Identifying Circular Economy Opportunities in the Palm Oil Sector in Indonesia

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LIST OF ABBREVIATIONS

APKASINDO	= Asosiasi Petani Kelapa Sawit Indonesia/ Indonesian Palm Oil Farmers Association
APOLIN	= Asosiasi Produsen Oleochemical Indonesia/ Association of Indonesian Oleochemical Producers
DMSI	= Dewan Minyak Sawit Indonesia/ Indonesian Palm Oil Council
CE	= Circular Economy
CO2	= Carbon Dioxide
CPO	= Crude Palm Oil
EFB	= Empty Fruit Bunch
FFB	= Fresh Fruit Bunch
GAPKI	= Gabungan Pengusaha Kelapa Sawit Indonesia/ Indonesian Palm Oil Association (IPOA)
GIMNI	= Gabungan Industri Minyak Nabati Indonesia/ Indonesian Vegetable Oil Industry Association
ISCC	= International Sustainability and Carbon Certification
ISPO	= Indonesia Sustainable Palm Oil
MF	= Mesocarp Fibre
NPO	= Neutralized Palm Oil
OPF	= Oil Palm Fibre
OPT	= Oil Palm Trunk
PKS	= Palm Kernel Shell
POCI	= Palm Oil Cattle Integration
POME	= Palm Oil Mill Effluent
RECP	= Resource Efficiency and Cleaner Production
RSPO	= Roundtable on Sustainable Palm Oil
R&D	= Research and Development
SBE	= Spent Bleaching Earth
SPOT	= Steamless Palm Oil Technology
TCLP	= Toxicity characteristic Leaching Procedure
UEDR	= European Union Deforestation Regulation
WTO	= World Trade Organization
5R	= Reduce, Reuse, Recycle, Refurbish, and Renew
9R	= Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, Recover

EXECUTIVE SUMMARY

The palm oil industry, along with other natural resource-dependent sectors, grapples with substantial challenges in developing environmentally sustainable products and enhancing their integrity for increased market access. Currently, Indonesia and Malaysia are collaboratively addressing the ratification process of the European Union Deforestation Regulation (EUDR), a significant initiative with potential implications for the palm oil sector. This report delves into Circular Economy (CE) practices within the palm oil industry, specifically targeting resource efficiency in materials, energy, water, waste, and emissions.

This study meticulously evaluates CE practices with a focus on resource efficiency, spanning across plantations, palm oil mills, and oil refineries—integral components of the palm oil industry. The approach integrates both qualitative and quantitative methods, ensuring a comprehensive analysis. Qualitatively, observations, in-depth interviews, Focused Group Discussions (FGD), and exploration of relevant institutional documents contribute to a nuanced understanding. The scope encompasses plantation companies, oil palm farmers, palm oil mills, academics, professionals, and industry associations within the palm oil value chain. Field studies conducted in Riau Province facilitate data collection.

Quantitatively, a structured questionnaire approach is employed within each segment of the palm oil industry value chain—plantations, milling, refining. The acquired data undergoes meticulous processing using descriptive statistical techniques and cross-tabulation. The quantitative approach is further enriched through resource efficiency analysis, encompassing aspects such as the effective use of fertilizers through Palm Oil Cattle Integration (POCI) practices, fertilizer efficiency with Palm Oil Mill Effluent (POME) application for both smallholder-owned plantations and companies, efficiency comparison between rodenticide and owl utilization, carbon emissions at the palm oil farmer level, carbon emissions with POCI practices, carbon emissions related to energy use at the plantation level, carbon emissions linked to fertilizer use, and carbon emissions at the palm oil processing company level.

The findings illustrate that both smallholder and corporate plantations have successfully adopted resource-efficient measures through diverse CE practices. These encompass a circular approach to material efficiency, guided by a commitment to achieving zero waste by maximizing the utilization of all components of oil palm trees. Elements such as empty stems, leaves, and fruit bunches are repurposed as fertilizers within the plantation area. Material efficiency in CE applications includes refuse (R0), rethink (R1), reduce (R2), reuse (R3), remanufacture (R6), repurpose (R7), recycle (R8) and recover (R9). A notable distinction between smallholder and corporate plantations lies in the utilization of leaf sensor-based fertilization by the latter, markedly enhancing the effectiveness and efficiency of fertilizer usage.

The adoption of CE practices in material and energy efficiency yields substantial reductions in the use of chemical fertilizers—by approximately 58.7% to 64.9% for smallholder plantations and 34.4% to 86.7% for corporate plantations. This dual emphasis on material and energy efficiency also contributes positively to the reduction of carbon emissions. Smallholder plantations achieve a 19.2% decrease in total carbon emissions, whereas extreme cases, such as complete replacement of chemical fertilizers by POME, result in a 65% reduction. Corporate plantations demonstrate an impressive 96.4% reduction in carbon emissions.

Palm oil mills exhibit intensive CE practices for resource efficiency. Material efficiency strategies involve minimizing chemical use in processes like separating palm kernel and palm kernel (R0). While hydrocyclone technology is commonly adopted, some milling companies transition to claybath technology due to drawbacks associated with hydrocyclones. Circular practices (R1, R4, R7, R9) address material utilization concerns, focusing on FFB quality control and minimizing palm oil loss during production. In terms of energy usage, circularity efforts focus on reducing non-renewable energy use, emphasizing a 90% reliance on renewable resources (shell and fiber) for boilers, with solar use in initial stages. Large milling companies implement CE for energy generation, including electricity through methane capture, achieving an impressive 80% fuel saving. Water optimization aligns with normal standards, maintaining a 1:1 ratio of water use per ton of FFB.

Waste circularity in milling companies involves R7 (Repurpose), converting liquid waste into fertilizer and repurposing solid waste for oil palm plantations. Solid waste from empty bunches, palm shells, and fiber serves as fuel for boilers. Energy-saving technologies contribute significantly to carbon emission reduction. Circular practices extend to transportation, with trucks using biodiesel for FFB transport. Digitalization and semi-digitalization initiatives enhance process efficiency and problem detection in the CPO production process, connected to Android-based mobile phones.

Milling companies practicing CE realize a commendable 2.31% reduction in carbon emissions (from 0.165 to 0.161 tons of CO2-eq per ton of FFB/year). Waste from CPO processing, fiber, and shell substitutes about 90% of solar functions in operating boilers, with the remaining 10% requiring fuel oil for the initial hour after the boiler starts functioning.

Refineries embrace diverse CE practices, converting solid waste (Spent Bleaching Earth) into valuable resources. Recovering oil from Spent Bleaching Earth for industrial applications, including biofuels, lubricants, oleochemicals, animal feed, and fertilizers, highlights the versatility of CE strategies. The recycling process significantly reduces waste and carbon emissions. Energy efficiency practices, such as utilizing hot steam, lead to cost reductions by 39.3%, and electricity use reductions by 13.5%.

CE practices have demonstrably enhanced the resource efficiency of smallholder oil palm plantations. Despite this positive impact, challenges persist. These encompass escalating prices of chemical fertilizers and pesticides, fertilizer scarcity, limited access to POME from milling companies, lack of government support for high-quality oil palm seeds, and insufficient training and socialization for farmers to implement CE practices effectively. Fundamental issues, including unclear land tenure status, ISPO certification difficulties, extended track seasons, and inadequate financial support for oil palm replanting, further compound challenges. In contrast, corporate plantations encounter fewer challenges, enjoying better access to resources and organic fertilizers from milling companies. Milling companies, however, face challenges related to insufficient FFB supply during track seasons, limited capital for cutting-edge technology, and a lack of government support, particularly in terms of tax incentives.

Considering the CE practices and challenges faced by stakeholders in oil palm plantations, milling, and refineries, the report advocates for holistic recommendations. These recommendations aim to address challenges and further promote resource savings in the palm oil sector. The detailed recommendations are presented at the conclusion of this report.

CHAPTER I INTRODUCTION

Natural resource-based industries such as palm oil are facing difficult challenges. This is related to approaches in building environmentally sustainable products, and improving products integrity for better market access. Currently, Indonesia and Malaysia are working together to provide input to the ratification of the European Union Deforestation Regulation (EUDR) which has likelihood to have an impact on the palm oil industry. EUDR can disrupt sustainable development practices that have been carried out by many business actors and this is not in line with the principles of global trade which prioritizes non-discriminatory principles, is transparent and consistent with World Trade Organization (WTO) regulations.

Although part of society views the palm oil industry as an ecological threat, this argument needs to be reviewed with evidence from this industry. From a theoretical perspective, environmental objectives have become a source of competitive advantage. For example, in their writings, Porter and Linde [1] said that the industry does not move in a static space but is dynamic. This condition brings "resource productivity, environmental improvement and competitiveness together". Porter and Linde's also said that "innovation in response to environmental regulation can fall into two broad categories, namely new technology and approaches that minimize cost, and improved resource productivity (substitutes)".

This study of the circular economy (CE) of the palm oil industry also supports the findings of Porter and Linde; that innovation in response to environmental objectives can promote the industry into two broad categories, namely new technology and approaches that minimize cost; and improving resource productivity (substitute options). CE practices in palm oil also help in achieving the SDGs such as SGDs 6 on energy, 8 on economic growth, 12 on sustainable consumption and production, 13 on climate change, and 15 on life and land .

The book Myths vs. Facts of Indonesia's Palm Oil Industry[2] mentions 100 issues developing in the palm oil industry. The book discusses global vegetable oil competition, palm oil in the Indonesian economy, the social side of rural development, poverty reduction, the global environment, environmental issues, nutrition and health, and sustainable governance. Of the 100 issues presented in the book, the circular side of the palm oil industry, from upstream to downstream, has not been fully addressed. The circular side of the palm oil industry has not received much attention. Even though many people say that the palm oil industry is a zero-waste industry, the implementation has not been easy. Many challenges in technology, raw materials, market structure, and behavior need to be addressed quickly and appropriately for this sector to be better prepared to move toward a circular system.

This study intends to provide an overview of the CE of the palm oil value chains that have been practiced with the principle of resource efficiency by business actors and its potential that can be optimized to increase value. Palm oil sectors have benefited by practicing resource

[1] Michael E. Porter dan Claas van der Linde. (1995). Green and Competition Ending the Stalemate, in *On Competition*, Michael E. Porter (Ed). Harvard Business Review, Boston.

[2] Sipayung T, Ulfa R. 2017. The Myths Vs. Facts: The Indonesian Palm Oil Industry In Social, Economis=C, And Environment Global Issues (The Fourth Edition). Bogor (ID): PASPI (Palm Oil Agribusiness Strategic Policy Institute.

efficiency in materials, energy, water, waste, and emissions. The current main challenge is encouraging the business actors to be more intense in practicing resource efficiency and following environmentally sustainable approaches. In addition, literacy on resource efficiency still needs to be deepened for all business actors. It is also essential to provide the government with scientific-based evidence to produce a better policy for CE development. Likewise, attractive incentives need to be given to those who have been able to practice a CE in their production chain. This report aims to explore CE practice, namely resource efficiency in materials, energy, water, waste, and emissions.

Morseletto[3] defines a CE as an economic framework built from awareness or knowledge to use products and resources efficiently. The implementation of resource efficiency can be seen through seven paths, namely: (i) changing the mindset of using resources from linear design to circular; (ii) improving resource governance by applying a life cycle approach to minimize environmental impacts; (iii) creating a closed loop supply chain to enable materials to be used repeatedly; (iv) using renewable and sustainable resources; (v) utilizing digital technology platforms to increase the level of precision of interventions and efficient use of resources; (vi) encouraging collaboration and cooperation to build a more efficient supply chain; and (vii) consistently evaluating to achieve the best performance.

The government has an important role to play in encouraging the development of a conducive ecosystem so that the paradigm shift from a linear economy to a CE can be accelerated optimally. The government has established five (5)[4] low-carbon development strategies, namely: sustainable energy, land restoration, waste management, green industry development, and low-carbon coastal and marine areas. All these strategies are closely related to the application of a CE.

Indonesia is the world's largest producer of palm oil with an area of 16.38 million hectares dedicated to its cultivation and a production value of 46.8 million tons of CPO.[5] Palm oil and its derivative products have strategic value both economically, socially, and environmentally. However, not all products resulting from the production process of the palm oil industry have been utilized optimally, including waste from the production process and consumption of palm products. However, along with better knowledge, as well as the availability of technology, various wastes and emissions resulting from production and consumption processes are being reused through CE applications. Even through the application of circular economic practices, things that can disrupt the productivity of this sector can be improved, such as soil quality, the need for fertilizers, and the availability of renewable energy can be handled properly. Various evidence is presented to show that the paradigm of the palm

[3] Morseletto, P. (2023). Sometimes Linear, Sometimes Circular: States Of The Economy And Transitions To The Future. *Journal Of Cleaner Production, 390*, 136138. Doi:Https://Doi.Org/10.1016/J.Jclepro.2023.136138Ranta, V., Aarikka-Stenroos, L., & Väisänen, J.-M. (2021). Digital Technologies Catalyzing Business Model Innovation For Circular Economy—Multiple Case Study. *Resources, Conservation And Recycling, 164*, 105155. Doi:Https://Doi.Org/10.1016/J.Resconrec.2020.105155

[4] The Future Is Circular Langkah Nyata Inisiatif Ekonomi Sirkuler Di Indonesia, Kementerian Perencana Pembangunan Nasional, 2022.

[5] Direktorat Jenderal Perkebunan. 2022. "Kontribusi Minyak Kelapa Sawit Indonesia Mengatasi Krisis Pangan Global." *Https://Ditjenbun.Pertanian.Go.Id/.* Retrieved September 9, 2023 (https://ditjenbun.pertanian.go.id/kontribusi-minyak-kelapa-sawit-indonesia-mengatasi-krisis-pangan-global/).

oil industry towards a CE has moved, and the current challenge is how to make this transformation move wider and deeper.

The outline of this paper will be divided into five parts, after the introduction, it is followed by a research methods section which explains how the approach, data and analysis techniques were carried out. The third section contains a literature review that describes the circular economy concept and its application in the palm oil industry value chain. The fourth section presents survey results for groups of smallholder oil palm farmers, large companies and palm oil processing factories. The fifth section presents the results of interviews related to field findings starting from circular economy practices for small farmers, private companies and state-owned companies. The sixth section contains quantitative analysis to measure efficiency in using resources. Finally, the final section contains conclusions and policy recommendations

CHAPTER II METHODOLOGY

This study evaluates CE practices in the context of resource efficiency, starting from the plantation, palm oil mills and oil refinery side. This process is an important part of the palm oil industry. Value chain-based analysis is useful to see the connection or interdependence in terms of material flow, waste and emissions which have been utilized in the 9R conception, namely (starting from a linear basis to circular): recover, recycle, repurpose, remanufacture, refurbish, repair, reuse, reduce, rethink, and refuse[4].

This study uses mixed methods (mixed method research). Mixed method research involves collecting both qualitative and quantitative data to answer research questions. Both types of data are collected in parallel (convergent parallel mixed method) to be interconnected and compared, and then analyzed[6].

Qualitative approach, carried out through observation techniques, in-depth interviews, focus group discussions, review of documents published by government organizations and official private institutions. The scope of study objects includes plantation companies, smallholders, palm oil mills, academics or professionals, and industry associations in the palm oil industry value chain.

Data collection through field studies was carried out in Riau Province and DKI Jakarta Province. Riau Province was chosen because it has the largest oil palm plantation area in Indonesia, which reaches 2.86 million hectares, and the amount of palm oil production

[6] John W. Creswell. (2014). Research Design Quantitative, Qualitative, And Mixed Methods Approaches. Sage, Los Angeles.

reaches 8.86 million tons[7]. The research team also conducted online discussions to deepen the findings (clarification) and involved many invitees from several regions[8].

The quantitative approach is carried out through a questionnaire instrument designed for each value chain of the palm oil industry, namely plantations, mills, refineries, and packaging/distribution. Before the questionnaire instruments were distributed to business actors, a questionnaire test was conducted involving several selected actors who had experience in each of the palm oil industry value chains. Based on input from experts, revisions were made to the questions in the questionnaire. Questionnaires were distributed with the help of industry associations. However, the hope of the research team to get optimal respondents was not achieved. Filling in the questionnaire can be broken down as follows: 13 oil palm farmers; 7 plantation companies; 2 mils company; 2 refineries; and 1 packaging company. The limited number of respondents has an impact on problematic robustness and interpretation when carrying out cross tabulations.

Furthermore, quantitative data is processed through statistical descriptive techniques and cross tabulation. Quantitative analysis was developed based on four main components, namely: materials, water, energy, waste, and emissions. The quantitative approach is enriched through resource efficiency analysis which includes efficiency in using fertilizers through palm oil cattle integration (POCI) practices and without POCI, efficiency in using fertilizers with POME applications (both for smallholder and company-owned plantations) and without POME, efficiency in using empty fruit bunches to fertilizers, as well as the efficiency between the use of rodenticide and owls. Furthermore, carbon emissions at the plantation level are also calculated, such as carbon emissions with POCI practices, carbon emissions related to energy use at the plantation level, carbon emissions related to the use of fertilizers. The research team also calculated the condition of carbon emissions at the palm oil processing company level.

To estimate carbon emissions in palm oil plantations, we refer to the method set out by the Intergovernmental Panel on Climate Change Guidelines in the IPCC Guidelines 2006. The application of this method has been stipulated under the Indonesian Minister of Environment and Forestry Regulation No P.73/MenLHK/Setjen/Kum.1/12/2017 dated December 29, 2017 concerning Guidelines for the Implementation and Reporting of Greenhouse Gas Inventory. The value of material components (such as chemical and organic fertilizers, pesticides, water etc.) and energy (solar and electricity consumption) are obtained based on the primary information from the smallholder and corporate palm oil plantations during our fieldwork in Riau Province in 11 – 16 February 2023.

Qualitative analysis was carried out by analyzing interview and discussion notes, and categorizing them into five categories, namely: strategy; innovation; people, skills, and operations; external engagement, monitoring, and impact evaluation of RE; and government policy and the role of Business Association. Furthermore, to complete the analysis, the study of company documents in the form of reports is also optimized, such as from PT. DSN; PT. SMART; Astra Agro Lestari. This information is used as a source of benchmarking lesson learn.

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[7] Discussion with the Director of the Food, Seafood and Fisheries Industry, Ministry of Industry, 28 July 2023, with the topic 'Strategy to Increase the Added Value of Natural Resources to Realize CPO down streaming'.

[8] See The Attachment for A List Of Invitees, Good Resource Persons Involved In In-Depth Interviews And Focus Group Discussions.

Finally, validity in a convergent approach is carried out based on quantitative validity and qualitative validity. Questionnaire-based quantitative data collection is still considered not optimal when compared to the potential of the existing population. Thus, the findings from the quantitative data need to be scrutinized with caution. Qualitative validity was carried out using a triangulation technique, namely by involving more respondents or interviewees. However, the findings from both quantitative and qualitative data can complement each other.

CHAPTER III LITERATURE REVIEW

The literature review was conducted through a semi-systematic literature review (SLR). An SLR is a rigorous evaluation that strictly follows a set of scientific methodologies to thoroughly discover, assess, and combine all the pertinent papers on a specific subject. [9] . The SLR process will help to minimize potential biases in exploring relevant studies or theories as it involves examining all the related existing materials and filtering them to fit the purpose of the research[8 10].

The semi-SLR was managed through scientific databases that provide open access to scientific research, such as ELSEVIER, SPRINGER, Google Scholars, and Google web search.

3.1. Circular Economy: A Fundamental Concept

Morseletto[3] (2023) defines a circular economy as an economic framework built from awareness or knowledge to use products and resources efficiently. This is manifested in form, reduction, and recirculation, preserving long-term value and closed loops of production and consumption. In his study, he concluded that the economy could mix between linear and circular. This is caused by several factors, such as the seller's profit, business opportunities, or limitations in terms of time, skills, manpower, or resources. Therefore, the role of innovation, cost and price structures, or scientific progress is relevant in the context of a CE. Gregson et al.[11]said that implementing a CE requires a radical transformation of economic governance, including fundamental recasting in manufacturing, retail, consumption, and property rights.

Figure 1 shows the circular economic value chain framework, which is the company ecosystem. This condition describes interactions within the company and outside the company. This figure shows that the CE moves in a systems approach. Eisenreich et al.[12] said that implementing a new circular value chain perspective' requires new managerial understanding in circular solutions to reduce resource-related CO_2 emissions and other pollution. Thus, it is important for companies to understand the new economic system, in this context, the government and associations need to carry out CE literacy consistently.

[9] Petticrew, M., & Roberts, H. (2005). *Systematic Reviews In The Social Sciences : A Practical Guide*: Williston, VT: John Wiley & Sons.
[10] Pickering, C., & Byrne, J. (2014). The Benefits Of Publishing Systematic Quantitative Literature Reviews For Phd Candidates And Other Early-Career Researchers. *Higher Education Research & Development, 33*(3), 534-548. Doi:10.1080/07294360.2013.841651
[11] Gregson, N., Crang, M., Fuller, S., Holmes, H., 2015. Interrogating The Circular Economy: The Moral Economy Of Resource Recovery In The EU. Econ. Soc. 44 (2), 218–243.
[12] Eisenreich A, Fuller J, Stuchtey M, Gimenez-Jimenez D. 2022. Toward A Circular Value Chain: Impact Of The Circular Economy On A Company's Value Chain Processes. Journal Of Cleaner Production 378 (2022): 134375.

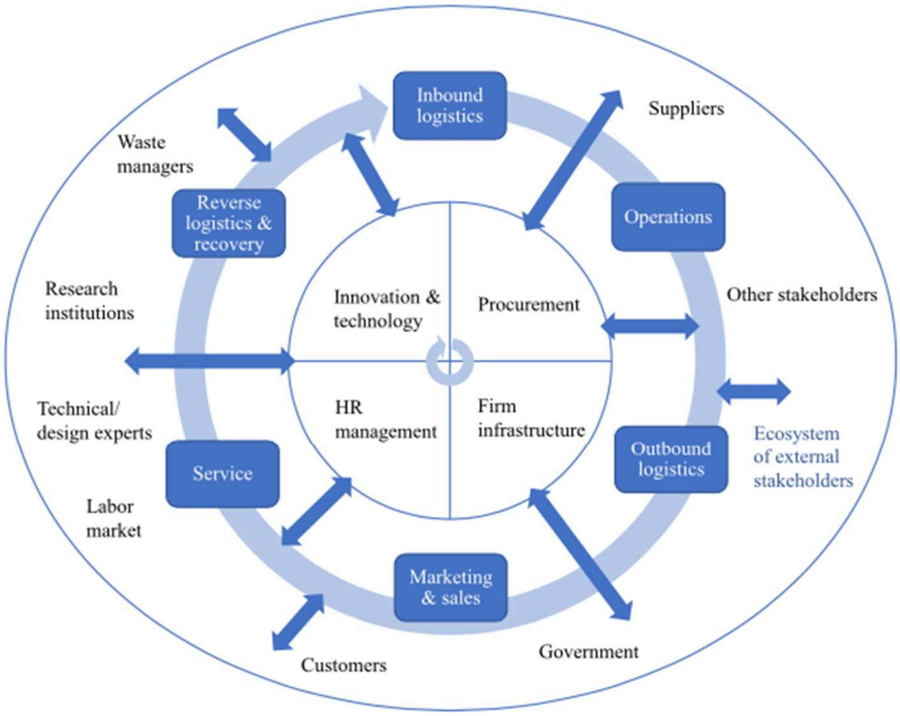

Figure 3.1. Circular Value Chain Framework.

Source: Eisenreich, et all[13]

Marsh et al. [13] said that more studies are still needed to find out policies to improve the implementation of a more effective CE, especially related to creating an economic environment and legal framework that is conducive to the running of the CE business model. Marsh et al. also provided a CE view that cannot be seen solely on the material and product side. But it needs to be put in a systems perspective. This is because potential synergies and tradeoffs will easily be identified when various circularity strategies are combined. Likewise, this can minimize the risk of negative impact from technology lock-in there/or initial failure of innovation.

Even though implementing a CE will positively contribute to the sustainable use of natural resources and the environment, a rebound effect will occur, which can interfere with optimal achievement (Figure 3.2). Castro, et al.[14] put forward two mechanisms that encourage the rebound effect, namely the initiator and developer mechanisms. The third mechanism is mitigating, which aims to mitigate the rebound effect. The initiating mechanism is a factor that drives the developer mechanism. The initiating mechanism for implementing the CE strategy, demonstrating a waste treatment efficiency policy, will increase behavior to dispose of more waste. Likewise related to innovation on the telecommunication side, which will also increase electronic waste.

