other words, under a linear and symmetric setting as in Equation (2), CPO price responds to a change in BCO price during a soothing period and does not capture the downturn period. To achieve the objective, the asymmetric ARDL technique was employed following the method developed by Shin *et al.* (2014). The NARDL model is an advanced method from the ARDL model, which introduces

the non-linearity of the series. For this study, the non-linear model can be articulated as Equation (3):

$$CPO_t = \alpha_0 + \alpha_1 BCO_t^+ + \alpha_2 BCO_t^- + \alpha_3 SBO_t + \alpha_4 PROD_t + \alpha_5 EXP_t + \alpha_6 POSTK_t + \alpha_7 SBOSTK_t + e_t \quad (3)$$

Shin *et al.* (2011) improved ARDL developed by Pesaran and Shin (1999) to an advanced model; non-linear ARDL (NARDL). This model is capable of analysing asymmetric short and long-run relationships between variables. The concept of NARDL is to decompose the exogenous variable into a partial sum process. BCO^+ and BCO^- are the asymmetric long-run parameters in which the CPO price responds asymmetrically during up and down periods of BCO price as shown in Equation (4) and (5):

$$BCO_t^+ = \sum_{i=1}^t \Delta BCO_i^+ = \quad (4)$$

and

$$BCO_t^- = \sum_{i=1}^t \Delta BCO_i^- = \sum_{i=1}^t \min(\Delta BCO_i, 0) \quad (5)$$

However, a few pre-tests need to be undertaken before conducting the NARDL model. Firstly, the stationarity of the series will be determined by performing ADF and P-P unit root tests. Then to confirm the existence of non-linearity in the data series, the study conducts the Brock, Dechert and Scheinkman (BDS) test (Brock, *et al.*, 1996). BDS is a powerful tool that researchers frequently use for detecting serial dependence in a time series and is also often used as a diagnostic tool for the residual. The underlying null hypothesis is independent and identically distributed.

After confirming the existence of non-linear dependence, the study will then formulate the ARDL model. The optimum lag structure will be determined by reducing the highest insignificant lag, one by one until a minimum value of AIC and SIC (indication of optimum lag number) is reached. Next is to check for the robustness of the model and adequacy of the data, especially serial correlation and stability tests. A good estimation model needs to pass the diagnostic test for normality, heteroskedasticity and functional form by performing the LM test. In addition, the study will also do the CUSUM stability test.

The study then proceeds to estimate the extent of the impact of BCO price volatility on the price of palm oil using a non-linear framework by using Equation (6). It will then estimate the existence of cointegration in non-linearity by comparing the F-statistics with the lower and upper critical values by Pesaran *et al.* (2001) and Shin *et al.* (2011). The

null hypothesis (no cointegration) will be rejected if F-statistics exceeds the upper bound. Shin *et al.* (2011) estimates from Equation (3) to ARDL procedure following Pesaran and Shin (1999) also Pesaran *et al.* (2001) as Equation (6):

$$\begin{aligned} \Delta CPO_t = & \alpha_0 + \alpha_1 BCO_t^+ + \alpha_2 BCO_t^- + \alpha_3 SBO_t + \\ & \alpha_4 PROD_t + \alpha_5 EXP_t + \alpha_6 POSTK_t + \\ & \alpha_7 SBOSTK_t + \sum_{i=1}^p \theta_i \Delta CPO_{t-i} + \\ & \sum_{i=1}^q (\theta_i^+ \Delta BCO_{t-i}^+ + \theta_i^- \Delta BCO_{t-i}^-) + \\ & \sum_{i=1}^r \vartheta_i \Delta SBO_{t-i} + \sum_{i=1}^s \tau_i \Delta PROD_{t-i} + \\ & \sum_{i=1}^w \sigma_i \Delta EXP_{t-i} + \sum_{i=1}^v \rho_i \Delta POSTK_{t-i} + \\ & \sum_{i=1}^n \pi_i \Delta SBOSTK_{t-i} + u_t \end{aligned} \quad (6)$$

RESULTS AND DISCUSSION

Table 1 presents the results of the commonly used unit root test: ADF (Dickey & Fuller, 1979) and P-P test (Phillips and Perron, 1988). In order to comply with the bound testing procedure in which no I(2) variables are involved, the study first runs each time series to the ADF and P-P unit root tests. SIC is employed for the optimal lag order and constants with trend were included for testing “at level”, meanwhile the study only included constants for

the 1st difference unit root test. Based on ADF and P-P unit tests, all-time series are integrated of order 1 or I(1).