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[13] Marsh ATM, Velenturf APM, Bernal SA. 2022. Circular Eonomy Strategies For Concrete: Implementation And Integration. Journal Of Cleaner Production 362 (2022): 132486

[14] Castro, C. G., Trevisan, A. H., Pigosso, D. C. A., & Mascarenhas, J. (2022). The Rebound Effect Of Circular Economy: Definitions, Mechanisms And A Research Agenda. *Journal Of Cleaner Production, 345*, 131136. Doi:Https://Doi.Org/10.1016/J.Jclepro.2022.131136

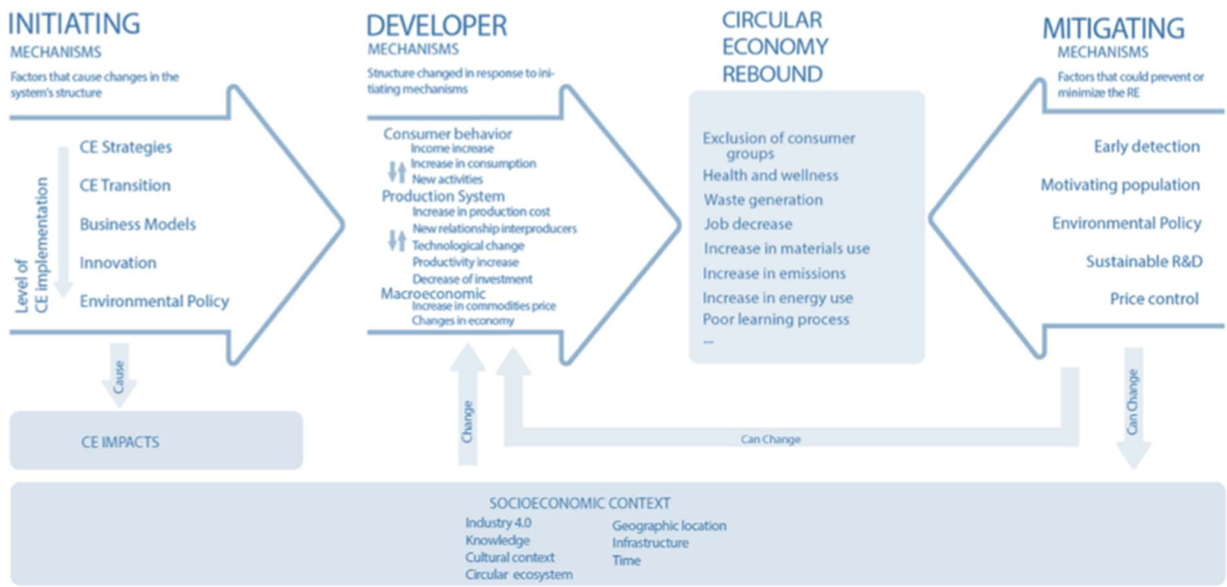


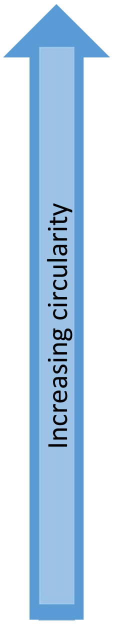
Figure 3.2. CE rebound phenomenon: The framework shows how the CE Rebound (CER) phenomenon occurs, illustrating the relation between the initiating, developers, and mitigating mechanisms, with the Rebound Effect (RE) and the socioeconomic context. Source: Castro et al. [15].

Kirchherr et al. [16]explain the core principles of CE are those relating to R-frameworks and the systems perspective. By referring to the European Union (EU) Waste Framework Directive[17], Kirchherr et al.[18], constructed R frameworks of hierarchy level of the CE loop under four dimensions (Reduce, Reuse, Recycle, Recover). Futher, UNDP[18] (2021) adopted 5R (Reduce, Reuse, Recycle, Refurbish, and Renew).

Potting et al.[19] expand the framework to become 9R (Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, Recover). These 9R are divided into three groups namely smarter product use and manufacture, extended lifespan of the product and its parts, and useful application of materials (Figure 3.3). These 9R are a set of principles to guide the transition from a linear economy to a more circular and sustainable economic activities. The analysis of this study adopts the 9R framework.

[15] Castro, C. G., Trevisan, A. H., Pigosso, D. C. A., & Mascarenhas, J. (2022). The Rebound Effect Of Circular Economy: Definitions, Mechanisms And A Research Agenda. *Journal Of Cleaner Production, 345*, 131136. Doi:Https://Doi.Org/10.1016/J.Jclepro.2022.131136
[16] Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing The Circular Economy: An Analysis Of 114 Definitions. *Resources, Conservation And Recycling, 127*, 221-232. Doi:Https://Doi.Org/10.1016/J.Resconrec.2017.09.005
[17] Waste Framework Directive. 2008. Directive 2008/98/EC Of The Eropean Parliament And Of The Council.
[18] UNDP. (2021). *The Economic, Social, And Environmental Benefits Of A Circular Economy In Indonesia*. Retrieved From Jakarta:
[19] Potting José, Marko Hekkert, Ernst Worrell, & Hanemaaijer, A. (2017). Circular Economy: Measuring Innovation In The Product Chain. Retrieved From Https://Www.Pbl.Nl/Sites/Default/Files/Downloads/Pbl-2016-Circular-Economy-Measuring-Innovation-In-Product-Chains-2544.Pdf

For the system perspective, Kirchherr et al.[20]) suggests that CE should be developed in three levels (micro, meso, and macro). The coverage of micro system perspective is at around product level changes, firms and/or consumers' preferences. The meso system perspective covers around CE at eco-industrial parks and/or the regional level. The macro system perspective includes CE practices at the overall industry, national, and/or global level. A fundamental change in every level is required, instead of incremental twisting of the existing system. In this process, the capacity of business sectors and the role of policy makers as well as other related stakeholders are crucial to implement the R framework.



Smarter product use and manufacture	**R0 Refuse**	Make product redundant by abandoning its function or by offering the same function with a radically different product
	R1 Rethink	Make product use more intensive (e.g. by sharing product)
	R2 Reduce	Increase efficiency in product manufacture or use by consuming fewer natural resources and materials
Extend lifespan of product and its parts	**R3 Reuse**	Reuse by another consumer of discarded product which is still in good condition and fulfils its original function
	R4 Repair	Repair and maintenance of defective product so it can be used with its original function
	R5 Refurbish	Restore an old product and bring it up to date
	R6 Remanufacture	Use parts of discarded product in a new product with the same function
	R7 Repurpose	Use discarded product or its parts in a new product with a different function
Useful application of materials	**R8 Recycle**	Process materials to obtain the same (high grade) or lower (low grade) quality
	R9 Recover	Incineration of material with energy recovery

Source: Potting, J., et al.,[18] (2017.) dan J. Kirchherr, et al.[22] (2017)

Figure 3.3. The 9R Framework of CE

3.2. Circular Economy from the Resource Efficiency Perspective

From the standpoint of resource efficiency, CE development entails creating, using, and consuming goods and services in a way that optimizes the value of resources by utilizing them as effectively as possible while minimizing waste and emissions over the entire lifecycle of a

[20] Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing The Circular Economy: An Analysis Of 114 Definitions. *Resources, Conservation And Recycling, 127*, 221-232. Doi:Https://Doi.Org/10.1016/J.Resconrec.2017.09.005

product[21 22 23] . There are seven key aspects that serve as the foundation for developing a CE for resource efficiency optimization successfully.

First is the mindset of circularity. The point of departure of CE development from the resource efficiency perspective is to have a stand and design the plan of the process and products for circularity[24 25] Viles E et al.[28] suggest that products should be designed with the possibility to use renewable, reused, and recycled materials throughout their entire lifecycle. Circular design concepts should also incorporate environmental concerns into product design to minimize waste and emissions, employ recyclable and biodegradable materials, and create products that can be disassembled and reused.

The second is adopting a life-cycle approach. Implementing a life-cycle approach to resource management entails taking into account the complete life cycle of a product, starting from the extraction of raw resources to its ultimate disposal. This method involves implementing strategies to optimize resource utilization and minimize adverse environmental effects.[24 26 27]. One of the methods of adopting this approach is establishing industrial symbiosis[28]. Industrial symbiosis mainly assists in creating a material network in the production processes of many industries to decrease the number of waste emissions produced by each production factory.

Third is creating a closed-loop supply chain[29 16 30]. Supply chain with a closed-loop system entails using materials and products in use for as long as possible. This is accomplished

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by designing work tools and products to be recyclable, reusable, recovered, etc. Furthermore, it also needs to prevent premature material disposal and ensure that commodities are retained in use for longer.

Forth is use of renewable and sustainable resources. This can be practiced by promoting renewable energy sources, like wind, bio-solar, and electricity. This can assist in encouraging sustainable resource management and lessen reliance on non-renewable resources. Using bio-based materials ought to be encouraged as well. In addition, bio-based materials should also be encouraged, such as biomass as a feedstock for manufacturing materials. By using fewer non-renewable resources and producing less hazardous waste, this strategy can minimize waste and increase resource efficiency. Dace et al.[31] and Feber et al.[32] suggested renewable materials should also be adopted in making sustainable packaging. It entails using eco-friendly materials and packaging design to minimize waste and maximize resource efficiency. This strategy can aid in lowering the consumption of non-renewable resources and the production of waste related to packaging.

Fifth is adopting digitalization and technology. Digitalization and technology can optimize resource efficiency by improving resource management, operating types of machinery, reducing waste, etc[33] [34] [28] . For example, in the upstream activities of oil palm plantations, using sensor leaf-based fertilizing can significantly improve the effectiveness and efficiency of fertilizer use. In the middle and downstream activities, technology platforms and data analytics can be employed to enhance the efficiency of supply chains and enable the tracking and monitoring of materials and products throughout their lifecycle.

Sixth is fostering collaboration and partnerships[35] [36] (Sposato, Preka, Cappellaro, & Cutaia, 2017; Velenturf & Purnell, 2021). Sposato et al. [38] suggest that developing a CE requires collaboration between various stakeholders, including enterprises, governments, non-governmental organizations, and consumers. Collaboration amongst stakeholders along the value chain is also part of CE activities. This involves engaging with suppliers to increase resource efficiency in the manufacturing process, following up with the customers to encourage the practice of behaviour, and also cooperating with waste management providers to guarantee that items are efficiently collected and repurposed.

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Finally, monitoring and assessing progress is crucial to follow up on the growth of a CE and pinpoint opportunities for development. Setting benchmarks and goals, monitoring development, and reporting on performance are all part of these practices.

Enabling Environment for Promoting Circular Economy from a Resource Efficiency Perspective

The government is advised to develop policies and regulations to incentivize CE and resource efficiency practices[37] [38] [39] [40]. The government needs to design the policy by addressing the needs and actual conditions of both the producers' and customers' side through appropriate schemes. On the producer side, the policy framework of circular development needs to be designed for extended producer responsibility (EPR). It entails holding manufacturers accountable for all product lifecycle aspects, including disposal and end-of-life treatment. This will motivate manufacturers to create products that can be recycled more readily and to take responsibility for the product's disposal and recycling[41].

As a foundation to develop a CE, promoting a circular culture is pivotal[42] [43] [28]Circular culture refers to a shift in social ideals and practices toward resource conservation and circularity. This involves fostering a culture that emphasizes resource conservation for future generations, supports sharing and reuse, and prioritizes sustainable and circular behaviors. From the perspective of resource efficiency, education and awareness are also crucial for maintaining CE practices. This involves educating stakeholders on the advantages of CE techniques and offering training and support for their implementation in business operations and supply chains.

It is evident that many business entities have limited financial resources to adopt circular practices. Thus, enabling firms to have capital is essential to implement circular practices successfully. This can include access to finance options promoting circular financing mechanisms, such as green bonds, and financial incentives for circular activities, such as tax exemptions or subsidies. Widening access to finance for firms engaging in circular activities would also encourage them to invest in research and development. Promoting innovation of

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[37] Barrie, J., Zawdie, G., & João, E. (2017). Leveraging Triple Helix And System Intermediaries To Enhance Effectiveness Of Protected Spaces And Strategic Niche Management For Transitioning To Circular Economy. *International Journal Of Technology Management &Amp; Sustainable Development, 16*(1), 25-47. Doi:Https://Doi.Org/10.1386/Tmsd.16.1.25_1

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new technologies, processes, and products that support a CE, such as new materials or waste-to-energy technologies, could increase the value added to the economy[44].

The provision of circular infrastructure is another fundamental condition for developing a successful CE. The effectiveness of resource recovery and recycling can be improved by investing in circular infrastructure, such as recycling centers and waste management systems. This could contribute to developing a closed-loop system where waste is reduced and resources are continuously utilized. The business sector can also be indirectly pushed to engage in circular practices by inviting them to establish factories in the industrial parks designed: for circular zones. In industrial parks, businesses are clustered together in one area to develop a closed-loop system whereby a different business uses trash from one company as a resource. By allowing the reuse of by-products and waste materials across industries, this strategy can minimize waste and improve resource efficiency.

The success of CE development requires strong support and collaboration with all stakeholders[45] [38] [39], including international counterparts. Hence, the transition to a CE is a worldwide challenge that calls for cooperation and collaboration on a global scale. Promoting international collaboration can aid in exchanging information, tools, and best practices and the growth of circular supply chains and markets.

3.3. Circular Economy and Resource Efficiency in the Palm Oil Industry

Using waste in the palm oil industry potentially optimizes resource efficiency implementation [46] [47]. These waste utilization efforts support the fundamentals of CE (Kurniawan et al., 2020). The waste generated by each oil palm manufacturing has been used in various ways, including fertilizer, bioenergy, other useful products. The CE practices in the palm oil industry effectively decreased 39.29% of imported vapor and 13.47% of imported electricity [50].

Table 3.1 maps the waste technology utilized to produce by-products from the waste utilization in the palm oil industry. The palm oil plantation has biomass waste, i.e. oil palm fibre (OPF) and oil palm trunk (OPT), which are re-utilized as fertilizer and bioenergy. Meanwhile, the CPO (Crude Palm Oil) milling process produces the waste of empty fruit bunch (EFB), palm kernel shell (PKS), mesocarp fibre (MF), and palm oil mill effluent (POME) re-utilized as fertilizer and bioenergy. In addition, the wood from the replanted palm oil trees can

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be used as raw material for furniture, and the best palm stems can also be further processed as sugar and food ingredients (sap sugar).

Oil palm plantations possess the inherent capability to sequester carbon dioxide as a characteristic of palm-like plants, consequently exerting an influence on the microclimate of their surrounding environment. Oil palm plantations with a nine-year age are able to absorb carbon up to 1,98 – 6,1 tons/ha/year. The standing stock carbon in oil palm plantations, whether in mineral or peat soils, typically ranges from 25 to 55 tons per hectare [48] [49] [50] [51]. It should be mentioned that the use of chemical fertilizers results in the majority of the carbon emissions from oil palm plantations. Carbon emissions can be decreased by decreasing chemical fertilizers and replacing them with organic fertilizers. The prospect of participating in the carbon trading scheme is not excluded by the implementation of zero emissions on palm oil plantations.

Table 3.1. The waste utilization technology of the palm oil industry

Waste Technology	OPF	OPT	EFB	MF	PKS	POME
Fibre making			✓			
Pelletizing	✓	✓	✓	✓	✓	
Briquetting	✓	✓	✓	✓	✓	
Fertilizer making			✓			
fermentation	✓	✓	✓			
Anaerobic digestion	✓	✓	✓			✓
Boiler (combustion)				✓	✓	
Fast Pyrolysis	✓	✓	✓	✓	✓	
Slow Pyrolysis	✓	✓	✓	✓	✓	
Activated Carbon Making					✓	
Gasification	✓	✓	✓			

Source: Yeo et al. [47] (2020)

Note: OPF: Oil Palm Fiber, OPT: Oil Palm Trunk, EFB: Empty Fruit Bunch, MF: Mesocarp Fiber, PKS: Palm Kernel Shell, POME: Palm Oil Mill Effluent

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The POME's waste released by CPO's process milling significantly impacts environmental pollution if thrown out directly without further processing[52]. The POME's waste is potentially re-utilized as biogas production material by an anaerobic digestion process. The utilization of POME as a biogas material resource is economically feasible. Because of the palm oil industry's proximity to the primary material resource, the biogas development utilizing the POME's waste is suitably implemented[53]. By waste utilization, the CE model in palm oil is an effort to support sustainable development and decrease the negative impacts of externality and potentially decrease the emission of CO2-eq[54].

In addition to POME's waste, Attasophonwattana[55] explained that EFB's waste utilization in the palm oil milling process is also used as biogas material in the anaerobic digestion process (Figure 3.4). Mass and energy balance calculations show that the energy output/input ratio value is above 1. Therefore, that process is feasible to be implemented. The integration of these materials (HTC / Hydrothermal Carbonization), gasification, and anaerobic digestion) for the valorization of EFB produces some useful products, such as green electricity (syngas and biogas), alternative fuels (char and tar), and precursor carbon (char).

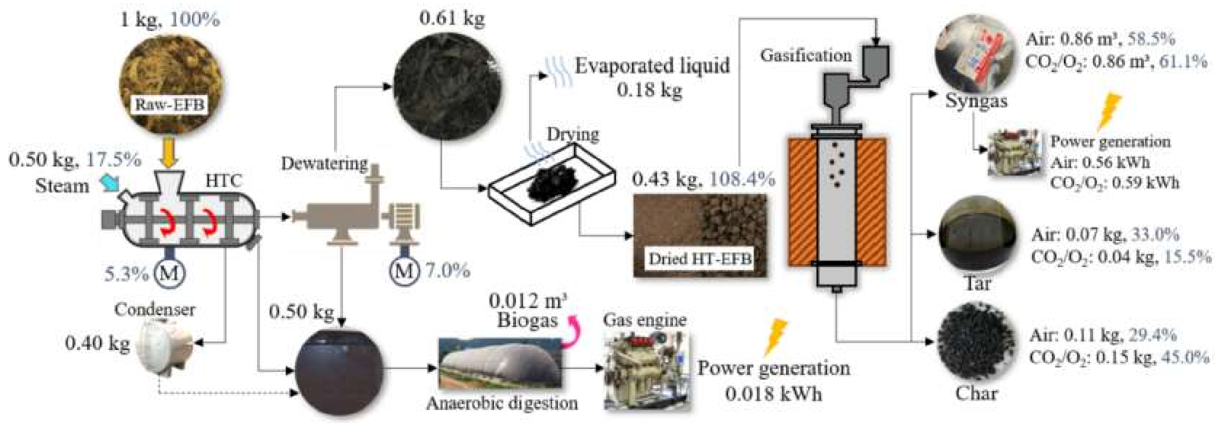

Fig. 7. Mass and energy balance for EFB conversion using the integration of HTC, gasification, and anaerobic digestion.

Source: Yeo et al. [47] (2020)

Figure 3.4. Mass and Energy balance for EFB conversion using the integration of HTC, gasification, and anaerobic digestion.

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Islamiya[56] explained one of the determinants affecting CPO's productivity decrease impacts the profit decrease, i.e. TC (Technological Change) which emphasizes the benefits of innovative technology in the CPO industry. Therefore, the government needs to strengthen economic policies by supporting technological advancement, i.e. research and technology development in production. In addition, the company should utilize the resource and technology which is more efficient and enhance the managerial expertise.

The production inputs in the palm oil industry, i.e., capital, labor, material, soil, and energy, are still needed to enhance their efficiency levels for achieving the optimum results of CPO/PKO[57]. Resource efficiency enhancement is necessary to reduce the production cost. Through that research, Ismiasih[58] explained the determinants of palm oil production are the number of productive trees, the plants' age, the urea fertilizer, SP36[1], NPK[2], labor, and synthetic pesticide. The efforts to enhance the technical efficiency are conducted by strengthening its members' cooperation role and enhancing palm oil farmers' involvement in the plasm pattern. In addition, the farmers should enhance the total number of productive trees and conduct replanting. Biomass waste utilization in the palm oil industry potentially decreases the greenhouse effects and produces a value-added product.

The efforts to enhance the efficiency of the palm oil supply chain potentially fulfill 50% of the national bioenergy target in 2023 and decrease the emission until 40 MtCo2eq/year. Moreover, palm oil biomass utilization potentially fulfills 50% of the electricity needs on Sumatra Island[59]. Cheah et al.[60] explained the circular economic implementation roles in maintaining the sustainability of the palm oil industry, mainly for solving the issues of environmental, economic, and social dimensions. Table 3.2 mapped various sustainability problems and potential measures of palm oil. That study result was supported by Ambarita & Romauli[61], explaining the CE of the palm oil industry potentially promotes sustainability. In addition, it has an opportunity as a bioenergy resource, cost decrease, and waste valorization for downstream by-products.

Table 3.2. Environmental, economic, and social issues and challenges by palm oil with its potential measures.

Component	Major issues and challenges	Potential measures
Environment	Climate change	• Technological application on site selection and yield optimization • Green and innovative crop management
	Claim to cause deforestation	• Technological applications on site selection

[56] Azzahra Tarbiyah Islamiya, H., Wulan Sari, D., Zeqi Yasin, M., Restikasari, W., Shaari, M. S., & Devis Susandika, M. (2022). Technical Efficiency And Productivity Growth Of Crude Palm Oil: Variation Across Years, Locations, And Firm Sizes In Indonesia. *Economies*, *10*(12), 303.
[57] Anam, M. K., & Suhartini, S. (2020). Efficiency Of Palm Oil Companies In Indonesia: A DEA Approach. *Habitat*, *31*(2), 55-63.
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[59] Harahap, F., Silveira, S., & Khatiwada, D. (2019). Cost Competitiveness Of Palm Oil Biodiesel Production In Indonesia. *Energy*, *170*, 62-72.
[60] Cheah, W. Y., Pahri, S. D. R., Leng, S. T. K., Er, A. C., & Show, P. L. (2023). Circular Bioeconomy In Palm Oil Industry: Current Practices And Future Perspectives. *Environmental Technology & Innovation*, 103050.
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		• Green and innovative management • Replanting if necessary • Circular bioeconomy • Effective information dissemination
	Waste generation	• Full-range palm oil waste refineries both in research and real application • Circular bioeconomy
Economic	Waste generation over supply issue	• Technological application for waste valorization • Circular bioeconomy for income generation
	"No palm oil" campaign	• Product diversification using technological applications • MSPO (Malaysia Sustainable Palm Oil) application • Circular bioeconomy • Effective information dissemination
	Other vegetable oil replacement causes reduction in palm oil demand	• Product diversification using technological applications • MSPO application • Effective information dissemination
Social	Labour shortage	• MSPO application to address social issues • Local labour training programs • Support from the government and business entities
	Claim to be violating human rights	• Effective information dissemination
	New generation lacks interest to continue working on palm oil's plantation	• Effecgive programmes on local communities • Support from the government and business entities • Effective information dissemination

Source: Cheah et al.[60]

Best Practice Circular Economy in the Palm Oil Plantation

The growing demand for palm oil has rapidly expanded oil palm plantations. Some oil palm plantations are unsuitable as natural growth places for oil palm. Thus, planting oil palms in a climate of low oil palm growing space requires more intensive treatment[62 63]. Intensive care and good irrigation lead to increased greenhouse gases and scarcity of water resources. Recommendations for planting on suitable land areas through increased productivity are a solution to meeting the need for palm oil[61]. The main characteristics for site selection consist of topography (slope; elevation above sea level on average), climate (annual average temperature, precipitation, and sundial hours; orientation), and soil characteristics (presence of clay loam and loam; depth of the subsoil).

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[62] Silalertruksa, T., Gheewala, S. H., Pongpat, P., Kaenchan, P., Permpool, N., Lecksiwilai, N., & Mungkung, R. (2017). Environmental Sustainability Of Oil Palm Cultivation In Different Regions Of Thailand: Greenhouse Gases And Water Use Impact. *Journal Of Cleaner Production*, *167*, 1009-1019.

[63] Suppalakpanya, K., Nikhom, R., Booranawong, A., & Booranawong, T. (2019). An Evaluation Of Holt-Winters Methods With Different Initial Trend Values For Forecasting Crude Palm Oil Production And Prices In Thailand. *Suranaree Journal Of Science And Technology*, *26*(1), 13-22.

Palm Oil cultivation starts from seedbeds, planting in the garden, maintenance, and harvesting. Oil palm seedbeds as locations for oil palm seed development have an important role in the success of oil palm cultivation. There are two types commonly cultivated by farmers: Elaeis *guineensis* Jacq., and *Elaeis oleifera*[64] Oil palm varieties are distinguished by the thickness of their endocarps and also by the colour of the fruit. Based on the thickness of the endotrap, oil palm is divided into three types: Pisifera, Dura, and Tenera. If based on the color of the fruit, there are Nigrescens, Virescens, and Albescens[63] [65] Planting new high-yielding oil palm varieties can increase yields from 15.2 to 22.8 ton FFB/ha-year and reduce water demand to 888 m^3/t FFB[66].

As palm oil production increases, there are concerns about environmental impacts, such as pollution, greenhouse gas emissions, water resource scarcity, and land conversion[67] [68]. Water resources are an important part of the plantation and palm oil industry. The need for water to produce FFB averages 1063 m3/t. Water needs are classified into green, blue, and grey waters, respectively, supplying 68, 18, and 14% of the total water needs[65].

Fertilization plays an important key to increasing productivity. Fertilizing usually use a combination of both chemical and organic fertilizers. Proper fertilization by paying attention to the time, dosage, type, and method, could reduce the use of organic and inorganic fertilizers by 55 - 60%[69]. Using non-organic fertilizers has a detrimental effect on the environment, contributing to greenhouse gas emissions[70].

The application of urea fertilizer to oil palm plants ranges from 19.11 – 22.17 kg of urea/ha fertilizer, resulting in emissions of 1,052.26-1,209.51 kg CO2-eq/ha[71]. Meanwhile, organic fertilizer derived from recycling palm waste into compost for plantations can reduce the smoke that occurs in the incineration of palm oil waste, reducing the adverse impact of oil

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[64] Rahmawati, A. (2023). Keragaman Genetik Varietas Kelapa Sawit (Elaeis Guineensis Jacq.). *JURNAL KRIDATAMA SAINS DAN TEKNOLOGI*, *5*(01), 35-40.

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palm plantation development on the environment[72] . In addition, using organic fertilizers can increase productivity by 16-21 percent[73] [74].

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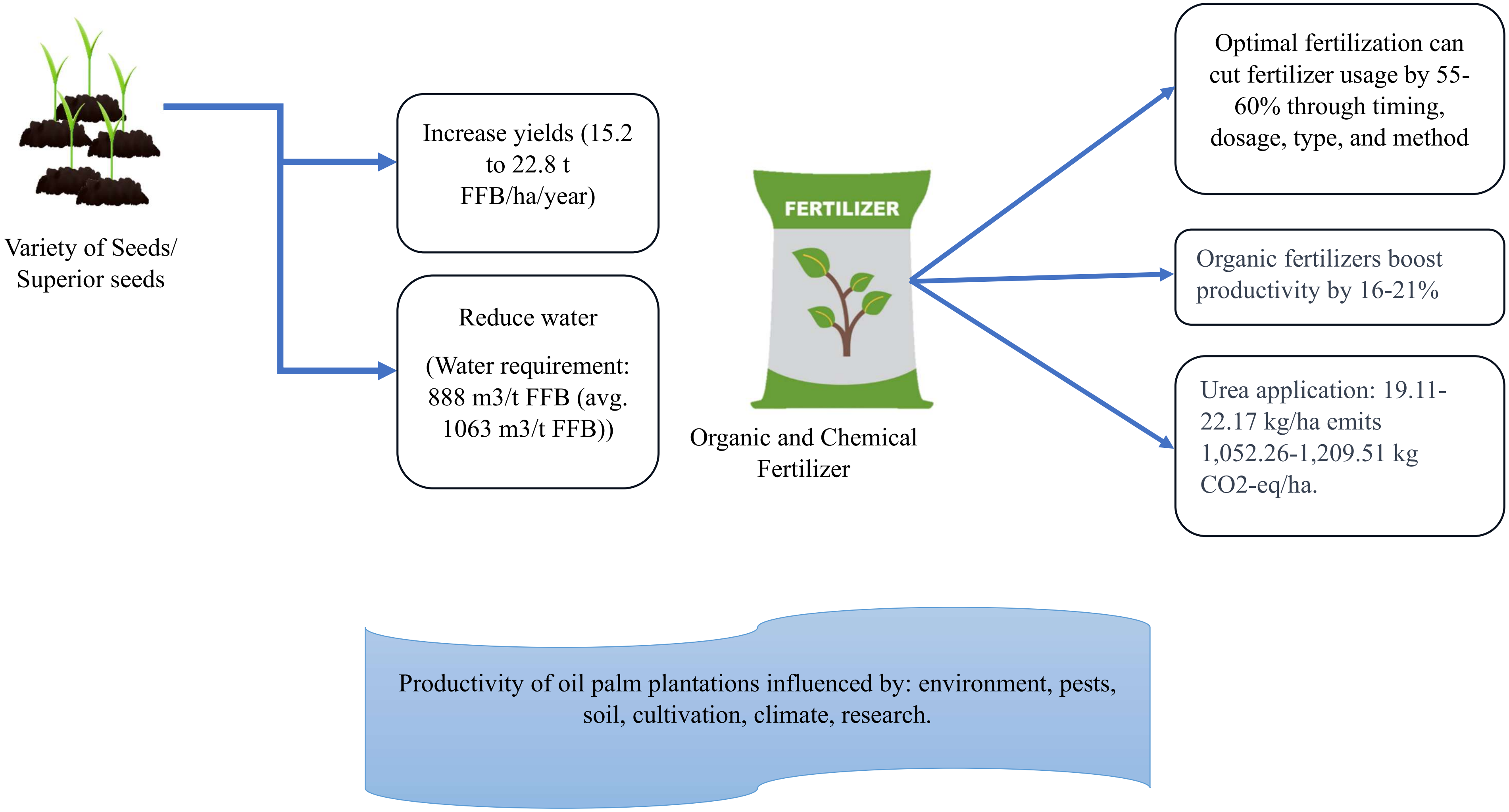

Figure 3.5 . CE and Resource Efficiency in the Palm Oil Industry – Best Practices

In oil palm harvesting activities, it is necessary to regulate the harvest so that the production has good quality and quantity. The utilization of fronds and leaves from frond waste when harvesting provides its own added value if managed properly. The resulting lidi (a broom made from the midribs of palm oil leaves) and fronds can be made into handicrafts that can be used in everyday life, such as brooms, curtains, and other ornate crafts. This handicraft product also has a high selling value, so it has become an export item abroad.[75] [76] In addition, palm fronds can also be used for carpentry wood using certain lamination techniques[77].

The decline in the productivity of oil palm plantations can occur due to various influencing factors. Some of the most common factors that can lead to a decrease in yield include:

1. Environmental factors: Drought, excessive rainfall, extreme temperatures, and other weather conditions can all impact oil palm tree growth and productivity. For example, trees may produce less fruit during the dry season, resulting in smaller fruits. Similarly, heavy rainfall can cause fruit bunches to rot or develop fungal diseases, resulting in lower oil yields[78] [79] [80].
2. Pests and diseases: Rodents, weevils, and fungal diseases such as Ganoderma and Fusarium wilt are common pests and diseases that affect oil palm trees. Effective pest and disease management strategies, such as the use of pesticides and regular plantation inspections, can help reduce the impact of pests and diseases on palm oil yields[81] [82].
3. Soil quality: The growth and productivity of oil palm trees can be influenced by soil quality. The tree may not grow well or bear much fruit if the soil lacks essential nutrients. Regular fertilization and soil testing are two effective soil management strategies that can help improve soil quality and maximize palm oil yields[83] [84].

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4. Cultivation practices: Palm oil yields can also be reduced by insufficient fertilization, pruning, and harvesting. For example, if a tree is not pruned regularly, it can become too dense, reducing sunlight and air flow and thus affecting fruit production. Similarly, if the tree is not harvested on time, the fruit may become overripe or rot, reducing the quality and quantity of palm oil[85 86].
5. Climate adaptation: To address the effects of climate change, measures to increase the resilience of oil palm trees may be required. These may include the selection of climate-adaptive cultivars, the use of irrigation systems, and the implementation of soil and water conservation measures[87 8883].
6. Research and development: Keep up with new research and technologies that can help boost palm oil yields. Precision agriculture, for example, can help increase crop yields by utilizing modern technologies such as sensors, drones, and remote sensing to optimize yield management[89 90 91].

3.4. Best Practice Circular Economy in The Palm Oil Milling

Wastes produced by palm oil mills include waste from empty fruit bunches (EFB), mesocarp fiber (MF), palm kernel shell (PKS), and palm oil mill effluent (POME). Burning empty fruit bunches (tandan kosong/ tangkos), kernel shells, and fiber is the most effective in reducing the environmental impact. Tangkos combustion is the most effective in reducing acid emissions of SO_2 and NO_x, ranging from 20 – 238% through combustion. Control and utilization of EFB and POME can reduce the impact of global warming relatively by 23 – 85% because it reduces CH4 gas emissions (Saswattecha et al., 2016). In addition, the cheapest use of EFB includes using organic fertilizer directly in plantations, organic mulch to control weeds, composting to be sold as organic fertilizer, production of EFB pellets as an energy source, and taking oil from decanter cakes.

While POME has considerable potential as a source of biogas, it has not been used optimally[50]The use of POME as biogas can be one of the solutions to reduce the greenhouse gas effect of palm oil mill waste. The high organic content in palm oil mill waste has excellent

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potential for biogas utilization[92]. The high content of Chemical Oxygen Demand (COD) of 50,000-70,000 mg / l in palm oil liquid waste provides the potential to be converted into electricity by capturing biogas (methane gas) produced through a series of stages of the purification process[93]. The processing of POME waste into biogas in Indonesia still requires a large investment. So small-scale palm oil mills will find implementing this biogas generation technology difficult. Large-scale companies are expected to be a motor in managing liquid waste from palm oil mills into new renewable energy sources by utilizing their waste. Referring to the study[50] using CE practices such as the use of POME waste, there will be a decrease in terms of steam and electricity needs, respectively (-39.3%) and (-13.5%).

Bejarano et al.[94]mentioned indicators that include waste and by-products by flow of materials (RRSMF), by using EFB as compost with a ratio of 2: 1 between POME and EFB, utilizing 82% fibre and husk as fuel and biochar, and utilization of 64.47% POME for composting, then the amount of carbon emissions becomes around 30,573 t CO 2 Eq. Furthermore, related to the formation of the carbon tax, by implementing a CE, it is estimated that a gained profit is USD 18,940.

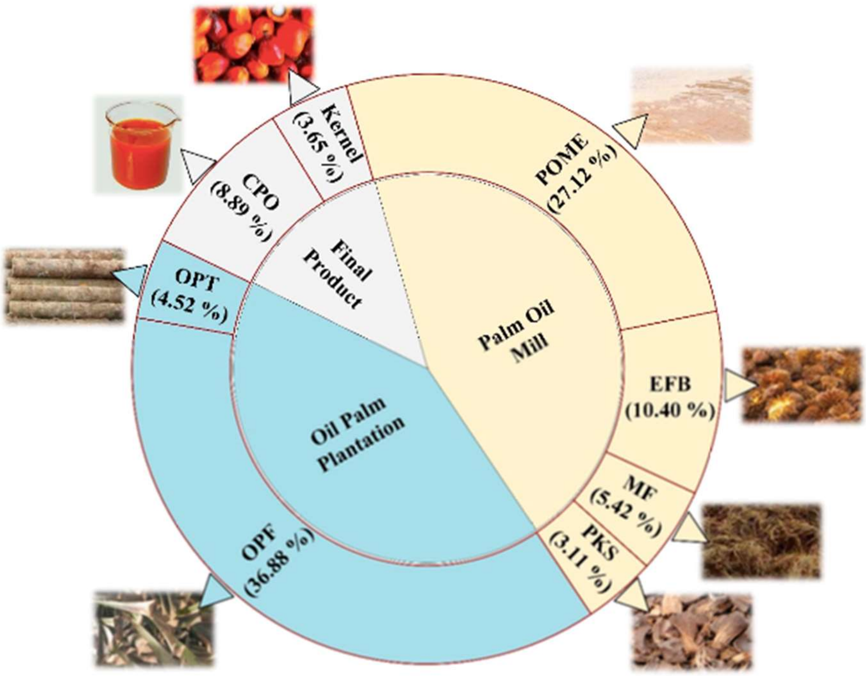

Figure 3.6. Typical Composition of Oil Palm Biomass (%).[50]

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[94] Bejarano, P. A. C., Rodriguez-Miranda, J. P., Maldonado-Astudillo, R. I., Maldonado-Astudillo, Y. I., & Salazar, R. (2022). Circular Economy Indicators For The Assessment Of Waste And By-Products From The Palm Oil Sector. *Processes*, *10*(5), 903.

Meanwhile, Figure 3.6 shows products from three main activity of palm oil, namely palm oil plantation, palm oil mill, and final products. There is a waste or palm oil clinker (POC) from the CPO processing process. POC is generated as waste from heating in boilers from the power generation process produced from oil palm fibre and calcination shells. Furthermore, it is stated that POC is very effective for stabilizing soil conditions. POC powder is proven to be pozzolanic with various contents such as CaO, SiO2, Fe2O3, and Al_2O_3. Using POC as an intumescent coating will help environmental conservation efforts and reduce production costs. Furthermore, it is also mentioned that around 37% of palm oil waste can be used as green concrete.

Another waste from the milling process is palm oil sludge which still contains some organic matter that can be used as composting material. In addition, boiler also produced waste in the form of ash from the heating process, categorized as Hazardous and Toxic Substances (HTS). This waste, if not treated properly, will cause environmental problems. The activity of microorganisms during the composting process is believed to be able to degrade heavy metals. The results showed that 50% sludge and 50% organic matter was the best material composition to reduce Pb and Zn[95] (Anisa Rahmawati et al., 2020).

Milling processes require huge amounts of water. The average water requirement to produce one ton of CPO from seven plants is 5,083 m^3. Meanwhile, Bejarano[93] provide an overview of the processing of 1 ton of FFB using about 1.5m^3 of water. As palm oil production increases, there are concerns about environmental impacts, such as pollution, greenhouse gas emissions, scarcity of water resources, and land conversion[66] [67]. Water resources are an important part of plantations and the palm oil industry. The average water requirement to produce FFB is 1063 m3/t. The classification of water needs is divided into green, blue, and gray waters supplying 68, 18, and 14% of the total water needs, respectively. The average water requirement for producing one tonne of CPO from seven mills is 5,083 m3. Planting a new variety of oil palm, namely Suratthani 7, was able to increase yields from 15.2 to 22.8 t FFB/ha-year and reduce water requirements to 888 m3/t FFB[65].

There are four valuable parts of palm-processed products. First, biofuels from the resulting waste can be viewed from several perspectives, such as complementary materials or substitutions to generate heat in boilers, as a complement or substitution of powerhouses, and as a substitute material to obtain biodiesel. These are obtained through a process such as direct combustion, carbonization, gasification, pyrolysis, torrefaction and thermolysis and biological processes such as anaerobic digestion. Second enzymatic activity using solid organic residues, the chemical method used is hydrolysis which is assisted by fermentation of biological processes. Third, sources of nutrients, which use solid organic residues, such as EFB, fibre and ash, and POME liquid waste. This material is rich in phosphorus, nitrogen, potassium, magnesium, and metal components of low value. The processing processes used such as composting, bioreactors, and pyrolysis. The last four are in the construction of buildings, which are associated with construction needs, using fibre, husk and ash.

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[95] Rahmawati, A., Mizwar, A., & Prihatini, N. S. (2020). Penyisihan Logam Timbal (Pb) Dan Seng (Zn) Pada Lumpur Wastewater Treatment Plant Dan Abu Boiler Industri Refinery Dan Biodiesel Minyak Kelapa Sawit Dengan Composting. *Jernih: Jurnal Tugas Akhir Mahasiswa*, *3*(1), 15-24.

Based on research conducted by Malithong et al.[96], palm oil waste has a residual value of around 919.35 million USD per year consisting of (1) the weight of all waste, palm leaves, and shell fibre in Thailand is around 3.64 million tons per year, equivalent to 243.44 million USD fertilizer; (2) the weight of the palm trunk is 89,958 tons per year, equivalent to 6.00 million USD of fertilizer; (3) the weight of empty bunches, coax, and wastewater of 2.86 million tons per year; equivalent to 191.21 million USD of fertilizer; (4) the weight of fibre and palm shells from the crude palm oil extraction process is 7.13 million tons; equivalent to 476.85 million USD of fertilizer; (5) palm oil mill liquid waste of 9.62 million cubic meters per year; equivalent to 1.85 million USD of electricity. Similarly, in the case of Indonesia, Hambali and Rivai[97], estimated that in 2030, oil palm waste biomass as follows: 54-million-ton EFB, 31 million tons MF, 15 million tons PKS (palm kernel meal), 130 million tons POME, 115 million tons oil palm frond, and 59,7 million ton oil palm trunk.

Technologies such as the synthesis of biofuels and biochemicals play an important role in using and recycling palm oil waste. The main products obtained from palm oil processing with a capacity of 30 tons/hour are CPO as much as 6,591 kg/hour (21.97% FFB), PK as much as 1.9 tons/hour (6.4%). Meanwhile, fiber (8%) and shell (7%) are used as boiler fuels[98]. This industry requires resources such as fertilizer, steam, fuel, and electricity. These resources can be met by utilizing biomass through biomass conversion technology. Such technology will help to reduce the material coming out of the system.

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[96] Malithong, A., Piputsitee, C., Sarobol, E., & Sriroth, K. (2017). Zero Waste Management To Increase Efficiency In Palm Oil Production And Processing For Food Security In Thailand. *Walailak Journal Of Science And Technology (Wjst)*, *14*(7), 589-596.

[97] Hambali, E., & Rivai, M. (2017, May). The Potential Of Palm Oil Waste Biomass In Indonesia In 2020 And 2030. In *Iop Conference Series: Earth And Environmental Science* (Vol. 65, No. 1, P. 012050). Iop Publishing.

[98] Suwandi, S. (2022). *Analisa Unjuk Kerja Boiler Kapasitas 45 Ton Uap/Jam Di PT. Rohul Sawit Industri* (Doctoral Dissertation, Universitas Islam Riau).

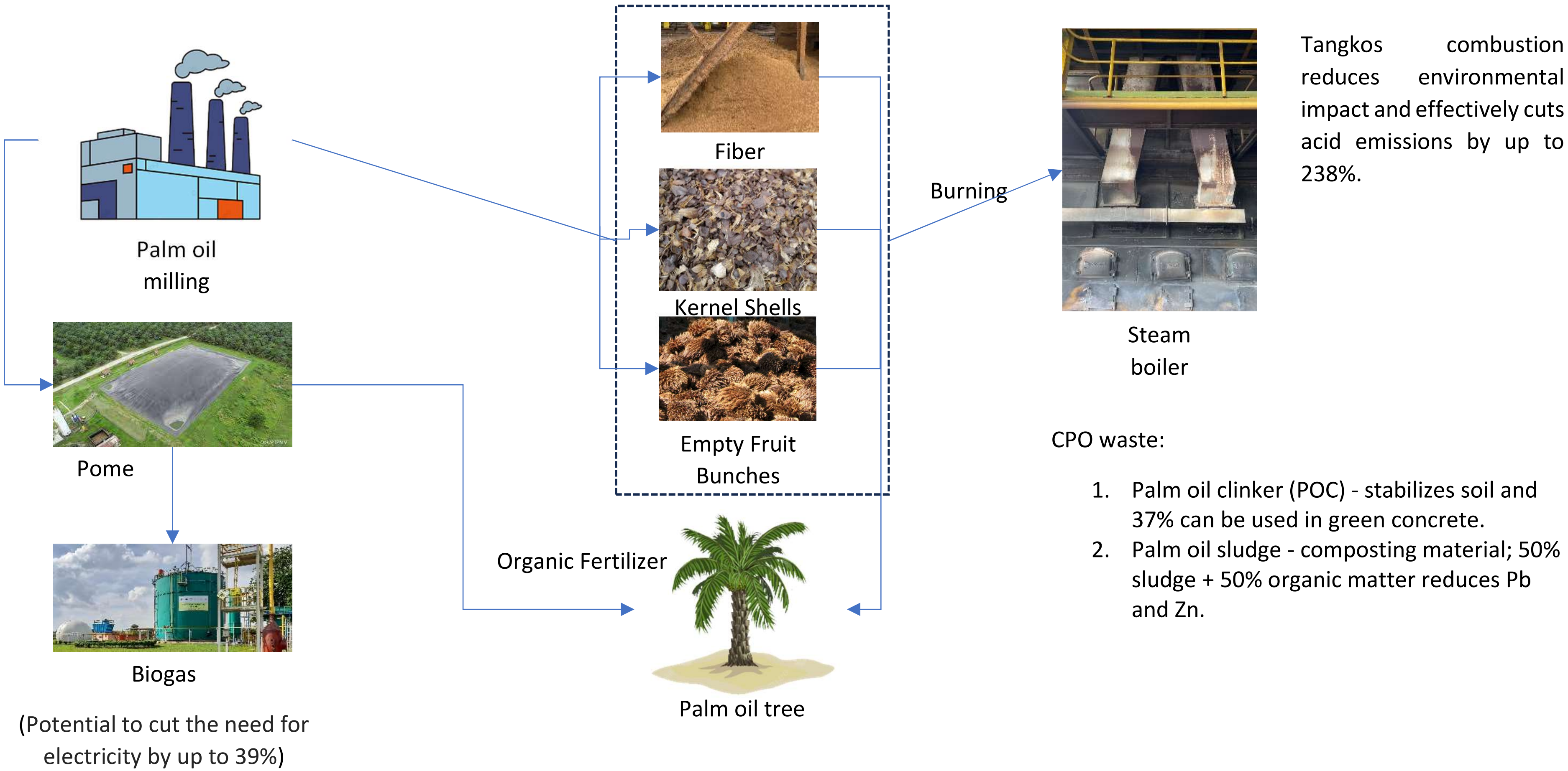

Figure 3.7. CE and Resource Efficiency in the Palm Oil Milling– Best Practices

Palm oil tree

empty bunches, coax, and wastewater - 191.21 million USD of fertilizer

fibre and palm shells from the crude palm oil extraction process - 476.85 million USD of fertilizer

Palm Leaves and Shell Fibre - Equivalent To 243.44 Million USD Fertilizer

Palm trunk is 89,958 tons per year - 6.00 million USD of fertilizer

Palm oil mill liquid waste - 1.85 million USD of electricity

Climate change impact reduction

1. POME composting cuts large-scale mill effects by 75%.
2. Biogas from POME reduces emissions by 44% in semi-mechanized plants and smallholders.
3. In 2020, PT. DSN began operating a Bio-CNG plant, saving 3.7M liters of diesel in 2022.
4. Biogas Engine and Bio-CNG cut 10,003 tCO2 emissions, equal to 3.7M liters of diesel.

Figure 3.8 . CE and Resource Efficiency in the Waste of the Palm Oil Milling– Best Practices[99]

[99] Malithong, A. et al. Zero waste management to increase efficiency in palm oil production and processing for food security in Thailand. (2017). Walailak Journal of Science and Technology (WJST), 14(7):589-596, 2017
Anyaoha, K.E., Zhang, L. Technology-based comparative life cycle assessment for palm oil industry: the case of Nigeria. *Environ Dev Sustain* **25**, 4575–4595 (2023). https://doi.org/10.1007/s10668-022-02215-8

A significant challenge for the palm oil industry is reducing its environmental impact (pollution and carbon footprint) and integrating a CE into operations. The life cycle analysis results show that large-scale palm oil mills perform worse (468 kg of CO2-eq per t FFB) than semi-mechanized mills and smallholders in their impact on climate change. In large-scale mills, the effects of climate change are reduced by 75% when raw palm oil mill (POME) waste is used in composting EFB. Similarly, the impact of climate change is reduced by 44% when biogas from POME replaces diesel in semi-mechanized plants and smallholder farmers[100]. Small-scale plant inputs and outputs (emissions and co-products) produce more GHG emissions, including CH_4, CO_2, and N_2O resulting from high diesel consumption. In particular, open combustion of biomass residues in small-scale plants emits many greenhouse gas emissions and causes air pollution. In addition, more budgets are spent on diesel consumption, while potential bioenergy sources are neglected[98],

Regulatory measures are needed to ensure better management practices in the production process. Particular attention should be paid to the utilization and reuse of biomass and POME. This reuse of biomass and POME provides useful references to help the sustainable energy transition to mitigate climate change and form a cleaner bio-economy[98]. Conventional treatments such as pool systems are the most widely practised method for POME processing by applying pool systems, including aerobic and anaerobic processing. Recently, Alternative techniques, such as coagulation, flocculation, adsorption, advanced oxidation process (AOP), and membrane technology, have demonstrated favorable outcomes in treating POME as compared to traditional procedures.[101].

Liquid waste from palm oil mills, namely POME, is a source of high-value renewable energy. PT. DSN in 2020 succeeded in starting the operation of the Bio-CNG plant from POME using methane gas capture technology (PT. DSN 2022). Currently the company has been able to generate 13.4 GWh of electricity which is used for the operational needs of factories, offices and employee housing. This electricity production is equivalent to a reduction of around 3.7 million liters of diesel during 2022. Bio-CNG has also been used by PT. DSN to replace vehicle fuel that has been using diesel. Furthermore, based on the Sustainability Report of PT. DSN 2022, it is known, from around 104,513 meters^3, POME waste which is processed in the Bio-CNG factory, is capable of producing around 7.7 GWh of electricity. Furthermore, around 10,003 tCO2 emissions of the equivalent of 3.7 million liters of diesel oil can be reduced from the use of Biogas Engine and Bio-CNG.

Recent developments show that steamless palm oil technology (SPOT) is being developed by the Indonesian government. There are at least three advantages of the dry process[102]. First, with this technology the nutritional content will be maintained in the oil. Second, the resulting carbon emissions will be much smaller because it does not produce POME. The carbon emission produced by SPOT is estimated about 269.7 kg CO2 eq/ton palm oil, which is lower than the carbon emssion produced by another technology about 1.296 kg

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[100] Anyaoha, K. E., & Zhang, L. (2022). Transition From Fossil-Fuel To Renewable-Energy-Based Smallholder Bioeconomy: Techno-Economic Analyses Of Two Oil Palm Production Systems. *Chemical Engineering Journal Advances*, *10*, 100270.

[101] Iskandar, M. J., Baharum, A., Anuar, F. H., & Othaman, R. (2018). Palm Oil Industry In South East Asia And The Effluent Treatment Technology—A Review. *Environmental Technology & Innovation*, *9*, 169-185.

[102] Discussion with the Director of the Seafood and Fisheries Industry, Ministry of Industry, 28 July 2023.

CO2 eq/ton palm oil. The three chlorides content will also become much smaller than the palm oil produced. Under these conditions, palm oil without steam can be referred to as SPO (Superior Palm Oil). SPOT technology is referred to as a new country of palm oil and does not need to use too large capacity. It only needs small modular units of around 5-10 tons per hour. Thus, it can be built in many locations and does not require land extensification to increase palm oil production. The government has prepared a pilot SPOT project with 17 units and a factory built in partnership with farmer cooperatives. The SPOT factory is equipped with an IRU (impurity removal unit) to produce food oil rich in antioxidants and vitamins; construction of a palm oil petrol park; and other downstream potential for food supply.

Table 3.3 Comparing Three Types of Technology of Palm Oil Processing

Product	Unit	CPO conventional	IVO/ILO	PMTU/SPOT
CAPEX	Rp. Billions/ ton FFB/hour	3,4	3,6	2,6
Processing Cost	Rp/Kg FFB	185	200	112
Yield Basis	%	100	99	102
Payback period	Year	5	4.5	3

Note:
Under the IVO/ILO Production Technology, Industrial Vegetable Oil is not for Food, but for green fuel production.

The Indonesian government is also making efforts to develop the red edible oil industry by optimizing the role of small-scale palm oil mills managed by small and medium enterprises and cooperatives. Red edible oil will have a better nutritional content than ordinary palm cooking oil or commonly referred to as anti-stunting oil, however, its development requires the cooperation of many parties, for example in terms of business capital, institutional assistance for farmer businesses, business feasibility preparation processes, DED (detail engineering design), establishment permits, environmental impact analysis, and product certification. Other things that are also important to pay attention to are studies from the feasibility perspective of efficient use of resources, as well as prospects for working with large palm oil mill companies.