Table 2 shows the test of BDS to confirm the existence of non-linearity. The null hypothesis in the BDS approach is rejected as the test statistics are far bigger than the critical values. In other words, the series is linearly dependent and was rejected. The results suggested that Brent crude oil price is non-linearly dependent. Thus, the study is valid to imply NARDL for achieving the objective.

The study discovered the robustness and stability of the estimation model by performing some diagnostic statistical tests on the residuals. This is important to see the adequacy of the model specification. The result is stated in Table 3. The residual tests showed that the estimation was free from serial correlation by employing the LM test. The Jarque-Bera (J-B), which tests the error term, were also distributed normally. Meanwhile, the Breusch-Pagan-Godfrey (BPG) test is for detecting heteroscedasticity in the model. The result shows a score of 0.6199 with a probability value of 0.8125, which is greater than 0.5 of the value of the BPG test at a 95% confidence level. This showed the absence of heteroscedasticity or means that residuals are normally distributed. Estimation of the model's stability was investigated by applying a residual recursive residual test as proposed by Pesaran *et al.*, (2001), which is CUSUM and CUSUMSQ statistics for testing structural stability (Figure 6).

TABLE 1. UNIT ROOT TEST

Variable	At level		1 st difference	
	ADF	PP	ADF	PP
CPO	-4.0986**	-2.9504	-4.3318***	-4.0944***
BCO	-1.7291	-1.8692	-5.2944***	-5.2944***
SBO	-2.4315***	-2.4950	-4.2609***	-4.2890***
POSTK	-4.7870	-2.4298	-3.3049**	-6.2042***
SBOSTK	-2.4753	-2.4804	-3.928***	-8.6671***
B5	-2.4968	-2.4758	-5.9161***	-5.9161***
B7	-0.8380	-0.8820	-5.9161***	-5.9161***

Note: CPO - Crude palm oil; BCO - Brent crude oil; SPO - Soybean oil; POSTK - Palm oil closing stocks; SBOSTK - Soybean oil closing stocks.

TABLE 2. NON-LINEARITY TEST

Dimension	LBCO				Residuals of LBCO (AR (1))			
	BDS Stat	Std. Error	Z-Stat	Prob.	BDS Stat	Std. Error	Z-Stat	Prob.
2	0.1264	0.0080	15.8100	0.0000	0.0382	0.0145	2.6280	0.0086
3	0.2184	0.0128	17.0322	0.0000	0.0808	0.0236	3.4241	0.0006
4	0.2453	0.0154	15.9281	0.0000	0.1029	0.0287	3.5876	0.0003
5	0.2521	0.0162	15.5643	0.0000	0.0813	0.0305	2.6634	0.0077
6	0.2619	0.0158	16.5953	0.0000	0.0917	0.0301	3.0506	0.0023

TABLE 3. STABILITY TEST

Variable	Coefficient	P-Value
Constant	8.7387	0.0000
CPO(-1)	-0.6819	0.0000
BCO+(-1)	0.0584	0.0678
SBO(-1)	0.2530	0.0436
POSTK(-1)	-0.4592	0.0001
SBOSTK(-1)	-0.2152	0.1010
B5(-1)	0.1314	0.0003
B7(-1)	0.0254	0.2864
Δ BCO+	0.3003	0.0118
Δ BCO+ (-1)	0.3185	0.0109
Δ SBO	0.9331	0.0000
Δ PROD	-0.4860	0.0000
Δ PROD(-1)	-0.2474	0.0001
Δ B5(-1)	-0.0617	0.0465
J-B	0.0757	0.9629
LM	1.6835	0.2085
Breusch-Pagan-Godfrey	0.6199	0.8125

Note: CPO - Crude palm oil; BCO - Brent crude oil; SBO - Soybean oil; POSTK - Palm oil closing stocks; SBOSTK - Soybean oil closing stocks; PROD - Palm oil production.