3.5. Best Practice Circular Economy in The Palm Oil Refinery

The process of refining palm oil can be categorized into two types, namely physical and chemical purification. Physical purification involves three main steps degumming, bleaching and deodorization. Physical purification is divided into two stages, namely the pre-treatment stage and the deodorization stage. The pre-treatment stage involves degumming and bleaching of palm oil. The aim of the process at this stage is to remove unwanted impurities that affect the stability of the final oil product. The goals of the degumming and bleaching processes are achieved through the chemicals used to react and absorb unwanted impurities. The chemicals used for this process are phosphoric acid and bleaching earth[103].

Degumming is a stage of a purification process that aims to separate gum, latex, and mucilage (phospholipids, proteins, residues and carbohydrates) in oil without reducing the amount of oil-free fatty acids. The working principle of degumming is to separate phosphatides into the water phase so that it can be separated by precipitation, filtering or centrifugation[104] [105](Gibon et al., 2007; Ketaren, 1986). There are several types of degumming methods , namely water degumming , acid degumming , dry degumming and enzymatic degumming (Sim et al.,[106] 2018). Water degumming was carried out to remove phosphatides in CPO using water. The degumming process can also use NaCl[107]) and use H_3PO_4 (Ristianingsih et al.,[108]). Such acid degumming consists of treating CPO with phosphoric acid or citric acid (with 2–5% water) in a temperature range of about 80 to 95 0 $^{C.}$ In dry degumming, CPO is mixed with 0.05% to 0.10% concentrated phosphoric acid. and heated to about 80 to 110 ^{0} C. In contrast, in enzymatic degumming, phospholipid degrading enzymes called phospholipases are used. Degumming using acid and water is generally more widely used in the cooking oil industry because it is more economical to use, safe to consume in large quantities and easy to find[109].

Bleaching is a bleaching process that aims to reduce beta-carotene levels and oil dobi levels to maintain the color quality of the products produced[101]. The bleaching process will reduce the color of CPO from brown to clear yellow, as well as remove residual dirt, latex gum, and residual free fatty acids (*asam lemak bebas* (ALB))[110]. The material used in the bleaching process is bleaching Earth with various trademarks[100]. During the bleaching process, the oil is heated with various types of bleach clay or bleach earth at high temperatures between 85 and 110 ^{0} Celsius in a vacuum (720 mm Hg to 760 mm Hg). This process helps remove traces of metals, color pigments, phosphatides and other impurities[103]. As a result, compounds such as phospholipids, dyes, soaps and other contaminants are removed from the oil system to produce the desired characteristics of refined vegetable oils. Some examples of bleaching clay or bleach earth is bleaching acid activated earth, fuller's earth, and activated charcoal[111].

The last process in *physical refining* namely deodorization Process, oil that has been previously processed is then deacidified and deodorized[101].The prepared oil is initially

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[103] Irawan, B., & Hasan, A. (2021). Pyrolysis Process Of Fatty Acid Methyl Ester (FAME) Conversion Into Biodiesel. *International Journal Of Research In Vocational Studies (IJRVOCAS)*, *1*(2), 01-10.
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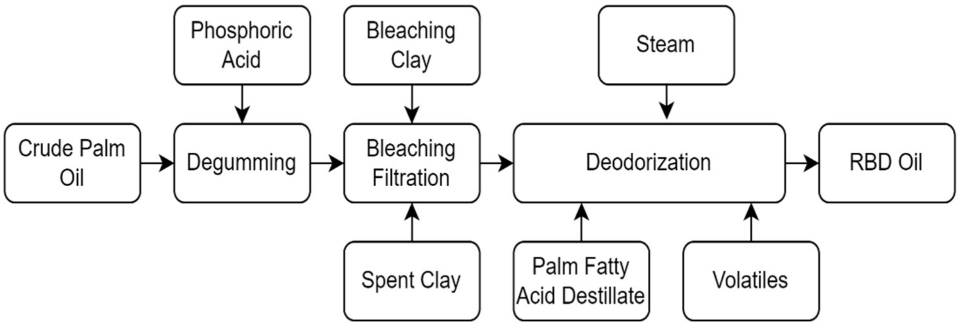
[107] Jazuli, A., Dan Susila, I. W., (2013), Perbaikan Kualitas Minyak Biji Karet (CRSO) Melalui Proses Degumming Menggunakan Natrium Klorida (Nacl) Sebagai Bahan Baku Pembuatan Biodisel. Jurnal Teknik Mesin, 2(1), Pp. 25-30.
[108] Y. Ristianingsih, Sutijan, A. Budiman, Reaktor, 13, No.4, 242 (2011)
[109] Anderson, D. (2005). A Primer On Oils Processing Technology. *Bailey's Industrial Oil And Fat Products*, *5*, 1-56.
[110] Amelia, J. R., Iryani, D. A., Indraningtyas, L., Sugiharto, R., Ginting, S., & Hasanudin, U. (2023). Pengelolaan Spent Bleaching Earth.
[111] Silva, S. M., Sampaio, K. A., Ceriani, R., Verhé, R., Stevens, C., De Greyt, W., & Meirelles, A. J. (2013). Adsorption Of Carotenes And Phosphorus From Palm Oil Onto Acid Activated Bleaching Earth: Equilibrium, Kinetics And Thermodynamics. *Journal Of Food Engineering*, *118*(4), 341-349.

dehydrated and followed by heating to 240 – 270 °C with heat exchanger before being pumped into the deodorizer, conditions under vacuum (2 – 5 mmHg). Temperatures above 270 ° Celsius are avoided to reduce loss of neutral oil, tocopherols / tocotrienols, and possible isomerization and unwanted reactions[112 113]. In these conditions with the help of stripping steam, the FFA that is still present in Pretated Oil, is distilled together with the more volatile odoriferous compounds and oxidation products such as aldehydes and ketones which can give the oil an undesirable odor and taste. At the same time, carotenoid residues are also decomposed, and the final product is light-colored (bland RBD oil). To maximize the recovery of heat energy, deodorized hot oil is contacted in the heat exchanger with Pretreated Oil up to 120 – 150 °C. Further cooling is carried out with water to a temperature of 55-65 °C before proceeding to *the storage tank* (storage)[114].



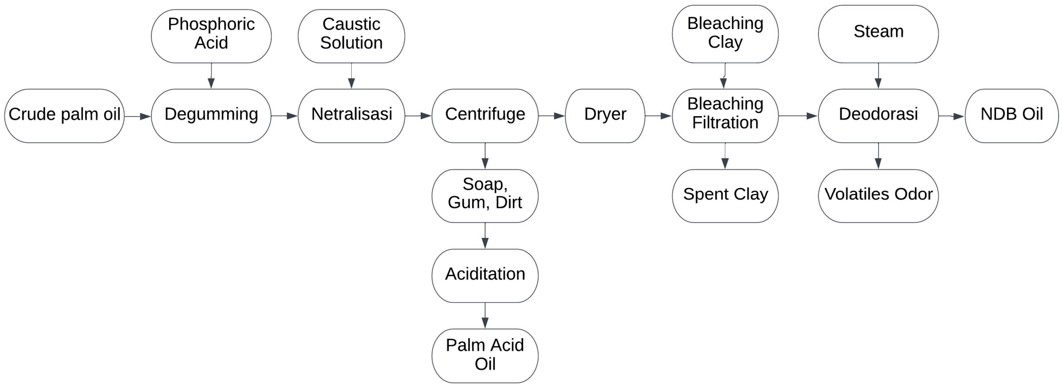
Figures 3.9. flowchart on the method physical refining[111]

Stage in the chemical process refining (purification in a manner chemistry) are Gum Conditioning (Degumming) and Neutralization. Technically it can be explained, namely crude oil is heated to a temperature of 80 – 90 °C. Phosphoric acid with a concentration of 80 – 85 percent is added at a rate of 0.05 – 0.2 percent of the feed rate crude oil. After that it was degummed oil treated with caustic soda solution (NaOH) with excess (based on FFA content in crude oil) about 20 percent.

While chemical purification, requires an additional purification step called neutralization. Neutralization is a chemical purification process, which converts the free fatty acids (FFA) in the degummed oil into soap, a soapy mixture of fatty acids, salts, phospholipids, impurities and neutral oils[103]. NaOH, potassium hydroxide (KOH), sodium bicarbonate ($NaHCO_3$) and sodium carbonate (Na_2CO_3) are the main alkaline reagents used in this process. The neutralization process involves gravity settling followed by separation of the soap stock from the neutralized oil. Finally, the alkaline residue is cleaned from the oil system using hot

[112] Ayustaningwarno, F. (2012). Proses Pengolahan Dan Aplikasi Minyak Sawit Merah Pada Industri Pangan. *Journal Vitasphere*, *2*(1), 1-11.
[113] Bailey, O., & Worrell, E. (2005). Clean Energy Technologies: A Preliminary Inventory Of The Potential For Electricity Generation.
[114] Damarani, Z. N., Sholihah, L. M., Zullaikah, S., & Rachimoellah, M. (2019). Pra-Desain Pabrik Refined Bleached Deodorized (RBD) Olein Dari Crude Palm Oil (CPO). Jurnal Teknik ITS, 8(1), 51–55. Https://Doi.Org/10.12962/J23373539.V8i1.41671

water[115]kindly technical, neutralized palm oil (NPO) carried out washing with 10-20 percent hot water to remove any remaining soap. After washing process washed the oil is separated from the washed soap through a centrifugation process and then vacuum dried until the moisture level is less than 0.05 percent. Neutralized palm oil then goes into in the bleaching stage and filtration, which at this stage is neutralized palm oil treated using bleach earth with the same treatment as in physical refine. Neutralized and bleached the oil then flows to the deodorizer in the same way as the physical refinery. The oil is then distilled at 240 – 260 ^{o}C and vacuum pressure 2 – 5 mm Hg by direct method steam injection. Under these conditions, residual FFA, volatile oxidation product, and odoriferous material are removed along with the breakdown of carotenoids due to heat. The final product is NBD (neutralized, bleached , deodorized) palm. The oil is then cooled to a temperature of 60 $^{\circ}$C and passed through *a polishing filter bag* before being pumped into a storage tank[111].



Figures 3.10. Flowchart on the method chemical refining[111]

Several palm oils producing countries have produced biodiesel as a renewable energy source from vegetable oils. Biodiesel production in Thailand started in 2003, with production continuing to increase until now. Biodiesel production in Thailand is around 1.62 million liters/day or 3% of world biodiesel production[116] (Wangrakdiskul & Yodpijit, 2015). Biodiesel production can be encouraged to meet Thailand's national biodiesel needs, so the provision of sustainable fresh fruit bunches (FFB) as feedstock for biodiesel is essential to achieve economic, social, and environmental stability[117]. Meanwhile, Indonesia issued a regulation on the use of biofuels as a substitute for fossil fuels in 2006. Then in 2018, the Indonesian government imposed biofuels as a substitute for fossil fuels in all sectors of the economy[118] (Tupa R. Silalahi et al., 2020). Using crude palm oil (CPO) is an alternative energy source and mitigation

[115] Calta P, Velíšek J, Doležal M, Hasnip S, Crews C, Réblová Z. 2004. Formation Of 3- Chloropropane-1,2-Diol In Systems Simulating Processed Foods. European Food Research & Technology 218:501-506.
[116] Wangrakdiskul, U. And Yodpijit, N. (2015). Trend Analysis And Future Of Sustainable Palm Oil In Thailand. KMUTNB International Journal Of Applied Science And Technology, 8:21-32
[117] Nupueng, S., Oosterveer, P., & Mol, A. P. (2018). Implementing A Palm Oil - Based Biodiesel Policy: The Case Of Thailand. *Energy Science & Engineering*, *6*(6), 643-657.
[118] Silalahi, F. T. R., Simatupang, T. M., & Siallagan, M. P. (2020). Biodiesel Produced From Palm Oil In Indonesia: Current Status And Opportunities. *AIMS Energy*, *8*(1).

of CO_2 emissions. It aims at the competitiveness of the CPO industry and efforts to reduce the use of fossil energy to preserve the environment[119].

Nigeria is one of the fifth largest palm oil producers after Indonesia, Malaysia, Thailand, and Columbia. Nigeria is a developing country whose economic resources depend on natural resources. However, about 60% of Nigerians still live below the poverty line. In addition, about 40% of Nigerians do not have access to electricity. One of the government's strategies in dealing with this issue is to support for developing biofuels (biodiesel) from palm oil. However, biofuel development in Nigeria is still in its early stages, so there are many challenges. The implementation of the use of biofuels (biodiesel) has the potential to make Nigeria not only a country rich in crude oil but a producer of biofuels. The development of biofuels (palm biodiesel) in Nigeria should be based on the mixing capability of diesel oil, the availability of the necessary raw materials (palm oil) and the environmental conditions suitable for production nationwide[120.]

The biorefining process is the continuous conversion of biomass into various advantages of biofuel-based products. The process develops biomass energy as a thermal energy generation, electricity, and biofuel. In the past ten years, biomass has also been used to produce various products other than biofuels, including fine chemicals, biomaterials, biopolymers, etc. The development has indicated that the existing fossil-based economy will be increasingly replaced by a biomass-based economy[117].

3.6. Circular Economy in The Palm Cooking Oil Distribution and Packaging

Sustainable palm oil supply chains require the company to manage all processes involved in producing and distributing palm oil, use environmentally friendly inputs, and convert inputs into outputs using technologies that do not harm the environment[121]. Palm cooking oil, as one of the CPO derivative products, is produced through a refining process of CPO, which is then fractionated. Two types of palm cooking oil are circulating in the market: bulk cooking oil and branded cooking oil. Bulk cooking oil, or normal olein, is a one-stage fractionation product of palm oil. In contrast, branded cooking oil or super olein (super olein) is obtained from the fractionation of two stages of palm oil[122]. Normal bulk cooking oil/olein usually has an IOD number of 54.33-59.14 Wijs, while branded cooking oil (super olein) is about 60.06-64.38 Wijs[119]. Refined palm products such as cooking oil in distribution must be packaged to improve cooking oil quality, safety, and health.

The supply chain process from upstream (plantations) to downstream (distribution) is described in the figure below. Some CE practices can be applied to packaging and distributing

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[119] Pattanapongchai, A., & Limmeechokchai, B. (2014). The Co-Benefits Of Biogas From The Palm Oil Industry In Long-Term Energy Planning: A Least-Cost Biogas Upgrade In Thailand. *Energy Sources, Part B: Economics, Planning, And Policy*, *9*(4), 360-373.

[120] Thompson-Duruibe, G. I. (2020). How Much Can The Circular Economy Principle Be Adopted Into Nigeria's Biodiesel And To What Extent Does Palm Oil As A Feedstock Represent A Strategic Market Opportunity.

[121] Hadiguna, R. A., & Tjahjono, B. (2017). A Framework For Managing Sustainable Palm Oil Supply Chain Operations: A Case Of Indonesia. *Production Planning & Control*, *28*(13), 1093-1106.

[122] Hasibuan, H. A. (2022). The Synthesis Of Sn-2 Palmitate As Human Milk Fat Substitute From Palm Oil Fractions By Enzymatic Interesterification–A Review. *Journal Of Oil Palm Research*, *34*(4), 608-621.

palm cooking oil[123 124]. Packaging is a significant source of waste in the distribution process. Therefore, it is strongly advised to use sustainable packaging instead of single-use plastics, such as reusable containers or biodegradable packaging materials. The CE can also be practised in transportation to increase fuel use efficiency. The company can also improve efficiency by optimizing the delivery routes to reduce the number of trips and use more fuel-efficient vehicles. It is also important to educate customers as the final users of palm cooking in order to have a good awareness of CE activities. For instance, customers can recycle or reuse palm cooking oil containers for other purposes, such as planters or storage containers.

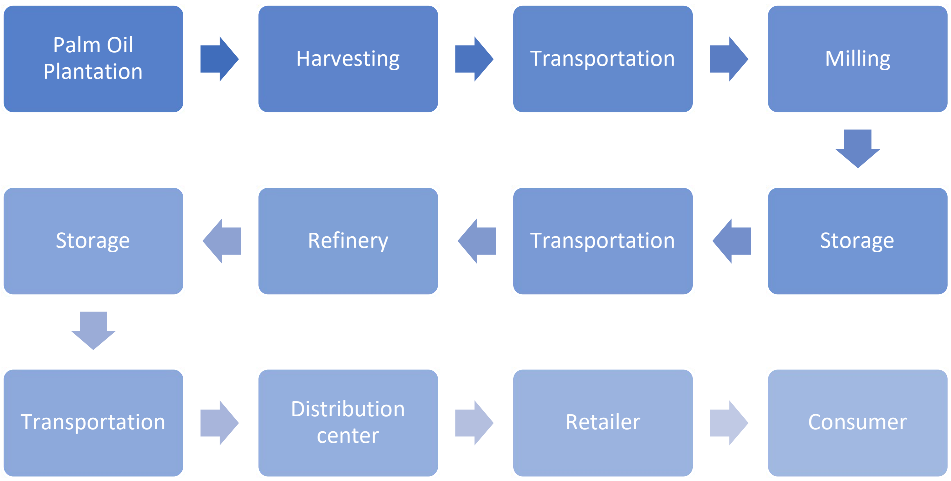

Figure 3.11. Palm Oil Supply Chain Process[118]

[123] Palazzo, M., Vollero, A., & Siano, A. (2023). Intelligent Packaging In The Transition From Linear To Circular Economy: Driving Research In Practice. *Journal Of Cleaner Production, 388*, 135984. Doi:Https://Doi.Org/10.1016/J.Jclepro.2023.135984

[124] Patwa, N., Sivarajah, U., Seetharaman, A., Sarkar, S., Maiti, K., & Hingorani, K. (2021). Towards A Circular Economy: An Emerging Economies Context. *Journal Of Business Research, 122*, 725-735. Doi:Https://Doi.Org/10.1016/J.Jbusres.2020.05.015

CHAPTER IV SURVEY RESULTS

We have created four types of questionnaire surveys based on the palm oil value chains (plantation, mills, refinery, and packaging/distribution). These questionnaires were developed by using the Survey Monkey platform and distributed to the potential respondents all across Indonesia. In distributing the questionnaire, we cooperated with palm oil business associations including GAPKI, APKASINDO, DMSI, GIMNI, and APOLIN.

The survey collection period is from 20 January to 15 March 2023. While we have actively engaged and intensively communicated with the business associations and the potential respondents through several means such as email and call phone, the response rate to fill in the survey from the potential respondents was relatively low. During that period, we gathered 13 respondents from smallholder palm oil plantations, 7 corporate palm oil plantations, 2 milling companies, 2 refinery companies, and 1 packaging distribution. Even though our sample size looks small in terms of quantity, the sample represented palm oil business actors from various groups in the value chain (smallholder palm oil plantations, corporate palm oil plantations, milling companies, refinery companies, and packaging distribution companies). Considering relatively small sample size, the quantitative method used in this study is based on descriptive statistics.

4.1 Survey Results: Smallholder Palm Oil Plantations

There were 13 respondents of smallholder palm oil plantations filled in the questionnaire (Figure 4.1). They spread across Riau Province areas, i.e. Kampar, Sei Putih, Indragiri Hilir, Siak, Bengkalis, and Bangkinang Province. The respondents consist of palm oil farmers with farming experience for more than 10 years (61.54%) and those with less or equal to 10 years of farming experience (38.46%). On average, farmer owns 2 hectares of land area with mature plants. The largest land area owned by a respondent is 10 hectares for mature plants and 25 hectares for immature plants.

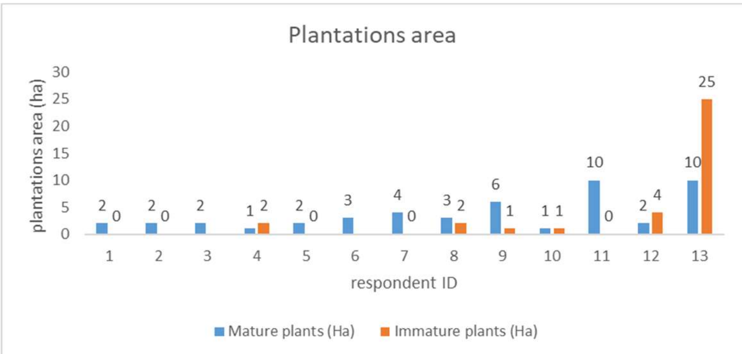

Figure 4.1. The respondents' land area.

We found that 23.08% of smallholder farmers do not understand the CE concept at all. Hence, it is not surprising that the proportion of respondents implementing the CE is relatively low. In general, many farmers have limited understanding of CE concepts. Furthermore, we found that no farmer is admitting to have a good understanding of the CE concept (Figure 4.2).

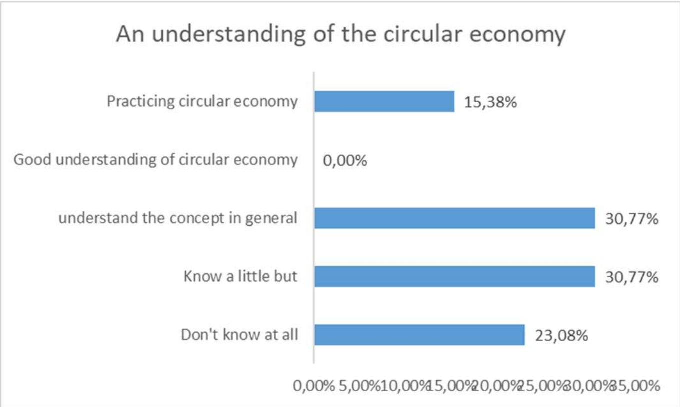

Figure 4.2. Farmers' understanding of the CE

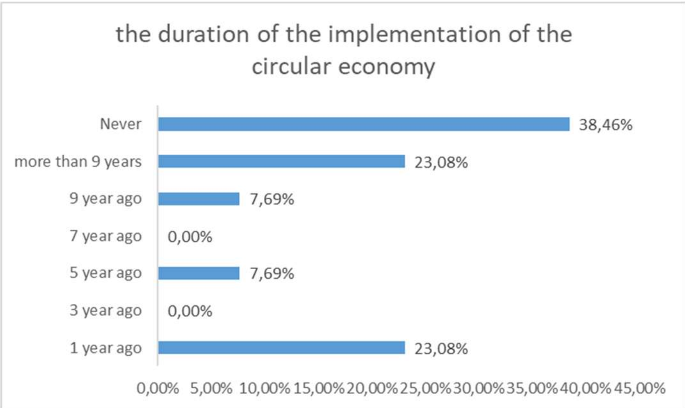

Figure 4.3. The duration of CE implementation

In the implementation stage (Figure 4.3), the percentage of farmers who have not implemented CE at all is quite high (38.46%). About 30.7% respondents have implemented CE for less than 5 years ago. The remaining are the ones who has consistently implementing CE for more than 9 years.

Material

On average, it is needed two employees per one hectare in the whole process from the hatchery until harvesting phase. In addition, an employee is needed for maintenance. Generally, smallholder palm oil plantation is assisted by their family members and rarely hire paid employees. About 23.08% of smallholder farmers conduct the hatchery independently, and the remaining 76.92% purchase germinate seeds from suppliers (Figure 4.4). Farmers cultivate various sorts of seeds, i.e. Tenera, Dura, Mangera, PPKS, Marihat, Tunggal Yunus, Marites, and DXP. Tenera is a seed used widely by 46.15% of respondent farmers.

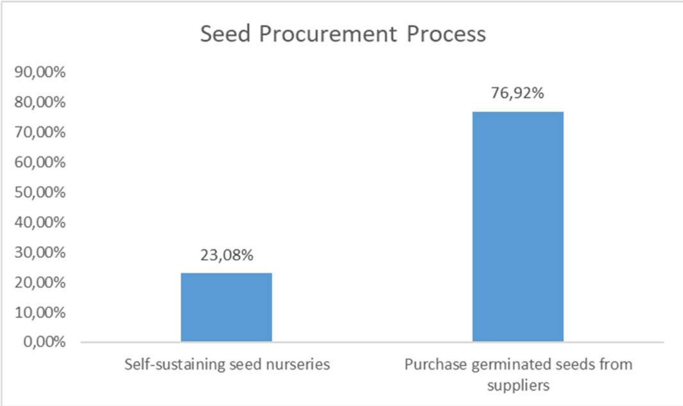

Figure 4.4. Seed procurement process proportion.

Table 4.1 shows material waste utilization through CE practices. Palm oil waste can be used to produce variety of products such as pellets, briquette, bio ethanol, biogas, biochar, fertilizer, and etc. However, due to limited skills and technology, majority of smallholder farmers respondents only use the palm oil waste to produce fertilizers from materials which have not been utilized yet such as midribs, trunks, empty fruit bunches, mesocarp fibre, palm kernel shell, and Palm Oil Mill Effluent (POME). A few respondents use FFB for bio-oil and scattered FFB for pellets. In addition, some farmers also use Palm Kernel Shell as biochar.

Table 4.1. Material waste utilization in the smallholder palm oil plantation

	Pellets	Briquette	Bio-ethanol	Biogas	Biochar	Bio-oil	EFB Fiber	Fertilizer	Other Active Carbon.	None
OPF	0%	0%	0%	0%	0%	0%	0%	69.23%	0%	30.77%
OPT	0%	0%	0%	0%	0%	0%	0%	46.15%	0%	53.85%
EFB	0%	0%	0%	0%	0%	0%	0%	61.54%	0%	38.46%
FFB	9.09%	0%	0%	0%	0%	9.09%	0%	18.16%	0%	72.73%
MF	0%	0%	0%	0%	0%	0%	0%	27.27%	0%	72.73%
PKS	0%	0%	0%	0%	9.09%	0%	0%	18.18%	0%	72.73%
POME	0%	0%	0%	0%	0%	0%	0%	53.85%	0%	46.15%

Source: Primary data, 2023

OPF: Oil Palm Frond.; OPT: Oil Palm Trunk; EFB: Empty Fruit Bunches; FFB: Fresh Fruit Bunches; MF: Mesocarp Fiber; PKS: Palm Kernel Shell; POME: Palm Oil Mill Effluent.

Table 4.2 and 4.3 show that CE has been practiced by all respondents to material resources in a different degree and in various forms. While all respondents have practiced CE in fertilizers, only half of the them implement CE on insecticide, fungicide, herbicide, and rodenticide. Most farmers implement the CE in materials through Refuse, Rethink, Reduce, Reuse, Repair, and Recover. On the other hand, the other CE principles, i.e., Refurbish, Remanufacture, Repurpose, and Recycle, are not implemented by farmers for all material resources

Table 4.2. Practice of CE to material resources

Sort of material	Yes	No	Total
Fertilizer	100.00%	0%	11
Insecticide	54.55%	45.45%	11
Fungicide	54.55%	45.45%	11
Herbicide	80.00%	20.00%	10
Rodenticide	63.64%	36.36%	11

Source: Primary data, 2023

Table 4.3. The CE principles implementation in the material resource

	Refuse (%)	Rethink (%)	Reduce (%)	Reuse (%)	Repair (%)	Refurbish (%)	Re manufacture (%)	Repurpose (%)	Recycle (%)	Recover (%)
Fertilizer	33.33	22.22	33.33	22.22	11.11	0	0	0	0	11.11
Insecticide	66.67	16.67	16.67	16.67	0	0	0	0	0	0
Fungicide	66.67	16.67	16.67	16.67	0	0	0	0	0	0
Herbicide	80	20	0	0	0	0	0	0	0	0
Rodenticide	50	16.67	33.33	16.67	0	0	0	0	0	0

Source: Primary data, 2023

This research also analyses the material expenditure retrenchment percentage estimation if the farmers implement the CE practices. Figure 4.5 explains there is only 18.18% of respondents which stated that they can economize the expenditure by more than 25% for fertilizer material and rodenticide by the CE implementation. The figure also interprets that through CE implementation, the farmers can economize the insecticide and herbicide material expenditure by 16% to 20% at the most. Meanwhile, the farmers economize fungicide expenditure by 21% to 25% at the most. The material expenditure retrenchment is affected by various cautions, including farmers' behaviour, knowledge, and skill.

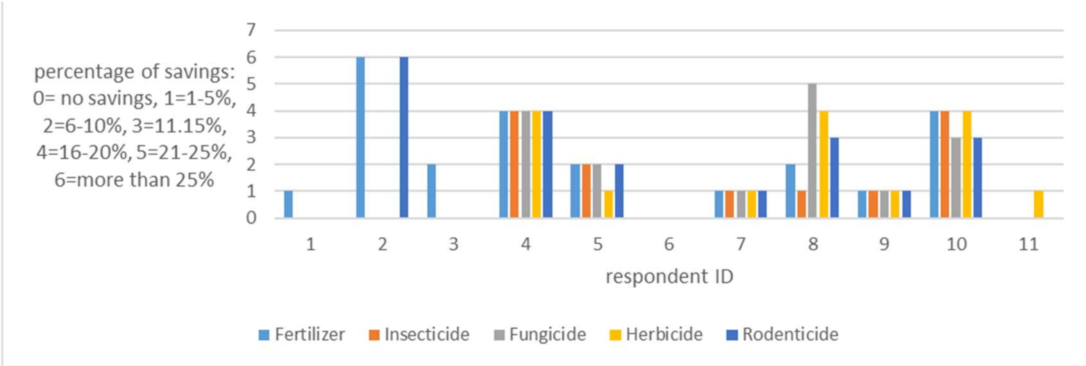

Figure 4.5. The percentage of material resource savings by the CE implementation.

Carbon Emission

The expansion of palm oil plantations has been highlighted by the international community as one of the largest contributors to carbon emissions. The European Union, for example, through the Renewable Energy Directive (RED II) policy places the use of biodiesel originated from palm oil as an *environmentally unfriendly* energy source and it is categorized as *high risk* and *unsustainable*. Carbon emissions in oil palm plantations come from various sources including emissions from direct and indirect land use change, germination and palm oil seeding, cultivation of immature crops, and cultivation of productive crops.

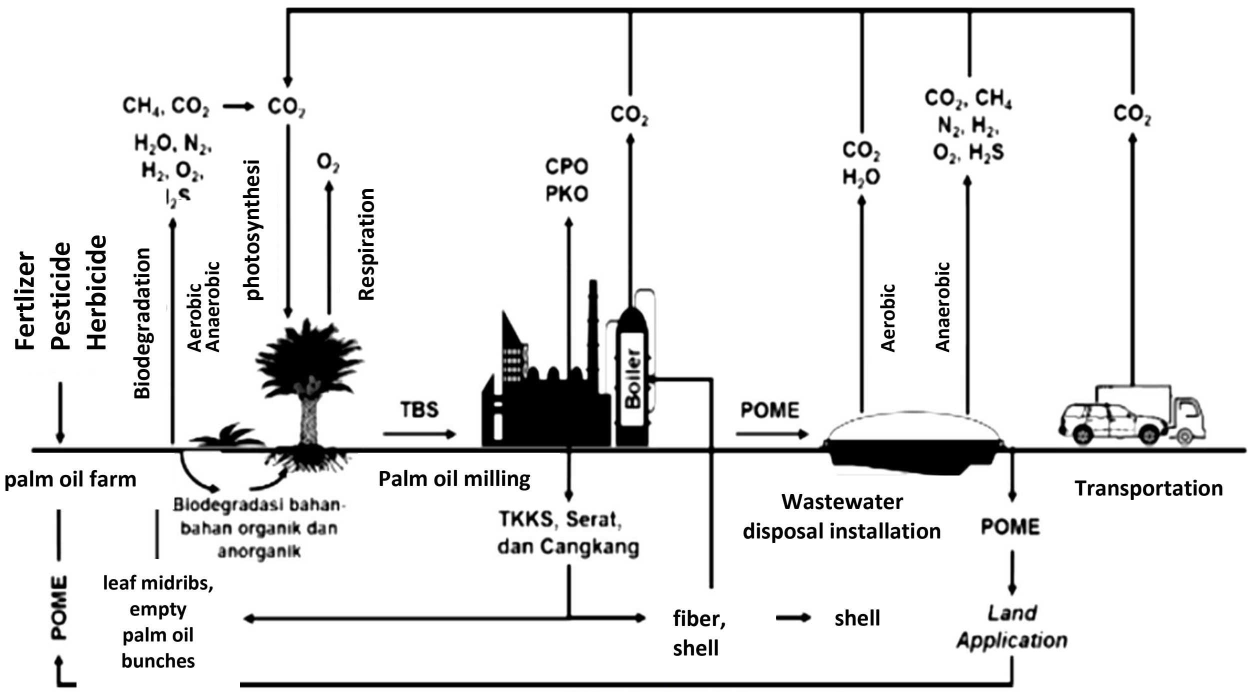

Figure 4.6. Palm Oil Carbon Cycle[125]

[125] Kahar, P., Rachmadona, N., Pangestu, R., Palar, R., Triyono Nugroho Adi, D., Betha Juanssilfero, A., Yopi, Manurung, I., Hama, S., & Ogino, C. (2022). An integrated biorefinery strategy for the utilization of palm-oil wastes. In Bioresource Technology (Vol. 344). https://doi.org/10.1016/j.biortech.2021.126266

The results of our questionnaire survey indicate that smallholder palm oil producers in Riau Province have not prioritized the practice of carbon emissions control.. There is only 8% of the respondents have a concern with applying the CE to reduce the carbon emissions. The majority of respondents (92%) have not been applying the CE to the carbon emissions at all. Our findings show that the CE practices in the palm oil plantations to reduce carbon emissions are generally carried out in the form of Refuse where farmers reduce or even do not use chemical fertilizers (NOX, SOX) at all in the palm oil fertilization process.

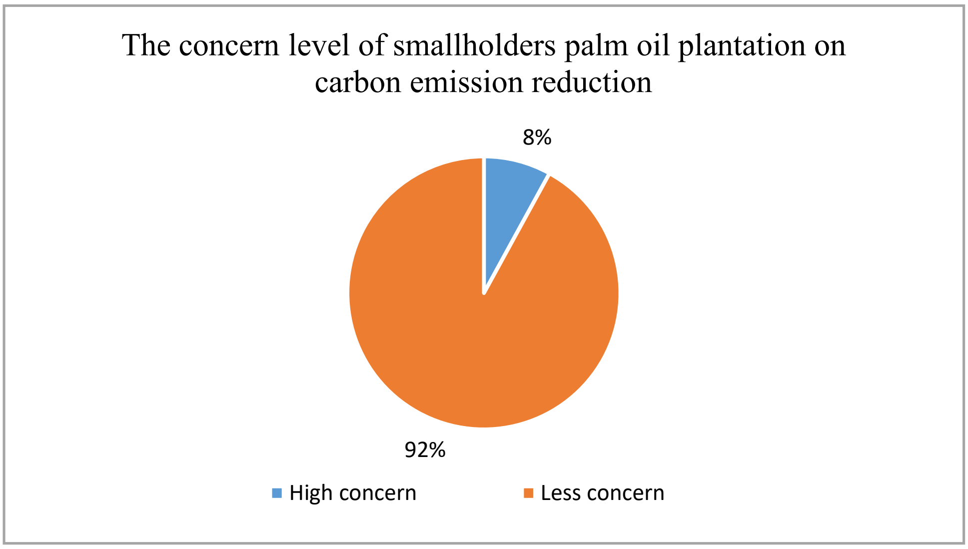

Figure 4.7 The concern level on carbon emission reduction in smallholders farming

During the 2018-2022 period, the respondents who practiced a CE (8% of the total respondents) stated that there was a reduction in carbon emissions by 1-5%. On the other hand, most respondents who do not practice a CE mentioned that there are no carbon emissions changes in their palm oil plantation. This could occur because most of the palm oil trees are not in the vegetative phase.

According to the interviews results and direct field observation, there are several reasons for not carrying out CE practices to reduce carbon emissions by smallholder palm oil farmers. First, it is related to the historical context where some smallholder palm oil farmers carry out plantation business as a legacy from their parents, in which their palm oil trees are in the generative phase. According to various studies, at this stage the palm oil plantation is very low in producing carbon emissions. Second, it is related to the clearing plantation land methods. Most of smallholder farmers open their palm oil plantation land by utilizing their own land and converting from forest land. According to the farmers, most of the conversion process was carried out normally without burning forests. These methods are categorized as harmless and hence produce low carbon emissions. Third, most of lands used for palm oil plantations are mineral land, not on peatland which releases a lot of carbon emissions when converted to palm oil plantations.

The crosstab analysis results show that respondents who have a high awareness of practicing a CE for carbon emission reduction are those who have ISPO certificates and have basic knowledge about the CE. The respondents who understand the concept and practice of

CE (46% of total respondents) and have ISPO certificates have been practicing CE on energy, materials, water, and waste treatment.

Productivity

One of the basic problems faced by smallholder palm oil plantations is low productivity and low quality of fresh fruit bunches (FFB) production. According to the survey results, there are 30% respondents having high productivity (20-30 tons FFB/ha/year), 50% respondents with medium productivity (10-20 tons FFB/ha/year), and the remaining 20% are those with low productivity (<10 tons FFB/ha/year). On average, the productivity of smallholder palm oil plantations in Riau province in 2018 was only 16.30 tons FFB/ha/year, and decreased by 3.3% to 15.76 FFB/ha/year in 2022. About 20% of smallholders experienced a significant decrease in productivity by 20-25%.

There are two main factors caused the declining of palm oil productivity: increase in fertilizer prices and low rate of replanting of old oil palm trees. The fertilizer prices in 2022 increased dramatically up to 300% of the previous year price. As a result, many farmers reduced the use of fertilizers and even some farmers did not fertilize their plantations at all because simply they had not enough money to do it. Meanwhile, the replanting process to produce palm oil returns to the normal productivity level takes up to four years.

The average productivity of smallholder palm oil plantations is much lower than that of large palm oil plantations which is 22.2 tons FFB/ha/year. Based on our direct observations and interviews with several farmers, the productivity of smallholder palm oil could be improved to reach an optimal point in the range of 30-36 tons of FFB / ha / year. Some smallholder farmers who use superior seeds and implement good agricultural practices (GAP) and precision agriculture can achieve this point of optimal productivity. Some farmers are even able to maintain this optimal productivity consistently. For this excellent achievement, some of the farmers received an award from the President of the Republic of Indonesia.

The crosstab analysis between productivity and production inputs, especially seeds, shows that the respondents with medium and high productivity used Dura, Mangera, PPKS, and DXP type of oil palm seeds. Meanwhile, respondents with low productivity generally use Tenera seeds[126]. Further, almost all respondents avoid using chemicals for soaking seeds. While palm oil seeds play a crucial role to the growth and FFB production, the farming techniques including fertilizing system will significantly influence the productivity. The survey results have not found the relation between productivity and ISPO certification ownership. The respondents with highest productivity (24 TBS tons / ha / year) apply CE practices consistently in the form of Reduce and Reuse.

Table 4.4 describes the crosstabulation between farmer's CE understanding and productivity changes in 2022 and 2018. Among 13 respondents, only 10 provide a complete data of their production and productivity. While we do aware that the level of productivity is influenced by various factors, including material, technical, external aspects (weather and climate), and the ability of farmers in farm management, this crosstabulation provide us a general overview of how CE practices relate to the productivity. We found that in general there

[126] We need to be more critical to see the results because of limited sample size.

is no clear relationship between understanding CE and changing productivity. For instance, there are 3 farmers who understand the concept of CE, but they differ in productivity. Similarly, farmers who do not know the concept of CE at all also vary in their productivity changes.

On the other hand, we found a different trend in the relations between CE implementation and productivity changes. There is a tendency that farmers who have practiced CE tend to increase their productivity levels (Figure 4.3).

Table 4.4. The Farmers' understanding of the CE and the productivity changes

Farmers' understanding of the CE	productivity changes (2022-2018)						Total
	-6	-4	-2	0	2	3	
Understand the concept in general	1	0	1	0	1	0	3
Practicing CE	0	0	0	2	0	0	2
Know a little	0	0	0	2	0	1	3
Don't know at all	0	1	0	1	0	0	2
Total	1	1	1	5	1	1	10

Source: Primary data, 2023

Table 4.5. The duration of CE implementation and productivity changes

The duration of CE implementation	productivity changes (2022-2018)						Total
	-6	-4	-2	0	2	3	
Never implement	0	1	0	2	0	0	3
1-5 years	0	0	0	1	1	1	3
More than 9 years	1	0	1	2	0	0	4
Total	1	1	1	5	1	1	10

Source: Primary data, 2023

The percentage of smallholder farmers respondents having an Indonesia Sustainable Palm Oil (ISPO) certificate is just 23.08% (Figure 4.8). We found there is no clear relationship between having and not having certificates with the changes in productivity level (Table 4.6).

Figure 4.8. The proportion of plantation certificate ownership.

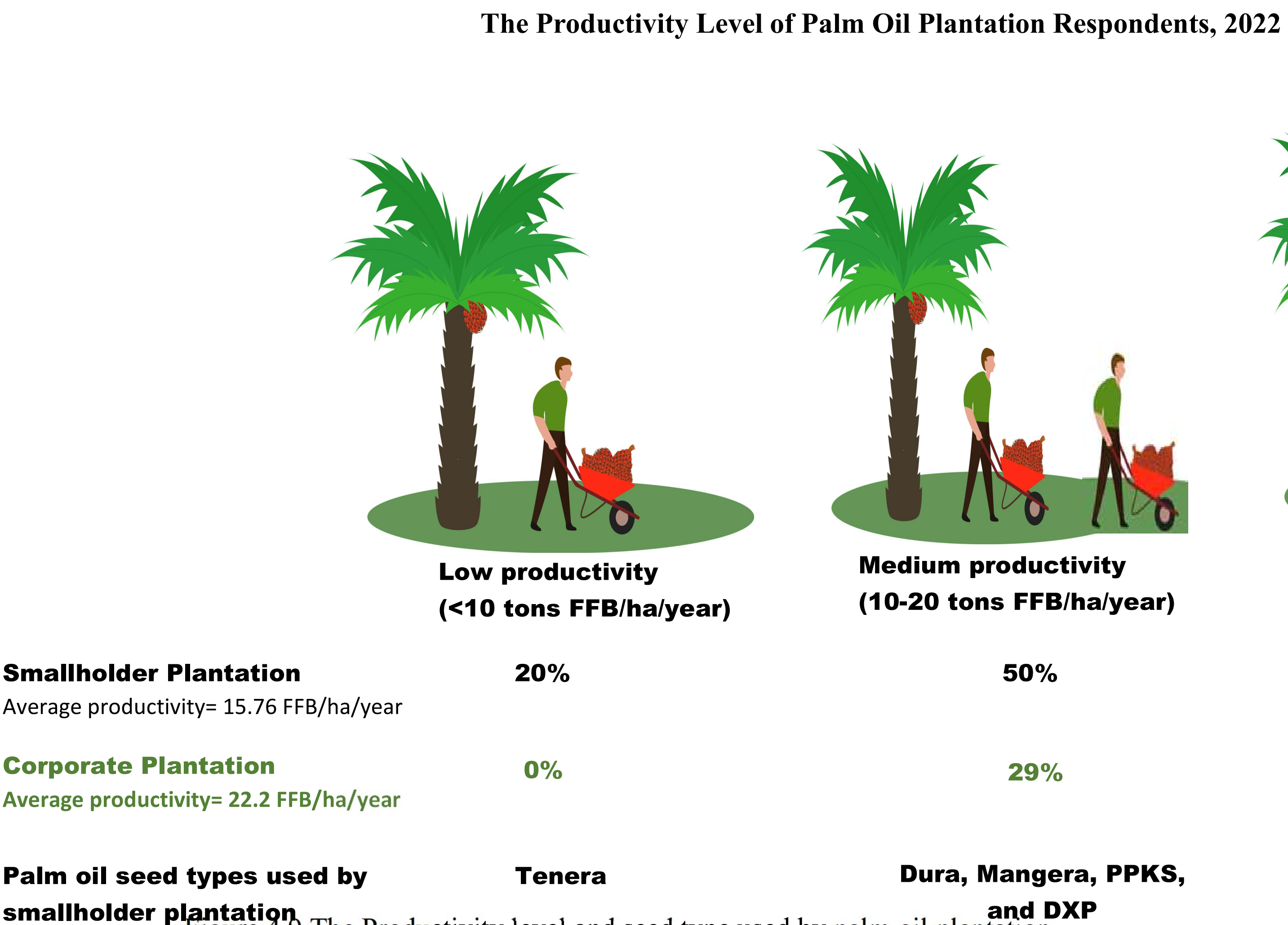

Figure 4.9 The Productivity level and seed type used by palm oil plantation respondents[127]

4.2 Survey Results: Corporate Palm Oil Plantations

There were 7 respondents of corporate palm oil plantation filled in the questionnaire. All respondents are categorized as large plantation based on the number of employees.[128] These respondents come from various areas in Indonesia, i.e., Riau, Medan, Bangka Belitung, and West Kalimantan Province. About 66.67% of respondents have a land area less of than 10,000 hectares, and 33.33% of respondents have a land area of more than 10,000 hectares. According to the companies' status, about 14.29% are Domestic Investment (DI). Meanwhile, 28.57% of companies are State-Owned Enterprises and the remaining 57.14% of respondents are Direct Foreign Investment (DFI).

Relating to the plantation certificate ownership, only 57.14% of company respondents have ISPO certificates and 28.57% of company respondents have ISPO and RSPO certificates.

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[127] Source of picture: Vecteezy.com

[128] Indonesia Bureau of Of Statistics (BPS) Defines Company Size According To The Number Of Employees. A Small Firm Is A Firm Employing 5 To 19 Employees; A Medium Firm Is A Firm With 20 To 99 Employees; A Large Firm Is A Firm With More Than 99 Employees.

About 14.29% of respondents have neither ISPO nor RSPO certificates. An ISPO certificate is a certificate released by the Indonesian Government to acknowledge that a palm oil producer has fulfilled the sustainability standards in producing palm oil. One of the criteria aspects in ISPO evaluation is sustainable agricultural implementation, including environmentally friendly fertilizer and pesticide utilization. As similar, RSPO focuses on the environmentally sustainable aspects of producing palm oil, i.e., to protect forests and biodiversity, decrease greenhouse gaseous emissions, and treat waste well.

Material

Majority of respondents (75%) cultivate the seed of Tenera type. Meanwhile, the remaining 12.5% of respondents cultivate the seed of Dura type, and 12.5% of respondents cultivate the seed of Sokfin and PPKS type. Relating to the seed procurement process, all respondents admitted that they purchased the seeds from suppliers. Otherwise, 28.57% of respondents did not only purchase the seeds from suppliers, but they also purchased the seeds independently.

Most companies implement CE to five material resources, i.e., fertilizers, insecticides, fungicides, herbicides, and rodenticides (Figure 4.10). The results of in-depth interviews and field observation explain the companies have adopted more environmentally friendly materials by substituting chemical material inputs, i.e., to decrease 50% of chemical fertilizer utilization by substituting it with organic fertilizer from remaining plantation results, and to substitute chemical pesticides with predators, namely owls that monitor rat pests. Otherwise, some companies still have used chemical pesticides and herbicides for monitoring pests. Some companies still use manual monitoring by grass-cutting tools, i.e., hoes, sickles, etc.

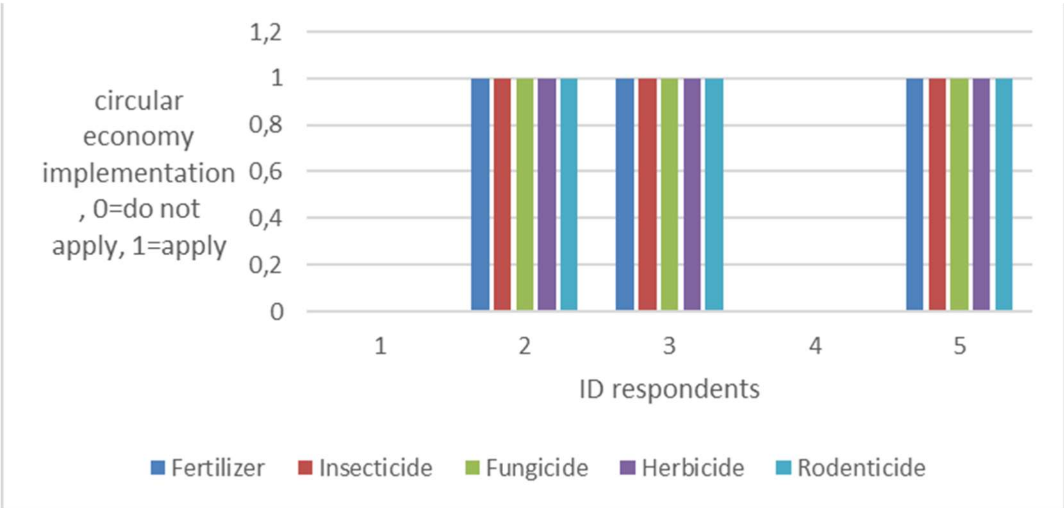

Figure 4.10. CE implementation of material resources by plantation companies.

Relating to plantation waste utilization for material resource input substitution, 42.86% of company respondents have utilized OPF as fertilizer. Besides OPF, all plantation wastes, i.e., OPT, EFB, TBS, MF, PKS, and POME have been utilized by 100% of company respondents as fertilizers (Table 4.6). POME (Palm Oil Mill Effluent) is liquid waste released by the palm oil production process. POME consists of organic matter, nutrients, and chemical compounds that pollute the environment if they are not treated well. By using POME as fertilizer, companies not only have a role to decrease environmental pollution but also enhance efficiency by resource expenditure retrenchment.

Table 4.6. Material waste utilization in the corporate palm oil plantation

	Pellets	Briquette	Bio-ethanol	Biogas	Biochar	Bio-oil	EFB Fiber	Fertilizer	Other Active Carbon	None
OPF	0%	14.29	0%	0%	0%	0%	0%	42.86	0%	57.14
OPT	0%	0%	0%	0%	0%	0%	0%	33.33	0%	66.67
EFB	0%	0%	0%	0%	0%	0%	0%	85.71	0%	14.29
TBS	0%	0%	0%	0%	0%	42.86	14.29	0%	0%	42.86
MF	0%	0%	0%	0%	0%	16.67	0%	16.67	16.67	50
PKS	0%	14.29	0%	0%	0%	14.29	0%	14.29	28.57	42.86
POME	0%	0%	0%	14.29	0%	0%	0%	100	0%	0%

Source: Primary data, 2023
OPF: Oil Palm Frond.; OPT: Oil Palm Trunk; EFB: Empty Fruit Bunches; FFB: Fresh Fruit Bunches; MF: Mesocarp Fiber; PKS: Palm Kernel Shell; POME: Palm Oil Mill Effluent.

Table 4.7 shows companies economize the expenditure by 21 to 25% at the most for all material resources, i.e., fertilizers, insecticides, fungicides, herbicides, rodenticides, and plastic bags by the CE implementation. Otherwise, some company respondents admitted there is no expenditure retrenchment by the CE implementation. That condition is affected by external factors, i.e., chemical fertilizer price tends to increase and to be high. Therefore, plantation waste utilization cannot decrease the fertilizer expenditure cost.

Table 4.7. Material resource expenditure savings by CE implementation

	1-5%	6-10%	11-15%	16-20%	21-25%	More than 20%	No retrenchment
Fertilizer	0%	25%	0%	0%	25%	0%	50%
Insecticide	0%	0%	25%	0%	25%	0%	50%
Fungicide	0%	0%	25%	0%	25%	0%	50%
Herbicide	0%	0%	25%	0%	25%	0%	50%
Rodenticide	0%	0%	25%	0%	25%	0%	66.67%

Source: Primary data, 2023

Table 4.8 shows the companies which have implemented the CE principles to material resources, i.e., fertilizers, insecticides, fungicides, herbicides, and rodenticides.