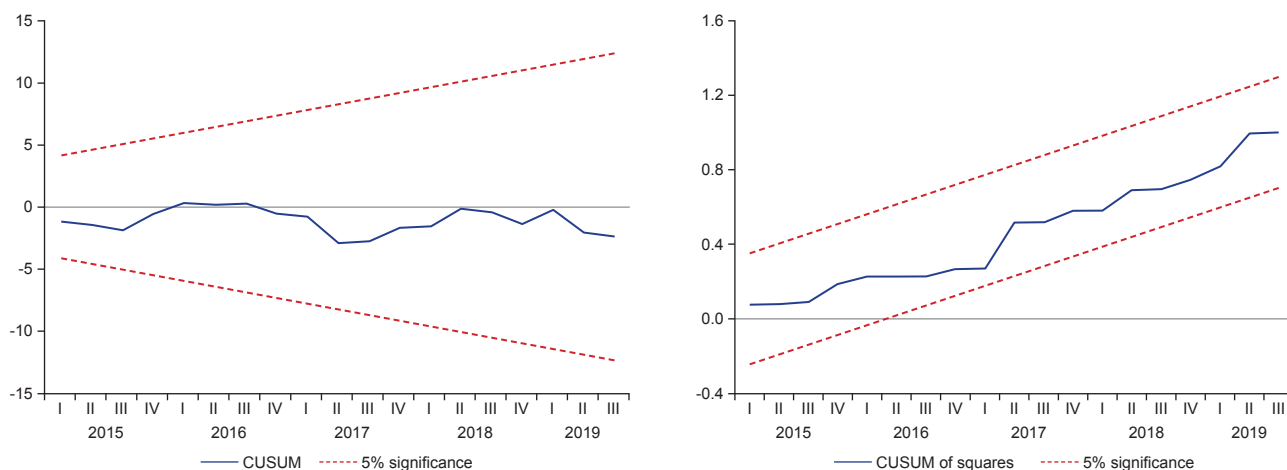


Figure 6. CUSUM and CUSUMSQ statistics.

From the bound test shown in Table 4, we conclude that in favour of asymmetric association between examined variables, the statistics 6.7707 exceed the critical upper bound. With this finding, we are in a position to assess crude palm oil price movements and their relation to positive and negative changes in BCO prices.

TABLE 4. BOUND TEST FOR NON-LINEAR

F-Statistics	95% lower bound	95% upper bound	Conclusion
6.7707	2.797	4.211	Cointegration

Notes: The critical values are from Narayan (2005), given the small sample size.

Table 5 discusses the empirical result of long-run nonlinear ARDL. As SBO and CPO are substitute oils, price changes in one oil will influence demand for the other. The study suggests that a 1.00% increase in SBO price will increase CPO price by 0.37%. Stocks are one of the supply elements. The lower the stocks, the better (higher) the price. Implementation of B5 in 2011 had a positive effect on CPO prices in the following year by 0.19%. In line with the main objective of this study, it showed that there is a significant asymmetric long-run relationship between CPO price and the increase in BCO price. Positive BCO price has a positive significant relationship with CPO price in the long run. The study suggests that a 1.00% increase in

BCO price will lead to a 0.09% increase in CPO price. Meanwhile, there is no significant relationship between the decrease in BCO prices and the changes in CPO prices.

In addition, the short-run nonlinear ARDL test is shown in *Table 6*. There is evidence of the presence of asymmetric. The study observed the significance of the positive change in BCO price. The change in the BCO price significantly influenced the CPO price to increase. A 1.00% increase in BCO price will immediately impact CPO price to increase by 0.32%.