The CE principles, from Rethink to Repurpose, are implemented for both sorts of material resources, i.e., insecticides and herbicides. Meanwhile, the CE principles, from Rethink to Remanufacture, are implemented in fertilizers and rodenticides. The CE principles, from Rethink to Refurbish, are implemented in fungicides. The palm weevil is one of the main pests in palm oil plantations that attacks palm oil trunks, leaves, and fruits. Companies use integrated pest monitoring methods, i.e., environmental sanitation, varieties utilization that are durable to pests and illnesses, bio-agent utilization, and monitoring.

Those CE implementations are more effective compared to chemical insecticide utilization that causes a dependable effect. Therefore, chemical insecticide affects negatively the environment. In addition, to monitor rat pests, the companies do not use chemical rodenticides anymore, but natural predators, i.e., owls. Plantation waste utilization as fertilizers is one of the effective solutions that decrease chemical fertilizer utilization. Therefore, it does not only affect positively the environment but also agricultural efficiency.

Table 4.8. CE principles implementation of material resources in plantation companies

	Refuse (%)	Rethink (%)	Reduce (%)	Reuse (%)	Repair (%)	Refurbi sh (%)	Re manufacture (%)	Repur pose (%)	Recycle (%)	Recover (%)
Fertilizer	0	33.33	66.67	66.67	33.33	33.33	33.33	0	0	0
Insecticide	0	50	100	50	50	50	50	50	0	0
Fungicide	0	50	100	50	50	50	0	0	0	0
Herbicide	0	50	100	50	50	50	50	50	0	0
Rodenticide	0	50	100	50	50	50	50	0	0	0

Source: Primary data, 2023

Water

The 9R framework of CE has been implemented in the utilization of water resources by up to 60%. This percentage is based on 5 respondents that answered the questionnaire. In the oil palm plantation industry, water-use methods that follow the CE model are becoming more and more crucial. Water utilization may be optimized, and water waste can be reduced, by putting this technique into effect. This unquestionably has a favorable effect on the surroundings of oil palm fields.

The 9R framework of CE is increasingly applied in various industries, including oil palm plantations. The CE practice in water has been mostly applied in the principle of Reuse. Oil palm plantation companies have now started using good ditch management or irrigation and have followed the contours of the plantation landscape, thus minimizing water run off during the rainy season and water use can be done optimally. This certainly has a positive impact on the environment around oil palm plantations. With the application of the 9R that focuses more on using water efficiently and effectively, the amount of water discharged will be reduced. As a result, it can help reduce negative impacts on the environment, such as decreased water quality and other environmental damage.

The CE is increasingly popular in the plantation industry, especially in the cultivation and harvesting process. According to the survey results, at least 40% of respondents stated that they apply more CE practices in both processes. In the process of oil palm cultivation, CE practices are applied by optimizing water resources. This is done by utilizing the available water efficiently through the creation of good irrigation paths by considering the contour direction of the plantation landscape. The water used can come from various sources, such as rainwater, rivers, or groundwater pumps. With the application of CE practices in the oil palm cultivation process, water use can be optimized and water waste can be minimized. In addition, this also has a positive impact on the environment around the plantation, especially on the availability of water which is a very valuable resource.

In the oil palm plantation industry, CE principles can be applied in cultivation and harvesting practices to improve resource use efficiency and reduce waste. One of the CE principles applied in the oil palm plantation industry based on this survey is Reuse, which is the reuse of materials or products that can still be used. The utilization of water resources in oil palm plantation companies emphasizes better irrigation management / water utilization management[129] [130].This can reduce excessive water use and increase the efficiency of water use in palm oil production.

The application of CE principles in oil palm plantation companies is a solution to reduce excessive water expenditure. In the period 2018-2022, many oil palm plantation companies have adopted this concept and succeeded in increasing water use efficiency in various stages of production. Water expenditure savings mainly occur in wastewater use. This can be seen from the percentage of savings that vary between 1-5% to more than 25%. Reuse of wastewater in palm oil production not only reduces water expenditure, but also help reduce the risk of environmental pollution due to waste disposal to water sources. One form of successful CE application is wastewater treatment through anaerobic-aerobic systems. PT Astra Agro Lestari Tbk recorded savings in wastewater use through this system reaching 4.6% in 2020 (Astra Agro Lestari, 2021). In addition, PT Smart Tbk also utilizes wastewater as liquid fertilizer through treatment with an aerobic system, so as to reduce the use of chemical fertilizers by up to 5% (PT Smart Tbk, 2021). The use of drip irrigation systems is also an alternative to saving water in oil palm plantations, such as PT Sampoerna Agro Tbk. The use of this technology can reduce water use by up to 50% (Sampoerna Agro, 2021).

The decrease in wastewater produced by 16-25% was mostly carried out in the harvesting process. Wastewater generated from oil palm plantations is very important to be managed properly because it can create negative impacts on the environment. The waste contains harmful chemicals such as pesticides and herbicides that can pollute water and soil

[129] Hafiz, M., Hawari, A. H., Alfahel, R., Hassan, M. K., & Altaee, A. (2021). Comparison Of Nanofiltration With Reverse Osmosis In Reclaiming Tertiary Treated Municipal Wastewater For Irrigation Purposes. *Membranes*, *11*(1), 32.

[130] Munasinghe, M., Jayasinghe, P., Deraniyagala, Y., Matlaba, V. J., Santos, J. F. Dos, Maneschy, M. C., & Mota, J. A. (2019). Value–Supply Chain Analysis (VSCA) Of Crude Palm Oil Production In Brazil, Focusing On Economic, Environmental And Social Sustainability. *Sustainable Production And Consumption*, *17*, 161–175. Https://Doi.Org/10.1016/J.Spc.2018.10.001

and damage wildlife and plants around the plantation. To address this problem, many oil palm plantation companies are taking steps to reduce the amount of wastewater produced. One of them is by reducing wastewater during the harvesting process. This technique can be done by using drip irrigation systems or better water management systems in oil palm plantations. In addition to the decrease in wastewater during the harvesting process, there are also other steps that can be taken to manage the waste generated by oil palm plantations. For example, by developing more effective sewage treatment systems, such as the use of activated sludge or biofilters. In addition, oil palm plantation companies can also carry out wastewater treatment in a better way using more sophisticated and modern technology.

Several palm oil companies in Indonesia have implemented drip irrigation systems on their oil palm plantations. For example, oil palm plantation company PT Sampoerna Agro Tbk. has implemented drip irrigation systems on most of their oil palm plantations in South Sumatra. They claim that this system can save water by up to 50 percent and increase the productivity of oil palm crops. In addition, several palm oil companies in Indonesia have also installed waste water treatment plants (WWTP) to manage wastewater generated during the harvesting process. For example, palm oil company PT Astra Agro Lestari Tbk. has built a WWTP on their oil palm plantation in Central Kalimantan, which can treat wastewater into cleaner, reusable water for irrigation purposes. However, there are still many palm oil companies in Indonesia that have not implemented drip irrigation systems or better water management systems. Therefore, further efforts are needed from the government and the palm oil plantation industry to raise awareness and encourage the use of more sustainable and environmentally friendly water management technologies and practices across the palm oil sector in Indonesia. It is not yet known how much water will be used in oil palm plantations to produce 1 ton of FFB between 2018 and 2022 or how much waste water will be generated during that time. This is due to the lack of responses from respondents.

Carbon Emission

Similar to the smallholder oil palm plantations, CE activities for carbon emissions reduction in corporate palm oil plantations have not been widely practiced. A small percentage of corporate plantation respondents are actively considering or expressing awareness about the impact of carbon emissions and are interested in implementing measures to address it.. Many have not applied the CE for the purpose of emission reduction. CE practices in corporate palm oil plantations to reduce emissions are generally carried out in the form of Reduce by consuming fewer chemical fertilizers (NOX, SOX).

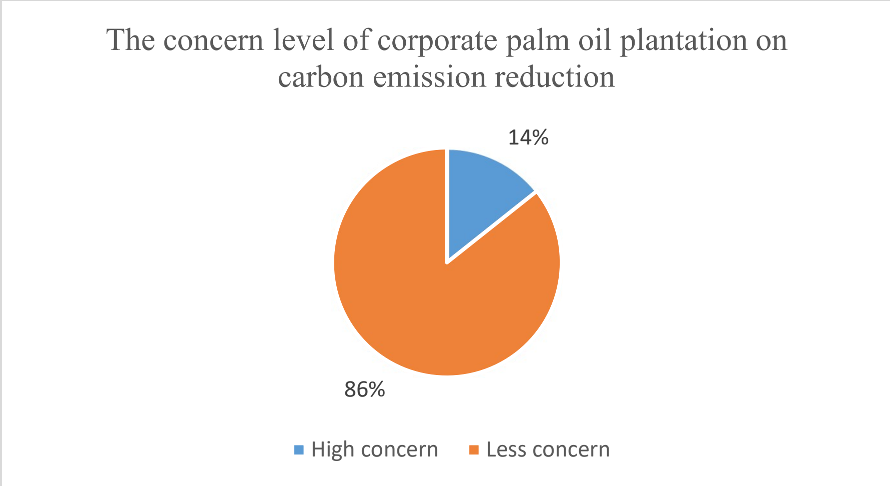

Figure 4.11 The concern level on carbon emission reduction in corporate farming

There are several factors causing corporate palm oil plantations able to suppress the use of chemical fertilizers: First, they use empty fronds and bunches as organic fertilizer. Some companies mention that the portion of organic fertilizer from fronds and empty bunches can reach up to 50% of the total fertilizer requirement. The midrib and leaves of the crop are left naturally to decompose approximately within 6 months. Second, they use digitalization and technology. The use of chemical fertilizers in corporate oil palm plantations can be significantly reduced to a minimum level because they apply fertilization technology based on leaf characteristic sensors in each plantation cluster.

Third, CO2 emissions can be reduced through the minimal use of oil-fueled equipment both gasoline and diesel. Frequent maintenance using mechanical equipment such as lawn mowers is carried out 3-4 times a year. The involvement of communities around plantations in labor-intensive maintenance can be a solution in reducing the use of oil-fueled equipment. Fourth, carbon emissions can be reduced by preventing land fires. The use of trenches that are controlled by monitoring the water level can help fire control on plantation land. In addition, online plantation monitoring closed circuit television (CCTV) or heat sensors can be used to prevent or control fires quickly and precisely.

The crosstab analysis shows that plantations that explicitly state to practice a CE for carbon emission reduction are Domestic Direct investment companies (PMDN). This company has ISPO certification and understands the concept of CE in general and has been practicing it for five years. Meanwhile, other corporate oil palm plantation companies, either PMDN or Foreign Direct Investment (FDI), have a general understanding of the CE, their focus is more on CE practices on energy, material, and waste aspects.

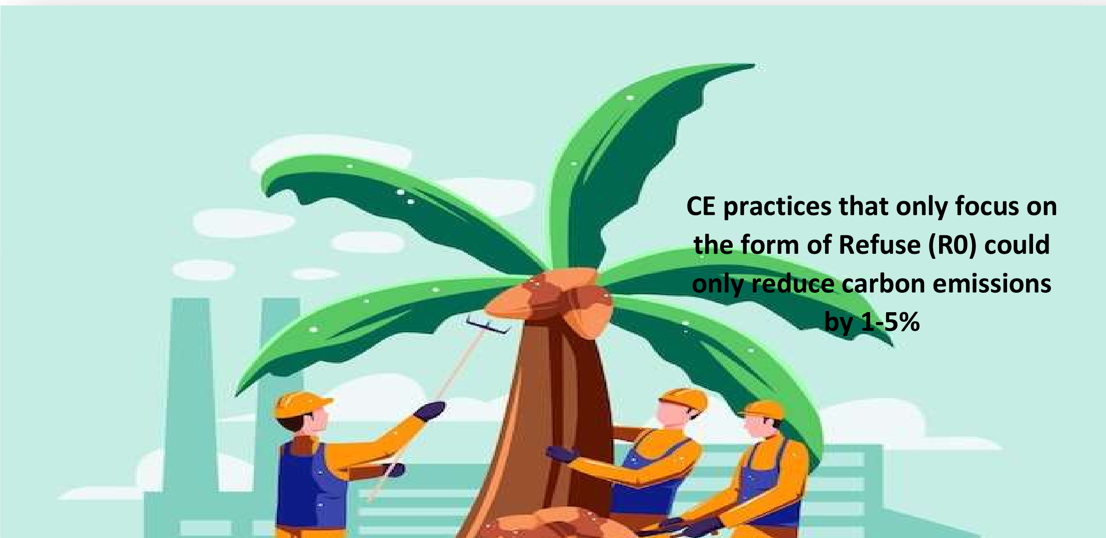

Figure 4.12 The CE practices to reduce carbon emissions are carried out in the form of Refuse (reduce or do not use chemical fertilizers at all)[131]

Respondents of corporate oil palm plantations that practice a CE on carbon emissions (14.3%) stated that there was a reduction in air emissions by 1-5% during the 2018-2022 period. This respondent's opinion is in line with the results of a study from Arif et. al (2017) which states that CE practices in the form of using POME waste as fertilizer can reduce emissions by 8.2% of the total emissions released.[132] One-third of respondents mentioned that they had decreased carbon emissions, another one-third had no change in air emissions, and the rest did not provide any information.

Productivity

The productivity of corporate palm oil plantations is much higher than that of smallholder oil palm plantations. The survey findings indicate that the typical productivity of corporate oil palm plantations in Riau province during 2018 amounted to 23.61 tons FFV/ha/year.. The majority of the respondents (86%) produce >20 tons FFB/ha/year with the highest achievement of 27.04 tons FFB/ha/year. In 2022, about 85% of respondents experienced a decreasing productivity with varying rates and only 14% of respondents stated that their productivity level increased. More than half of respondents experienced a decrease in productivity between 1 -10% and as many as a third of respondents experienced a decrease in productivity by 15 -30%.

This phenomenon is in line with the results of the GAPKI study which states that there has been a decrease in productivity in corporate oil palm plantations of around 2 percent per

[131] Source of picture: https://www.freepik.com/

[132] Arif Dwi Santoso, Nawa Suwedi, Reba Anindyajati Pratama Dan Joko Prayitno Susanto. (2017). Renewable energy and green house gasses reduction emission from palm oil mill effluent. Jurnal Teknologi Lingkungan Vol. 18, No 1, Januari 2017, 88-95

year in the last 15 years. In their analysis, GAPKI used a sample of seven corporate oil palm plantation companies listed on the Indonesia Stock Exchange (IDX). Even more concerning, it turns out that this decline in productivity is accompanied by an increase in production costs of around 6% per year.[133]

Some factors that are thought to have an influence on the decline in productivity of corporate oil palm plantations in 2022 are: First, many palm trees have entered old age and need replanting. Second, a decrease in palm oil production in plasma plantations affiliated with corporate palm oil plantations. The decline in plasma palm oil production is most likely due to scarcity factors and rising fertilizer prices which cause many of them to reduce the dose of fertilizer use. Third, natural factors such as extreme wet weather.

All corporate palm oil plantation uses Tenera seeds. There were 14% of respondents who used a combination of Tenera and Dura seeds. All respondents stated that palm oil seeds were obtained from suppliers and there were 29% of respondents who also carried out seed breeding independently by their own company. The majority of respondents avoid using chemicals for soaking seeds. Most respondents (86%) already have ISPO certificates. About 29% respondents have ISPO and RSPO certificates and 14% have ISPO and International Sustainability and Carbon Certification (ISCC). Only 14% of respondents have no all these certificates. In relation to productivity, no specific relation was found between the level of productivity and ownership of the above certification. Respondents who experience in the increasing of productivity carry out CE practices in the fertilization process.

Many factors affect more or less CE implementations in palm oil plantations. Generally, all companies have implemented the CE, but the CE understanding of human resources in companies is still low (Table 4.9). In companies, the CE is generally implemented in plantation waste utilization as organic fertilizers. As many as 42.86% of companies stated that they had never implemented a CE (Table 4.10), this was because the understanding of the CE was still low. The decline in productivity experienced by most companies is more due to other factors, including technical factors, the productive age of plants, track period, and the company's capability in plantation management.

Table 4.9. The cross tabulation of CE understanding and Δ productivity

understanding of the CE	Δ productivity (2022-2018)							Total
	-6.8	-4.24	-2.4	-1.13	-.86	-2	6,05	
Good understanding of CE	0	0	0	0	0	1	0	1
Understand the concept in general	1	0	0	0	1	0	0	2
Practicing CE	0	0	0	1	0	0	0	1
Know a little	0	1	0	0	0	0	0	1
Don't know at all	0	0	1	0	0	0	1	2

[133] Https://Www.Kompas.Id/Baca/Nusantara/2022/10/20/Sawit-Nasional-Hadapi-Penurunan-Produktivitas-Dan-Peningkatan-Ongkos-Produksi

Total	1	1	1	1	1	1	1	7

Source: Primary data, 2023

Table 4.10. The cross tabulation of the duration of the CE implementation and Δ productivity

The duration of CE implementation	Δ productivity (2022-2018)							Total
	-6.8	-4.24	-2.4	-1.13	-.86	-2	6,05	
Never implement	0	1	1	0	0	0	1	3
1-5 years	1	0	0	0	0	0	0	1
6-9 years	0	0	0	1	0	0	0	1
More than 9 years	0	0	0	0	1	1	0	2
Total	1	1	1	1	1	1	1	7

Source: Primary data, 2023

Table 4.11 describes the relationship between certificate ownership and productivity differences from 2022 and 2018. Most companies have experienced a decrease in productivity, one of which is due to the declining productive age of oil palm plants. The majority of companies also have palm oil certificates, but there is one company that does not have palm oil certificates.

Table 4.11. The cross tabulation of certificate ownership and productivity changes

Certificate Ownership	productivity changes (2022-2018)							total
	-6.8	-4.24	-2.4	-1.13	-.86	-2	6,05	
ISPO	1	1	0	1	0	0	0	3
ISPO dan ISSC	0	0	0	0	1	0	0	1
ISPO dan RSPO	0	0	0	0	0	1	1	2
Tidak ada	0	0	1	0	0	0	0	1
total	1	1	1	1	1	1	1	7

Source: Primary data, 2023

4.3 Survey Results: Palm Oil Milling

Water

The data of respondents who filled in the surveys was used to perform a survey on the water requirements for milling in the palm oil sector. Both of the respondents came from the palm oil mill sector. Reduce and Reuse in surface water sources (rivers, lakes, and seas) and Repurpose in wastewater sources from the milling process are examples of CE 9R uses in the milling process. The Reduce and Reuse approach can be utilized in surface water sources, such as rivers, lakes, and oceans, to minimize water use and maximize water reuse. The milling process requires a lot of water to produce palm oil and the liquid waste produced from this process generally contains organic waste and chemicals that can contaminate the water source. By applying the principle of reduce and reuse, water use can be reduced and water that has been used can be reused in the production process. In addition, the principle of Repurpose can be applied to wastewater sources from the milling process in palm oil mills. This liquid waste can be processed into valuable resources, such as organic fertilizer or biogas fuel. By processing effluent into reusable products, palm oil mills not only reduce the environmental impact of effluent, but can also improve production efficiency[134] [135].

The use of palm oil mill effluent as fertilizer is one form of application of the CE 9R application in the crude palm oil (CPO) processing process at the milling stage. The use of POME as an organic fertilizer can also help in improving soil quality and productivity of oil palm plants. In addition, the use of organic fertilizers can also help in reducing the use of chemical fertilizers which tend to be more expensive and can create environmental pollution if not treated properly[136] [137].

The form of application of the 9Rs of CE in the milling process is mostly in the form of Repurpose. The milling process is an important stage in palm oil processing, which produces POME liquid waste products as a by-product. Most palm oil mill industries already use POME as fertilizer, however, there is still a lot of potential that has not been optimally utilized. POME is a waste rich in nutrients and organic compounds that can be used as organic fertilizer in agriculture. However, the use of POME as an energy source is also an attractive alternative, as it can reduce dependence on fossil energy sources and reduce greenhouse gas emissions. Therefore, the use of POME waste as an energy source is the focus of attention in the context of a CE.

The various time periods from 2018 to 2022 saw a reduction in wastewater. Information from respondents was gathered in the range of 1–5% and more than 25%. The adoption of POME as a biogas energy source can account for a more than 25% reduction in liquid waste. This demonstrates how employing the CE effectively may benefit both the economy and the environment. 9R CE strategies are able to lessen adverse effects on the environment and bring about major economic gains by using waste as a useful resource.

According to the survey results, no responders filled out the question about how much water is required to produce one ton of FFB. Based on literature reviews, it was determined that the amount of water needed for oil palm processing varies based on the fruit's quality, the technique employed, and external elements like the season and weather. However, based on the data gathered, it is anticipated that between 5 and 7 cubic meters (m3) of water are needed

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[134] Dolli, C., Romdhon, M. M., & Reswita. (2018). Nilai Ekonomi Pemanfaatan Limbah Kelapa Sawit Di Kabupaten Bengkulu Utara Provinsi Bengkulu. *Jurnal Agripita*, *2*(2), 103–109.

[135] Purba, F. S., Dewi, N., & Maharani, E. (2018). Analisis Rantai Pasokan Tandan Buah Segar Kelapa Sawit Di PTPN V Sei Pagar Kabupaten Kampar. *Jurnal Online Mahasiswa (JOM) Bidang Pertanian*, *5*, 1-7.

[136] Supriatna, J., Setiawati, M. R., Sudirja, R., Suherman, C., & Bonneau, X. (2022). Composting For A More Sustainable Palm Oil Waste Management: A Systematic Literature Review. *The Scientific World Journal*, *2022*, 1–20. Https://Doi.Org/10.1155/2022/5073059

[137] Widiastuti, L. The Impact Of Palm Oil Mill Effluent Treatment Using Land Application.

to generate 1 ton of crude palm oil (CPO)[138 65].(Subramaniam et al., 2014; Suttayakul et al., 2016).

Depending on the technology and procedures employed in the process, different amounts of wastewater might be generated during the production of 1 ton of crude palm oil (CPO). But according to numerous studies, the typical volume of wastewater generated during the procedure ranges from 0.5 to 3.5 cubic meters (m3) per ton of CPO[139 140 141].0

Carbon Emission

Carbon emissions generated by Palm Oil Processing Industry (milling) or *Pabrik Kelapa Sawit (PKS)* come from three main sources which include: (1) the process of transporting FFB from plantation to milling; (2) FFB processing in the factory; (3) liquid and solid waste from production. The CE practices in milling for the purpose of resource efficiency and reducing carbon emissions have been carried out through energy saving mechanisms and methane gas utilization. Of the two milling companies that filled out this questionnaire, one company explicitly stated that it had practiced a CE intended to reduce carbon emissions.

The CE practices in milling to reduce carbon emissions have been carried limited to the 9R principles in the form of Reduce in terms of energy use, such as solar and electricity and methane utilization. Energy saving practices are more widely applied in the FFB processing phase in factories, for example for boiler operations. The comparison of energy use for boilers is fiber and shell (90%) and diesel (10%) where diesel is only used to produce steam in the first hour when the boiler starts operating.

One interesting fact is that a respondent who has practiced circularity to reduce carbon emissions is a domestic direct investment (DDI), some of whose products are exported, while those who have not applied circularity to carbon emissions have FDI legal status whose entire market is marketed domestically. Both respondents have ISPO and ISCC certifications and received a blue PROPER rating.[142] In addition, these two respondents also understand the concept of CE in general and have practiced circularity in resource efficiency efforts in energy, materials, and waste for more than five years. According to the respondents' estimation, CE

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[138] Subramaniam, V., Muhamad, H., Hashim, Z., & May, C. Y. (2014). Water Footprint: Part 3 - The Production Of Crude Palm Oil In Malaysian Palm Oil Mills. *Journal Of Oil Palm Research*, *26*(4), 292–299.

[139] Bala, J. D., Lalung, J., & Ismail, N. (2014). Palm Oil Mill Effluent (POME) Treatment "'Microbial Communities In An Anaerobic Digester'": A Review. *International Journal Of Scientific And Research Publications*.

[140] Ilmannafian, A.G., Lestari, E. And Khairunisa, F. (2020). Pengolahan Limbah Cair Pabrik Kelapa Sawit Dengan Metode Filtrasi Dan Fitoremediasi Menggunakan Tanaman Eceng Gondok (Eichhornia Crassipes). Jurnal Teknologi Lingkungan, 21(2), 1–10.

[141] Mohd Pauzi, F., Muda, K., Basri, H. F., Omoregie, A. I., Hong, C. Y., Aftar Ali, N. S., Mohamed Najib, M. Z., Mohd Amin, M. F., Ismail, S., Mohamad Shahimin, M. F., & Dahalan, F. A. (2023). A Mini Review And Bibliometric Analysis Of Palm Oil Mill Effluent In Past Five Years. *IOP Conference Series: Earth And Environmental Science*, *1143*(1), 12019. Https://Doi.Org/10.1088/1755-1315/1143/1/012019

[142] PROPER is Public Disclosure Program for Environmental Compliance. PROPER is an assessment program designed by the Ministry of the Environment (KLH) in 1995. It aims to evaluate and encourage firms to enhance their environmental management practices. The company's image and reputation will be determined by its effective management of its environment, as assessed by a thorough evaluation. The image is color-coded with shades of gold, green, blue, red, and black. Authentic gold is the most valuable asset, indicating that the organization has established and maintained a thorough and ongoing system for environmental management.

practices that only focus on the form of Refuse (R0) could only reduce carbon emissions by 1-5%.