CONCLUSION

This study provides conclusive evidence of the asymmetric relationship between crude oil and palm oil prices and how the asymmetric relationship impacts the palm oil industry. For this purpose, the study employed a nonlinear autoregressive methodology to confirm the asymmetric impact. To check the stationary properties of the variables, the study used ADF and P-P unit root tests. The result confirmed that all series were stationary at level I(0)

and some after the first differencing I(1), concluding that no series is stationary at the second difference I(2). The BDS test applied rejected linearity of the examined variable. Next, to assess the magnitude of Brent crude oil price volatility in the non-linear framework, the study applied NARDL, breaking down the variable into positive and negative shocks. The estimated NARDL model confirmed the existence of an asymmetric relationship in the changes in palm oil prices. This study found that in the long run, there is a significant relationship between the increase in BCO prices and CPO prices while no significant relationship between the decrease in BCO prices to CPO prices in the long run. The study suggested that a 1.00% increase in BCO price will lead to an increase of 0.09% in CPO price. In the short run, only the changes in BCO prices positively affect palm oil price inflation. We anticipate our finding is vital for industry players especially to the biofuel producers and exporters since the changes in CPO price will directly affect their profitability and cost of production. This paper has shown that CPO price reacts significantly to an increase in BCO price, compared to a decrease in BCO price. Thus, it suggested that when Brent crude

TABLE 5. LONG RUN RELATIONSHIP

Variable	Coefficient	P-Value
Constant	8.7387	0.0000***
BCO+	0.0857	0.0614*
SBO	0.3710	0.0077***
POSTK	-0.6734	0.0000***
SBOSTK	-0.3156	0.0825*
B5	0.1928	0.0012***
B7	0.0372	0.2640

Note: ***, ** and * signify statistically significant at 1%, 5%, and 10%, respectively.

BCO - Brent crude oil; SBO - Soybean oil; POSTK - Palm oil closing stocks; SBOSTK - Soybean oil closing stocks.

TABLE 6. SHORT RUN RELATIONSHIP

Variable	Coefficient	P-Value
Constant	8.7387	0.0000
CPO(-1)	-0.6819	0.0000
BCO+(-1)	0.0584	0.0678
SBO(-1)	0.2530	0.0436
POSTK(-1)	-0.4592	0.0001
SBOSTK(-1)	-0.2152	0.1010
B5(-1)	0.1314	0.0003
B7(-1)	0.0254	0.2864
ΔBCO+	0.3003	0.0118**
ΔBCO+ (-1)	0.3185	0.0109**
ΔSBO	0.9331	0.0000***
ΔPROD	-0.4860	0.0000***
ΔPROD(-1)	-0.2474	0.0001***
ΔB5(-1)	-0.0617	0.0465**

Note: ***, ** and * signify statistically significant at 1%, 5%, and 10%, respectively.

CPO - Crude palm oil; BCO - Brent crude oil; SBO - Soybean oil; POSTK - Palm oil closing stocks; SBOSTK - Soybean oil closing stocks; PROD - Palm oil production.

oil increases, investors and biofuel producers should react to that positive shock to optimize higher profit from it.

The findings of this study benefit the stakeholders on the existence of a nonlinear relationship that revealed the question of 'why do palm oil prices surge even when there is a significant drop in crude oil prices especially during COVID-19?'. This is because the impact of positive change in crude oil price is higher than the effect of negative changes. Therefore, from a policy implication perspective, producing countries like Indonesia and Malaysia need to emphasise more local industries through increased efficiency and reduced production costs. This should reduce the impact of crude oil price shocks in the long run and act as a buffer to the impact of oil price fluctuations. Besides, in terms of monetary policy, the government is advised to monitor the policy changes in Indonesia, especially for their development of the biodiesel industry as it will not continue to rely on non-renewable energy sources for their country. This is important because Indonesia's action will have an impact on the fluctuation of palm oil prices and other vegetable oil prices. For future research, this is more beneficial if more empirical studies into similar agri-commodities in other producing countries with different biodiesel policy structures would link these results with market power and international trade policy.

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