CHAPTER V FIELDWORK FINDINGS

This section discusses the fieldwork findings and FGDs reports. The fieldwork was conducted in Riau Province on 11-16 February 2023. We visited and discussed deeply with the owners of four smallholder palm oil plantations, the managers of three corporate palm oil plantations, and the managers of two milling companies. In addition, we also had discussion with a senior lecturer at Riau University, two formers' employees of the largest refinery company in Riau, and office manager of palm oil association (GAPKI Riau) and secretary general of APKASINDO Riau. Here is the list of the respondents:

Table 5.1 List of respondents and their position

Name of Plantations/Companies/Individuals	Persons attended the discussion and their position
Smallholder Plantation	
Smallholder farmer 1	Owner
Smallholder farmer 2	Owner
Smallholder farmer 3	Owner
Smallholder farmer 4	Owner
Corporate palm oil plantations	
PT. Sari Lembah Subur (SLS)	Administrator/ General Manager, Head of Plantation, Head of Office Administration
PT. XXX*	Plant Manager, Plantation Assistant Manager, Staff at Environmental Division
PTPN V (State-Owned Enterprise/SOE)	Head of Plantation
Milling Companies	
PTPN V (State-Owned Enterprise/SOE)	Administrator/ General Manager, Head of Milling
PT. XXX*	Plant Manager, Plantation Assistant Manager, Staff at Environmental Division,
Academician and Practician	
Academic at Riau University	A senior Lecturer
A former employee of the largest refinery company in Riau	Head of division for refinery quality, Staff at CPO production division
Business Associations	
APKASINDO	Secretary general

GAPKI Riau	Head of office

* respondents who are interested in keeping the name confidential

5.1 Circular Economy Practices by Smallholder Palm Oil Plantations

While many smallholder palm oil plantations in Riau Province have implemented resource efficiency through the CE practices, the way they implement CE is relatively traditional with limited to certain aspects. For instance, to monitor weeds, palm oil farmers have decreased the utilization of fossil fuel machines. Then, they substituted it with a conventional method, i.e., sickle. In addition, the governmental policies relating to bio-solar utilization, also decrease the utilization of nonrenewal fuel. Relating to the material utilization behavior, palm oil farmers have conducted the utilization of palm oil biomass waste and reutilized it as essential agricultural input.

Materials

All parts of the palm oil trees are utilized, or in other words, there is no waste. The trunks and leaves of palm oil are used as fertilizers and re-implemented into the plantation area. The stick (stick) of palm oil is also re-processed, becoming a more economically value-added product. In addition, the empty fruit bunches are re-utilized as fertilizer by farmers. In palm oil processing, there are fruit bunches and fiber that are utilized as bio-fuel by the company. Farmers also utilize the wastewater and solid fertilizer from the waste of palm oil processing, which is popularly known as POME. Those fertilizers are useful for soil fertility. In addition, the wastewater from palm oil processing is utilized as biogas by the company. The residual fruit bunches and fiber are re-utilized as organic fertilizer by farmers. Therefore, the CE implementation at the level of palm oil farmers has included some 9R principles, such as Refuse, Rethink, Reduce, Refurbish, Repurpose, Recycle, and Recover.

Water

Relating to water utilization, palm oil farmers have utilized water resources more smartly by utilizing various water resources with other farmers by utilizing rivers or wells altogether (Rethink). By utilizing the wastewater of palm oil processing implemented in the plantation area, palm oil farmers have implemented the fundamentals of Reuse and Repurpose principles. That wastewater is also beneficial for maintaining soil fertility and decreasing chemical fertilizer.

Waste and Emission

The palm oil farmers also implement the CE relating to the utilization of waste, both the waste processed personally by the farmers and the waste from palm oil processing. In addition, they have utilized the waste more smartly and lengthened the lifetime of waste through the treatment process. They also enhance the value of waste by becoming an economically value-added product, i.e., utilizing the lidi (stick) as a broom or creative economic product. Relating to emission management, they have decreased the need for inorganic fertilizer by utilizing organic fertilizer from biomass waste and livestock manure. Therefore, they have implemented the CE practices in the form of Reduce principle. Those implementations decrease greenhouse gas emissions in the agricultural sector.

Factors Affecting the Implementation of Circular Economy by Smallholder Palm Oil Plantations

Strategy

The farmers' strategy to implement CE is mostly focused on reducing materials in a traditional way. For instance, by replacing the use of chemical fertilizers with the organic one that is more environmentally friendly. Some farmers utilize plantation waste to produce organic fertilizers, such as OPF (Oil Palm Frond), OPT (Oil Palm Trunk), EFB (Empty Fruit Bunches), FFB (Fresh Fruit Bunches), MF (Mesocarp Fiber), PKS (Palm Kernel Shell), and POME (Palm Oil Mill Effluent). In addition, some farmers utilize cattle manure as fertilizer through palm oil-cattle integration. Chemical fertilizer price tends to increase. It is one of the cautions those farmers conduct some efforts to decrease chemical fertilizer utilization. Organic waste utilization decreases not only chemical fertilizer utilization but also agricultural costs.

The CE implementation is not only useful economically but also socially and environmentally. Otherwise, farmers face some risks when implementing the CE, i.e., productivity decrease. As the use of material resources decreases through CE, the productivity level cannot be generalized among farmers. The cautions are palm oil productivity affected by various things, i.e., the quality and quantity of other agricultural inputs (fertilizers, herbicides, pesticides, water, etc), land area type, illness and pest attack, climate and weather, and farmers' capability in agricultural management.

Innovation

Innovation in CE implementation has been introduced by smallholder farmers to reduce the cost of production and maintain soil fertility. To monitor rat pests, farmers have introduced a traditional method by using palm oil predators, i.e., owls. To support the CE implementation, farmers have also invested in ground cover plants, i.e., *Leguminosae* or lentils, that are useful for fertilizing the soil because they enhance the nitrogen level. To reduce the expenditure of chemical fertilizers, farmers use POME as fertilizer. They cooperate with palm oil processing companies to obtain the POME. These CE practices have economized agricultural expenditure by more than 25%. Furthermore, almost all smallholder farmers engage in the digitalization process of acquiring information. Most farmers have used smartphones to obtain some information about supply chain, marketing, and more environmentally friendly resource utilization. In addition, some farmers utilize blockchain-based smart contracts to create given price transparency based on product' quality and quantity. Therefore, farmers obtain the best price by selling Fresh Fruit Bunches (FFB). The government and APKASINDO are the two main actors facilitating the farmers' knowledge improvement on CE implementation.

External engagement, monitoring and impact evaluation of RE

Relating to external engagement, farmers obtain palm oil seeds from suppliers or contract-farming companies if they are plasm farmers. The actors have some essential roles in providing high-quality seeds, which certainly affect productivity and the amount of needed material resources. Regarding capital, farmers are much supported by banking, but some farmers use their or their family's capital.

Government policy and the role of Business Association

To support the CE implementation by resource efficiency, Government needs to formulate some policies relating to: 1) high-quality palm oil seeds and organic fertilizers, 2) technology that substitutes oil fuel utilization for machines, or technology in plantation, i.e. using other energy resources provided in the planting area, i.e. the energy of the sun, wind, micro hydro, etc. 3) maintaining water quality by minimizing chemical material utilization for avoiding pollution, 4) disseminate and socialize waste utilization technology, 5) reduce the emissions arising from agricultural inputs which have negative externality effect to environment, 6) training and socializations relating to farmer capability enhancement in resource efficiency implementations.

5.2 Circular Economy Practices by Corporate Palm Oil Plantations

Energy

Fuel oil consumes a greater amount of energy. The workers who oversee will be more efficient in supervision as the implementation of digitization systems can reduce mobilization.. They use software on smartphones to monitor and manage energy use. Large-scale palm oil producers like PT Sari Lembah Subur, a division of PT Astra TBK, engage in this approach. If Indonesian farms carry this out in large quantities, it will have a significant impact.

Material

Inorganic fertilizers, in particular, can be saved by using foliar analysis technologies prior to crop fertilization. Based on the plant's requirements, the dosage and type of fertilizer required by the palm plant are estimated. Empty bunches and palm oil mill liquid waste (PKS) are examples of organic fertilizers that can minimize the need for non-organic fertilizers by up to 50%.

Water

There are not many substantial barriers to water consumption in oil palm fields. By building terraces on hilly territory to lessen flow and avoid landslides, water resources are reduced. By making trenches in plantations with sloping topography and by installing water control equipment, the water can be always be managed at a height of 40 to 60 cm. This preserves the availability of water from rivers as well as rainfall collection. Giving PKS liquid waste to plants as an organic liquid fertilizer is how it is utilized. The consumption of inorganic fertilizers may be decreased by using this liquid waste.

Waste

On plantations, there is no waste that needs to be transported to a specific location. For replanting palm trunks, all chopped or fallen oil palm components can be used as organic fertilizer. Alternatively, they can be simply placed in a row between the oil palm plants to degrade on their own. The harvested fronds and leaves are left to degrade naturally for roughly six months. Oil palm plantation trash may be converted into extra value by using broomsticks and leaf sheath debris. Dry lidi costs between IDR 4,000 and IDR 5,000 per kilogram, with special requirements for exporting palm oil of the normal and super varieties.

The normal category is green or brown and has a minimum length of 90 cm. The super-quality lidi is 100 cm long, has a tint of yellowish green, a 30% drought rate, and is mold-free[143]Palm frond curtains, also known as tipasa, are an intriguing craft that can be produced with palm fronds. Depending on the model and size, the cost per sheet at the artisan level ranges from IDR 25.000 to IDR 250.000. 37–40 old palm fronds are required to manufacture one tipasa sheet[144] [145].

Emission

By employing fuel oil, including both gasoline and diesel, CO2 emissions can be decreased while using less equipment. Maintenance that frequently involves using mechanical tools like lawn mowers is performed three to four times a year. One way to lessen the use of oil-fired machinery is to include local people near plantations in labor-intensive upkeep. By reducing the number of land fires, carbon emissions can be decreased. Using ditches that are always submerged in water can make it simpler to put out fires in plantation land areas. Fires can be rapidly and precisely put out with online plantation monitoring using devices for monitoring plantations (CCTV or heat sensors).

Factors Affecting the Implementation of Circular Economy by Corporate Palm Oil Plantations

Strategy

Efficiency targets are pursued in every stage of oil palm development. The discrepancies found in each stage earlier will be able to reduce losses. The use of digital technology in each stage can find out symptoms that are not suitable in its stages, such as the presence of fires, drought of trenches, and symptoms of leaf changes due to lack of plant nutrition. Monitoring is also carried out at every stage.

Resource efficiency efforts are carried out through saving input materials in plantations, including water, fertilizer, and fuel oil (BBM). First, water saving through the management of ditches using technology (water management system). The availability of water in controlled ditches also facilitates fire control, because in addition to water ditches as barriers, it is also a source of water for fire suppression in the event of a fire in the area of oil palm plantations.

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[143] Doya, Sangun. 2022. "Begini Kriteria Lidi Sawit Untuk Komoditas Ekspor - Elaeis.Co." *elaeis.co*. https://www.elaeis.co/berita/baca/begini-kriteria-lidi-sawit-untuk-komoditas-ekspor (February 24, 2023).

[144] Anang. 2023. "Kerajinan Tirai, Produk Olahan Dari Pelepah Sawit Mendatangkan Cuan." *Radar Bengkuli Online*. https://radarbengkulu.disway.id/read/656237/kerajinan-tirai-produk-olahan-dari-pelepah-sawit-mendatangkan-cuan (February 24, 2023).

[145] Hendrik, Hutabarat. 2021. "Sumber Duit Petani: Kini Ada Tipasa, Tirai Pelepah Sawit - Berita Seputar Sawit." *Asosiasi Sawitku Masa Depanku*. https://samade.or.id/news/sumber-duit-petani-kini-ada-tipasa-tirai-pelepah-sawit/ (February 24, 2023)

Fertilizer savings are carried out using plant indicators, such as in PT Sari Lembah Subur, which has used foliar analysis to determine the types of fertilizers needed by oil palm plants sampled for leaves. The results of this analysis will be a reference in applying fertilizer according to the type, dosage, and time needed by oil palm plants. The third savings on fuel oil are carried out by applying technology in the form of digitizing field monitoring tools.

Innovation

In corporate farming, research and development (R&D) begin on the seedbeds and plantations. Seedbeds are used to produce high-yielding seedlings with a classification of insect resistance, high production, and lifespan. R&D is also done by keeping an eye on how plants grow and making sure the right fertilizers are being used. The following investments have been undertaken to increase efficiency: The application of mechanical and hand fertilization techniques. If most fertilizers are applied mechanically while a small number are still applied manually, the use of foliar analysis techniques improves fertilizer effectiveness. Depending on the outcomes of foliar analysis, different types of fertilizers are combined using a fertilizer mixer in specific regions. Investment in the use of digital monitoring technology for the management of water resources. Employees who develop innovations within the organization or who have innovations will receive rewards.

Because of the savings in various areas, the investment is particularly advantageous and affects cost effectiveness. The corporation collaborates with community groups, academic institutions, and research facilities.

Operations

One of the interviewed respondents, PT Sari Lembah Subur, has started to operate the digital system since 2020. This system was very helpful during a pandemic. There are several benefits to monitoring, and it is possible to spot strange activities right away and take appropriate action. Using resources from plantations has allowed certain businesses to save money. It effectively utilizes water resources by using regulated ditches. Use of fertilizers in accordance with oil palm plant requirements; requirements derived from leaf analysis and signs of physiological changes in plants

External engagement

At the unit level of the company, partnerships and collaborations with smallholder farmers are carried out, such as in the form of core-plasma partnerships. The company provides seeds and fertilizers for plasma farmers joining in the partnership. For organic fertilizer, they use liquid waste from the MCC as well as empty fruit bunches. They sell it to the plasm farmers at a fair selling price. Companies were polled at the unit level; therefore, top-down or central office policies apply to the system and all plasm farmers. The digital system that has been put in place makes monitoring to increase efficiency easier. Managers at the central level can also monitor the processes that are taking place, in addition to managers at the unit level.

Government policy and the role of Business Association

It is necessary for government institutions or agencies to increase their human resource capability in areas other than business, such as environmental parameter analysis in accredited labs and the treatment of B3 waste. Access to technology is simple.

The association plays a role in the weekly pricing of FFB and the reference in determining the wages of employees who are members of the association. Research institutions / universities have high-tech equipment in soil quality analysis, this will be very useful if optimized to provide services to smallholders in knowing the condition and status of land planted with oil palm.

5.3 Circular Economy Practices by Private Palm Oil Milling

The practice of CE in many palm oil processing companies (milling) has been implemented in certain degree and in some forms of 9R principles. To provide an overview of circularity practices in private company-based palm oil milling, the following are CE practices in energy, materials, water, waste, and emission. In addition, we also briefly discuss the factors affecting the way the company implement CE practices to achieve a better resource efficiency. These factors include vision and strategy, innovation, people and skills, operations, external engagement, and government policy and the role of business association.

<u>Materials</u>

Private company-based palm oil milling practices CE in materials use to improve their efficiency. These practices, however, are still limited to some forms of 9R principles, such as: (a) Refuse by avoiding the use of chemical substances in the process of separating the palm kernel and shell. Many millings company adopt hydro cyclone technology for this purpose. In terms of cost, the average cost of running hydro cyclone operations is actually cheaper than other available technologies. However, there are some drawbacks to adopting hydro cyclone technology: needs huge investment cost, wasteful of water, and high losses. Considering these disadvantages, some milling companies have replaced hydrocyclone technology with clay bath technology. The model of separation of the core (kernel) and shell with clay bath requires a chemical substance called Calcium Carbonate. In this process, the core (kernel) and shell are separated by a specific gravity element. When such a chemical substance is added, the finished kernel rises andseparates from the shell. The difference in the cost of hydro cyclone and clay bath technic is about 1%. The current price, in 1 ton of FFB the loss is around Rp 1,000. But this depends on the price of the palm kernel oil, if the kernel is cheap, the losses are lower and vice versa.

Another circularity practice in material use is Rethink, which controls the quality of FFB that goes to the milling processing. This is required to obtain FFB with a high yield rate. The milling company also applies Repair to maintain the lifetime of machine components according to their technical age through certain techniques and maintenance. Another circularity practice in the material use is Recover by minimizing oil loss during the process.

The general standard for oil loss is 1.3%. Some milling companies are even set a higher standard of 0.7%. The key factors for achieving a loss of 0.7% or lower are (a) Technology. A new technology that has recently introduced is G-force engines above 5000 rpm. It comes originally from Germany and the investment value for this technology is about IDR 3 billion; (b) Energy. Steam should be available in sufficient amounts. Steam produced by boilers will be used for generating turbines. These turbines generate electricity and other machinery to drive all means of production; (c) Skilled labour (skilled). Three types of skills are necessary at this stage, namely skills of delivering FFB into the lorry (manual and engine power), machine operation, and monitoring skills. This process must be synergistic with other stations/divisions. The disturbances in one division will hinder the work of others.

Energy

The practices of CE in the energy use in private company-based palm oil milling are generally carried out in the form of Reduce and Recover. One of the most common practices is to reduce the use of non-renewable energy such as solar in generating boilers. Instead, they utilize renewable materials such as fibre and palm kernel shell for replacing solar. In the current practice, the comparison of energy use for boilers is 90% renewable energy resources (shell and fibre) and 10% solar. Solar is only used at the initial stage to make steam within about one hour operation.

Some big companies have been practicing CE to produce energy including electricity through methane capture process. It can save about 80% of fuel. However, it needs substantial amount of investment to develop methane capture technology, which is estimated at IDR 15 billion for 750 KW.

Water

Normal standards of water use in the milling process to produce CPO is 1-ton FFB will need 1 M^3 of water. Water use can be saved if a boiler replacement technology is found, for example, with an oven or electrical energy. A company (PT. NGA) is developing a new technology of FFB processing into crude palm oil from wet to dry process. Their technology is focused for smallholder milling company. The company is also developing technology to process biomass removed from Mills to be macro-biological back into bio-organic fertilizer.

Waste

Palm oil products are zero waste. All wastes of palm oil products in the milling companies can be reused or recycled for their own use or sold to other firms or palm oil farmers. Initial palm oil waste is categorized as hazardous and Toxic Substances (HTS). After getting specific treatment, the waste becomes useful material. The circularity process for waste in the milling company include Repurpose by processing liquid waste into fertilizers and solid waste to be used back as fertilizer in the palm oil plantation. Liquid waste from milling processing usually still has a CPO content of 0.5%. Liquid waste treatment is carried out in certain waste ponds to decompose waste so that it does not become HTS.The shell and fibre are used to fuel the boilers. Solid waste is also used for fertilizer. The latest technology allows empty bunchs to be processed into fuel (energy) for boilers.

The empty bunch cannot be burned immediately because the water content is still high at 20%. It must be pressed to reduce the water content to achieve a maximum moisture of 4%, and so that it can be burned.

Emission

The CE practices in milling companies are mostly carried out in the form of Reduce through energy saving mechanisms and methane gas utilization. Energy saving practices are more widely applied in the FFB processing phase in factories, for example, for boiler operations. The comparison of energy use for boilers is fibre and shell (90%) and diesel (10%), where diesel is only used to produce steam in the first hour when the boiler starts operating. Another circularity of Reduce principle in milling companies is also implemented in transportation, where some trucks are fuelled by biodiesel. The CE practice in the transportation, however, is still limited and only some milling companies have implemented this practice.

Factors Affecting the Implementation of Circular Economy by Private Milling Company

Strategy

Having a clear vision and strategy is a foundation for any firms including processing palm oil milling company to implement successful resource efficiency through CE. Our respondent, a private milling company in Riau, is one of the good examples that successfully implement the circularity process. This milling company has a measurable target to control the production processes, resource efficiency improvement and productivity increase. For example, to improve resource efficiency, the company has set a target of maximum oil losses in FFB processing at 0.7%. The company puts a stricter standard than the common standard practiced by other milling companies, which is 1.3%. To achieve this target, various circular practices have been carried out in the oil palm processing stages. Moreover, the company also applies a risk management strategy to ensure that each division /station in the mill processes carry out the job appropriately. The management staff of the company actively conducts routine supervision both manually and automatically by adopting digitalization.

Innovation

The board of directors actively provides direction and support process and product innovation to improve resource use and productivity appropriately. The company has invested in various production equipment and technologies, including (a) machinery, such as hydro cyclone. This is used to separate the palm kernel oil and palm shell. This technology was used several years ago but was eventually replaced with the clay technique. The main reason is that the losses with the hydro cyclone method are too high. There is a difference of 1% compared to the clay technique; (b) waste treatment facilities. The company has built seven ponds to collect the liquid wastes and treat them to become more useful and valuable materials; and (c) digitalization equipment. This is used in some divisions/stations to control the production process interactively in stews, boilers, and engine rooms.

People, skills and operations

Integrating production processes between divisions/stations requires that all employees work efficiently and precisely. The interruption at one division will hinder other divisions. Therefore, to quickly and precisely detect the problem of CPO production processes, the company has been implementing digitalization or semi-digitalization to integrate and control the production processes. Digitalization aims to connect tools in each division and enhance the efficiency of the production process. Currently, the company has been digitalizing about 20% of production processes. The cost of semi-digital boilers is around Rp 3 billion (about USD 206,897).[146] This technology is connected to an Android-based cell phone.

The company has a plan to increase digitalization in most of the production process. Consequently, this might reduce the number of employees working in the technical processes. For example, boiler technology has a moving floor technology to distribute fuel automatically with an optimal dose according to engine control. This machine will reduce the labour force by about 20%. Shifting from manual labour to digitalization will enable the company to cut operational costs significantly, such as salary payments. Furthermore, the new technology will also speed up the production process with lower losses. The current general labour standard required to produce CPO from 1 ton of FFB is 2 employees.

In order to improve the employees' technical skills, the company send some managers and operators to attend the trainings. The trainings is expected to equip the managers with improved skills in managing the factory such as the optimum utilization of the production, the quality of CPO, costs management, zero work accident, report accuracy, and customer engagements. For the operators, the focus of the training is to improve their skills in operating the engines, types and standards of oil and kernel losses, boiler water control, chemical material controls, and etc.

External engagement, monitoring and impact evaluation of RE

To support the CE practices, the company has partnered with the state electric company (PLN) to supply the electricity. This cooperation is built on the principle of mutual benefit. The company buys electricity from PLN that generates biodiesel-based electricity. In order to update new palm oil production technology developments, the company manager has also been actively engaging in the knowledge-sharing forum via WhatsApp and university alumni networks.

The monitoring process of some production stations is carried out by manual and digitalization methods. One of the purposes of this continuous monitoring and evaluation is to increase cost efficiency. For example, the consistent practices of circular have significantly reduced energy expenditures. In the coming years, a more intensive digitalization will also be expected to reduce operational costs about 20%, especially for salary expenditure.

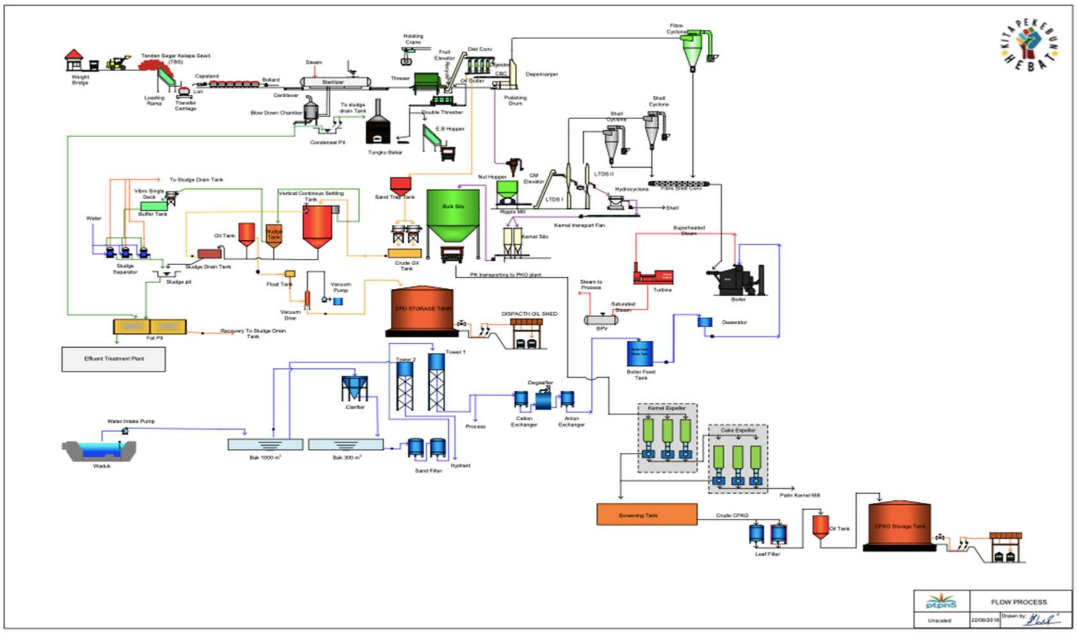
Government policy and the role of Business Association

[146] The Assumption Of Exchange Rate Is 1 USD = Rp 14,500

The milling company suggests that the government should provide reward and punishment systems for companies that implement and do not implement circular practices, for example, by giving tax discounts. Another suggestion is that certifications such as Indonesia Sustainable Palm Oil (ISPO) certification and PROPER certification need to be accompanied by real rewards that are attractive to milling companies. For example, companies with a gold and blue category can get a tax discount.

5.4 Circular Economy Practices by State-owned Enterprises Milling

In general, the processing of FFB into palm oil and palm kernel oil is divided into two subsystems (see Figure 4.1). First, the main station which consists of fruit reception, sterilizer, stripper, digester, presser, clarifier, and separation of seeds and kernels. Second, support stations consisting of power, laboratory, water treatment, bulking, and workshops[147] [148]The main objective of the FFB processing system is to minimize oil loss in both CPO and PKO. This is because the loss of oil also means a loss for the company. In their study, Ulimaz et al[137]said that the level of loss is influenced by raw materials, human resources, machines, and the environment. In relation to raw materials, the ability to optimally separate the kernel shells is important, as well as getting the palm kernel as soon as possible by separating it from the kernel and shell. HR skills and experience are important to reduce losses, as well as the ability to maintain machine reliability.



[147] Pahan, I. (2006). Complete Guide To Palm Oil: Agribusiness Management From Upstream To Downstream. Swadaya Co. Jakarta

[148] Ulimaz, A., Nuryati, N., Ningsih, Y., & Hidayah, S. N. (2021). Analisis Oil Losses Pada Proses Pengolahan Minyak Inti Kelapa Sawit Di PT. XYZ Dengan Metode Seven Tools. *Jurnal Teknologi Agro-Industri*, *8*(2), 124-134.

Figure 5.1 PTPN V Palm Oil Production Process

PTPN 5 already has Foss NIR DA1650 technology, which is an analysis tool to find out losses quickly in each production process chain[149]. Measurement results are carried out accurately and quickly for oil loss. This tool has been widely used by CPO refineries. This tool is connected to the palm oil production system and when a loss occurs, it can be quickly repaired. However, the price of this technology is still quite expensive, namely IDR 800 million. Another technology that is also beneficial for the palm oil industry is the Foss NIR DA 2500, which is a fertilizer and leaf analysis tool. Thus, it appears that the high losses that occur due to constraints on raw materials, human resources, machines, and the environment can be minimized with Foss NIR DA1650 technology.

Figure 5.2 Foss NIR DA165 that Owned by PTPN V

In addition to efforts to reduce loss, the waste generated in the FFB processing process also has great value if it can be processed properly. The company has utilized POME waste to produce biogas and used it for the combustion process in the boiler (gas blower). Currently around 100 -120 cubic meters per hour of methane gas is produced. This can reduce the burning of shells and fiber. Because the use of shells can be reduced, the shells can be sold and become income for the company. This biogas can also be used to generate electricity, but the company has not applied it yet.

The biogas power plant was built based on the synergy between the Agency for the Assessment and Application of Technology (BPPT), the Research and Technology Agency for Research and Technology and the Education Fund Management Institution (LPDP). Through biogas technology, companies can also obtain International Sustainability & Carbon Certification (ISCC) and with this certification, companies will earn USD 12-13 per tonne of CPO on the European market[150].

The current challenge is how to supply FFB so that it reaches the company's business scale, especially during the truck season or decreased FFB production due to seasonal factors.

[149] Https://Www.Kharisma-Sawit.Com/Mengenal-Foss-Nir-Da1650-Alat-Analisa-Oil-Loss-Cepat/
[150] Https://Ptpn5.Com/2019/11/Ptpn-V-Menuju-100-Persen-Sertifikasi-Iscc/

Because there are many palm oil mills without plantations, this is an obstacle to producing biogas.

The Utilization of palm oil's trees

Figure 4.4 describes the utilization of each part of the palm oil tree in plantations until it is processed in palm oil mills, both those that have been carried out by smallholders and corporate plantations. Palm oil's leaves and fronds are returned to the soil as organic fertilizer. Likewise, palm oil's stems that are no longer producing are applied to the soil as organic fertilizer. However, this circular economic behaviour is not carried out by 100% of farmers and business actors. There are still groups of farmers and business actors who have not implemented this circular economic behaviour. Several farmer groups have also used oil palm sticks as broomsticks and other creative economic products.

Business actors at the oil palm processing level have also processed Fresh Fruit Bunches (FFB) waste in the form of Empty Fruit Bunches (EFB) as organic fertilizer at the plantation level. Smallholders also receive EFB from processing factories which will be used as organic fertilizer. After separating the bunches, the flesh and kernel of the palm fruit are then processed into oil and palm kernel oil. The company reuses shells and fibre as briquettes or fuel at the palm oil processing level. In addition, there are several business actors who use shells and fibre as organic fertilizer. In the milling process, there is liquid waste known as POME which is reused by the company as biogas and organic fertilizer.

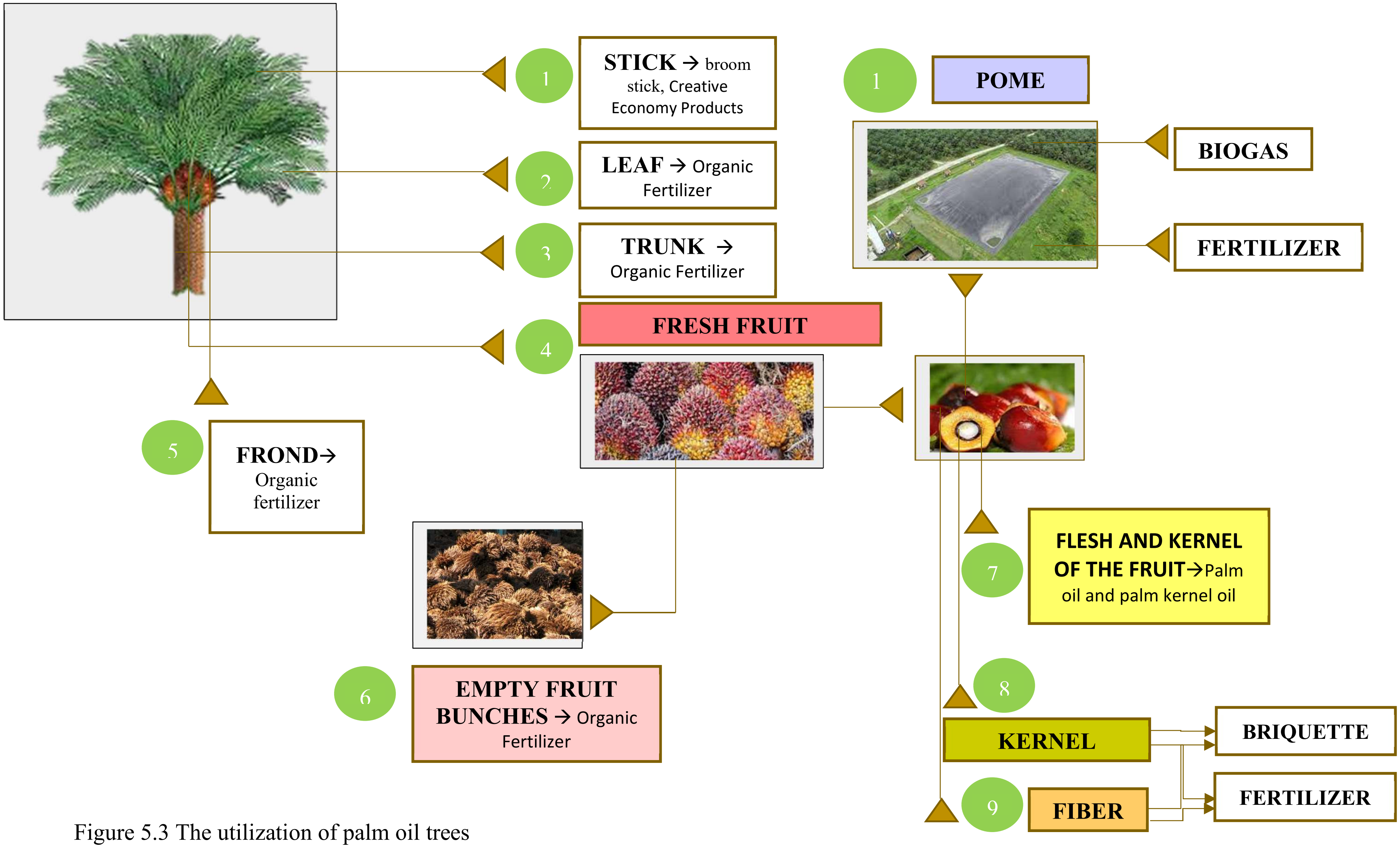


Figure 5.3 The utilization of palm oil trees

CHAPTER VI MEASUREMENT OF CIRCULARITY FOR RESOURCE EFFICIENCY AND CLEANER PRODUCTION (RECP)

6.1.Material Efficiency in Palm Oil Plantations

Fertilizers are essential agricultural input that affect palm oil's productivity significantly. However, in the long run the use of chemical fertilizers will cause adverse effect on soil fertility and environment. Hence, it is strongly advised that the use of chemical fertilizers should be reduced. In the economic context, this view also needs to be supported considering that fertilizer prices are expensive and tend to increase over time. Therefore, it is necessary to improve resource efficiency through chemical fertilizers reduction by practicing CE.

Material resource efficiency by Implementing Palm Oil-Cattle Integration (POCI)

The circular economic implementation in the palm oil plantation is conducted by a farmer (RR; pseudonym) in Riau Province by palm oil-cattle integration (POCI) system, i.e., cattle are herded on palm oil plantation. Therefore, cattle obtain feed from grass growing on the plantation. Meanwhile, midrib and cattle manure are used as organic fertilizers. The sort of seed used by RR is tenera RR's land area is 10 hectares for mature palm oil trees and 23 hectares for immature palm oil trees. RR has been working as a farmer in the last 20 years. The POCI system is proven to decrease chemical fertilizer expenditure by 58.68% and chemical fertilizer utilization by 47.73% (Table 1) though RR admitted that he does not have some palm oil certificates, i.e., ISPO and RSPO..

One of the farmers' motives for implementing the POCI system is the expensive price of chemical fertilizer. In addition to obtaining economic prices from palm oil plantations, farmers also obtain profit from selling cattle. Edwina and Maharani (2014) explained one of the essential factors in implementing the POCI system is not only determined by technology advance and natural resource support but also by farmers' characteristics. Ilham et al. (2021) stated that one problem of POCI system implementation in people's plantations is farmers' plantation land areas are not adequate to be herding areas.

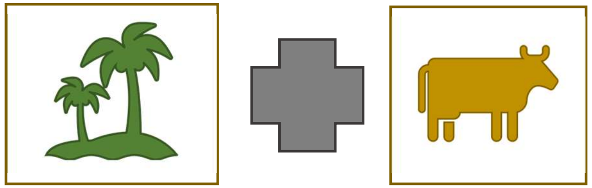
Cattle manure wastes, i.e., solid and liquid waste become the main material in solid and liquid organic fertilizer formation. Liquid organic fertilizer formation uses a mixture of molasses and EM4 (Effective Microorganisms-4). Meanwhile, solid organic fertilizer formation uses a mixture of molasses, EM4, and agricultural lime. Calculated costs are the purchasing price of molasses, EM4, and agricultural lime. Meanwhile, cattle manure cost is not calculated. In the liquid fertilizer formation, the comparison use of EM4 (Effective Microorganism 4) and molasses respectively are 1/100 and 6/100 for 1 litre of cattle urine. Meanwhile, in the solid fertilizer formation, the comparison use of EM4, molasses, and agricultural lime respectively are 1:1:1 for a ton of solid fertilizer. Table 1 provides the prices which have calculated the purchasing price of EM4, molasses, and agricultural lime. By POCI system and cattle manure waste use, the Fresh Fruit Bunches (FFB)'s productivity decreases insignificantly. The productivity difference before and after using the POCI system is 0 to 20% depending on other external factors, i.e., climate, weather, or track time. Although palm oil's productivity decreases when farmers use the POCI system, they obtain more profit because of agricultural expenditure costs, specifically, fertilizer needs decrease to 58.68%. In addition to using the POCI system, farmers also utilize palm oil midribs as organic fertilizer by leaving them in the plantation embankment, and then, they change to becoming palm bunch ash. In 3 months, a palm tree will produce 10 to 12 midribs which function as organic fertilizer.

If we assume that FFB's price per kg is Rp 2,200 and we only calculate fertilizer as a cost component, then the farmers implementing the POCI system will obtain more profit by 43.46% compared to farmers who only just use chemical fertilizers. That value calculates the FFB's income and the expenditure of farmers who only use chemical fertilizers and the expenditure of farmers who have implemented the POCI system. The thing that needs to be underlined is as follows. Although the incomes of farmers implementing the POCI system are lower than farmers just depending on chemical fertilizer, the profit of farmers implementing the POCI system is higher because agricultural cost amount has decreased significantly.

Table 6.1. Fertilizer efficiency by POCI in smallholder palm oil plantations

Sort Of Fertilizer	Total Use Before using POCI implementation Kg/Ha/Year)	Total Use After using POCI implementation (Kg (Liter)/Ha/Year)	Difference In Chemical Fertilizer Use (Kg/Ha/Year)	Price/Kg (Liter) (Rp)	Expenditure Cost Before Using POCI implementation (Rp)	Expenditure Cost After Using POCI implementation (Rp)	Expenditure Difference (Rp)
Urea	300	150	150	9,200	2,760,000	1,380,000	1,380,000
Kcl	300	150	150	12,000	3,600,000	1,800,000	1,800,000
Npk	600	100	500	25,000	15,000,000	2,500,000	2,500,000
Tsp	300	150	150	8,000	2,400,000	1,200,000	1,200,000
Za	200	100	100	1,700	340,000	170,000	170,000
Dolomite	500	500	0	8,400	4,200,000	4,200,000	-
Liquid Fertilizer (Cattle Urine, Em4, Molasses)	0	1,500	1,500	243	-	364,500	364,500
Solid Fertilizer (Cattle Manure, Em4, Molasses, Agriculture Lime)	0	2,000	2,000	39	-	78,000	78,000
Total Chemical Fertilizer Utilization	2,200	1,150	1,050		28,300,000	11,692,500	16,607,500
Percentage Of Chemical Fertilizer Utilization by Chemical Fertilizer Reduction			**47,73%**	**Percentage of Cost Decrease By Chemical Fertilizer Reduction**			**58.68%**
Productivity Of FFB (Fresh Fruit Bunches) Before Using Organic Fertilizer (Ton/Ha/Year)						12-18	
Productivity Of FFB (Fresh Fruit Bunches) After Using Organic Fertilizer (Ton/Ha/Year)						12-14.4	
Productivity Difference						0-20%	
Total Income Before Using Chemical Fertilizer (Assumption: The FFB Price Is Rp 2,200/Kg)						Rp 39,600,000	
Total Income After Using Chemical Fertilizer (Assumption: the FFB Price Is Rp 2,200/Kg)						Rp 31,680,000	
Income Difference						Rp 7,920,000	
Total Profit Before Using Organic Fertilizer (Assumption: Only Fertilizer Expenditure Cost Is Calculated)						Rp 11,300,000	
Total Profit After Using Organic Fertilizer (Assumption: Only Fertilizer Expenditure Cost Is Calculated)						Rp 19,987,500	
Profit Difference (Assumption: Only Fertilizer Expenditure Cost Is Calculated)						**43.46%**	

Source: Consultant’s team calculation (Case study by one farmer)



FERTILIZER EFFICIENCY BY POCI (PALM OIL-CATTLE INTEGRATION)

	TOTAL CHEMICAL FERTILIZER	TOTAL EXPENDITURE COST	PRODUCTIVITY	INCOME	PROFIT	EMISSION
BEFORE POCI IMPLEMENTATION	2.200 kg/ha/year	Rp 28.300.000 Ha/year	12-18 Ton/ha/year	Rp 39.600.000 Ha/year	Rp 11.300.000 Ha/year	2,17 ton CO2-eq
AFTER POCI IMPLEMENTATION	1150 kg/ha/year	Rp 11.692.000 Ha/year	12-14,4 Ton/ha/year	Rp 31.680.000 Ha/year	Rp 19.987.500 Ha/year	1,75 ton CO2-eq
DIFFERENCES	(1.050) kg/ha/year	RP (16.607.000) Ha/year	0-(3,6) Ton/ha/year	Rp (7.920.000) Ha/year	Rp 8.687.000 Ha/year	(0,42) ton CO2-eq

Figure 6.1. Fertilizer Efficiency By POCI (Palm Oil-Cattle Integration)

Material resource efficiency by Implementing POME and EFB waste utilization

In addition to using the POCI system, there is also circular economic principle implementation in fertilizer material resource using liquid waste from Palm Oil Processing (POP) or it is usually mentioned as Palm Oil Mill Effluent (POME). POME is liquid waste released during the crude palm oil process becoming palm oil and solid fibre. POME consists of many organic matters, i.e., fat, fatty acid, protein, phenolic acid, and nitrogen. This waste consists of matters that tend to pollute the environment if it is not treated well. As it consists of many organic matters, POME is used as fertilizer in palm oil plantations. Both companies' plantations and people's plantations use POME as organic fertilizer. The result of an in-depth interview with a farmer (SB; pseudonym) explains that he obtained POME from POP's expenditure cost of Rp 2,000,000 for 4,000 litres of POME and it was implemented once a year. By POME waste implementation, SB, the farmer, decreases the chemical fertilizer utilization such as urea, dolomite, TSP, and ZA. Table 2 explains the economic profit difference before and after using POME as fertilizer. Maharani et al.[151] explained that POME released from the anaerobic pond potential as plant fertilizer without previous treatment. As a fertilizer, POME utilization also enhances a plant's productivity because the plant treated with POME fertilizer, its leaves tend to be longer and have more branches.

POME utilization as fertilizer is proven to decrease chemical fertilizer use and agricultural expenditure cost. Table 2 explained that POME implementation as organic fertilizer in palm oil plantations decreases total chemical fertilizer utilization by 64,91% and fertilizer expenditure cost by 63,30%. In smallholder farmers. In addition, POME utilization as fertilizer enhances the FFB's productivity by 14.29%. That condition is different among farmers because the sort and amount of fertilizer are not just determined by the commodity's type, but also seed's type, area feasibility, fertilizer supply, and farmers' knowledge and behaviour. In addition, palm oil's productivity is also affected by various factors, i.e., area type, climate and weather, treatment, pest attack, etc. Based on the calculation, by chemical fertilizer utilization decrease, income difference, and profit, farmers obtain higher profit by 41,64% compared to previously without POME waste. That calculation just considers fertilizer expenditure cost. Meanwhile, other agricultural input expenditure costs are not calculated. Therefore, farmers receive different incomes. The calculation in Table 2 just explained the profit directly if using POME waste as fertilizer. Otherwise, the POME waste utilization as organic fertilizer in palm oil plantations has many benefits besides direct economic profit. The farmer's household economic sustainability is also maintained by using more environmentally friendly POME waste than chemical fertilizer. Yet, not all farmers can access POME waste from POP. Some farmers in Riau also stated they do not use POME waste because of ignorance and POME waste supply limitation. Farmers also admit the purchasing price of POME waste tends to increase. A caution of POME waste limitation from POP is the company has utilized the POME waste itself, both as organic fertilizer and other things, such as biogas.

Chemical fertilizer utilization efficiency by POME implementation was also conducted by corporate oil palm plantations (Case study Smart Plt.) which economized the fertilizer need

[151] Maharani, P. L., Pamoengkas, P., & Mansur, I. (2017). Pemanfaatan Pome Sebagai Pupuk Organik Pada Lahan Pascatambang Batubara The Application Of Pome (Palm Oil Mill Effluent) As Organic Fertilizer For Ex-Coal Mine Soil. *Journal Of Tropical Silviculture*, *8*(3), 177-182.

by 86,68% and expenditure cost by 85.57% in 2013 (Table 3). The POME utilization as fertilizer is a strategy to monitor water pollution. In addition to being useful for the environment, POME utilization also affects positively economic efficiency. POME consists of some elements that fertilize the soil, i.e., Nitrogen, Phosphor, and Kalium[152]. In addition to utilizing the liquid waste or POME, Smart Plt. also treats the solid waste released by palm oil factories, i.e., Empty Fruit Bunch as organic fertilizer. The Empty Fruit Bunch utilization decreases chemical fertilizer need by 34,39% and expenditure cost by 54.51% (Table 4). According to a case study analysis of people's palm oil plantations and companies' plantations, it summarizes that organic fertilizer utilization from palm oil processing waste decreases the fertilizer expenditure cost. Relating to its productivity has not been determined yet because palm oil's productivity is determined by various determinants, both technical factors, i.e., land area, illness and pest attack, seeds, fertilizers, water, climate and weather, and social factors, i.e. farmers' characteristics.

[152] Septiawan, H., & Thohari, M. (2014). Analisis Pengelolaan Lingkungan Pabrik Kelapa Sawit Batu Ampar-PT. Smart Tbk. Dalam Implementasi Indonesian Sustainable Palm Oil. *Jurnal Pengelolaan Sumberdaya Alam Dan Lingkungan (Journal Of Natural Resources And Environmental Management)*, *4*(2), 136-136.

Table 6.2. Fertilizer efficiency by POME implementation in smallholder palm oil plantations

Sorts Of Fertilizer	Total Use Before Using Pome Kg/Ha/Year)	Total Use After Using Pome (Kg(Litre)/ Ha/Year)	Difference In Chemical Fertilizer Use Kg/Ha/Year)	Price/Kg (Litre) (Rp)	Expenditure Cost Before Using Pome (Rp)	Expenditure Cost After Using Pome (Rp)	Expenditure Difference (Rp)
Urea	1,000	350	650	9,200	9,200,000	3,220,000	5,980,000
Tsp	300	150	150	8,000	2,400,000	1,200,000	1,200,000
Za	300	150	150	3,400	1.020.000	510,000	510,000
Phonska	250	0	250	1,700	425,000		425,000
Dolomite	1,000	350	650	8,400	8,400,000	2,940,000	5,460,000
Liquid Fertilizer (Pome)	-	4,000	-	500	-	2,000,000	- 2,000,000
Total Chemical Fertilizer Use	2,850	1,000	1,850		21,445,000	7,870,000	13,575,000
Percentage Of Chemical Fertilizer Utilization Reduction			**64,91%**	**Percentage Of Cost Decrease By Chemical Fertilizer Reduction**			**63,30%**
Productivity Of FFB (Fresh Fruit Bunches) Before Using an Organic Fertilizer Mixture (Ton/Ha/Year)						24	
Productivity Of FFB (Fresh Fruit Bunches) After Using an Organic Fertilizer Mixture (Ton/Ha/Year)						28	
Productivity Difference						4	
Total Income Before Using Chemical Fertilizer (Assumption: The FFB Price Is Rp 2,200/Kg)						Rp 52,800,000	
Total Income After Using Chemical Fertilizer (Assumption: The FFB Price Is Rp 2,200/Kg)						Rp 61,600,000	
Income Difference						Rp 8,800,000	
Total Profit Before Using Organic Fertilizer (Assumption: Only Expenditure Cost Is Calculated)						Rp 31,355,000	
Total Profit After Using Organic Fertilizer (Assumption: Only Fertilizer Expenditure Cost Is Calculated)						Rp 53,730,000	
Profit Difference (Assumption: Only Fertilizer Expenditure Cost Is Calculated)						**41.64%**	

Source: Consultant’s team calculation

Table 6.3. Fertilizer efficiency by POME utilization in corporate oil palm plantations (Case Study Smart Ltd.)

Sorts of fertilizer	Fertilizer per ha/year		Fertilizer efficiency		Fertilizer cost per ha/year		Fertilizer efficiency	
	Normal (Kg)	POME implementation (Kg)	(Kg)	(%)	Normal (Rp)	POME implementation (Rp)	(Rp)	(%)
Urea	619	-	619	100%	1.115.078	-	1.115.078	100%
DAP	35	-	35	100%	372.357	-	372.357	100%
RP	283	-	283	100%	388.041	-	388.041	100%
TSP	51	51	-	0%	102.661	102.661	-	0%
MOP	634	78	556	88%	1.860.015	228.423	1.631.592	88%
Super dolomite	26	45	- 19	-73%	43.085	74.419	-31.334	-73%
Kieserite Powder	11	42	- 32	-300%	20.661	82.644	-61.083	-300%
Kieserite Granular	50	-	50	100%	98.736	-	98.736	100%
HGFB/NBI/47	13	13	-	0%	104.353	104.353	-	0%
Total	1.722	229	1.493	**86,68%**	4.104.986	592,5	3.512.486	**85.57%**

Source: Septiawan et al. 2014

FERTILIZER EFFICIENCY BY POME (PALM OIL MILL EFFLUENT) IN SMALLHOLDERS PLANTATIONS

	TOTAL CHEMICAL FERTILIZER	TOTAL EXPENDITURE COST	PRODUCTIVITY	INCOME	PROFIT	EMISSION
BEFORE POCI IMPLEMENTATION	2.850 kg/ha/year	Rp 21,445,000 Ha/year	24 Ton/ha/year	Rp 52,800,000 Ha/year	Rp 31,355,000 Ha/year	2,48 ton CO2-eq
AFTER POCI IMPLEMENTATION	1.000 kg/ha/year	Rp 7,870,000 Ha/year	28 Ton/ha/year	Rp 61,600,000 Ha/year	Rp 53,730,000 Ha/year	1,26 ton CO2-eq
DIFFERENCES	(1.850) kg/ha/year	(Rp 13,575,000) Ha/year	4 Ton/ha/year	Rp 8,800,000 Ha/year	Rp 22.375.000 Ha/year	(1,22) ton CO2-eq

Figure 6.2. Fertilizer Efficiency by POME (Palm Oil Mill Effluent) In Smallholders Plantations

Table 6.4. Fertilizer efficiency by empty fruit bunches (EFB) utilization in corporate oil palm plantations (Case Study Smart Ltd.)

Sorts of fertilizer	Fertilizer per ha/year		Fertilizer efficiency		Fertilizer cost per ha/year		Fertilizer efficiency	
	Normal (Kg)	EFB implementation (Kg)	(Kg)	(%)	Normal (Rp)	EFB implementation (Rp)	(Rp)	(%)
Urea	619	57	562	91%	1.115.078	103.074	1.012.003	91%
DAP	35	0	35	100%	372.357	-	373.357	100%
RP	283	915	-632	-223%	388.041	1.253.670	-865.629	-223%
TSP	51	51	0	0%	102.661	102.661	-	0%
MOP	634	48	586	92%	1.860.015	141.405	1.718.610	92%
Super dolomite	26	45	-19	-73%	43.085	74.419	-31.334	-73%
Kieserite Powder	11	0	11	100%	20.661	87.81	-67.149	-325%
Kieserite Granular	50	0	50	100%	98.736	-	98.736	100%
HGFB/NBI/47	13	13	0	0%	104.353	104.353	-	0%
Total	1722	1130	592	**34,39%**	4.104.986	1.867.392	2.237.594	**54,51%**

Source: Septiawan et al. 2014

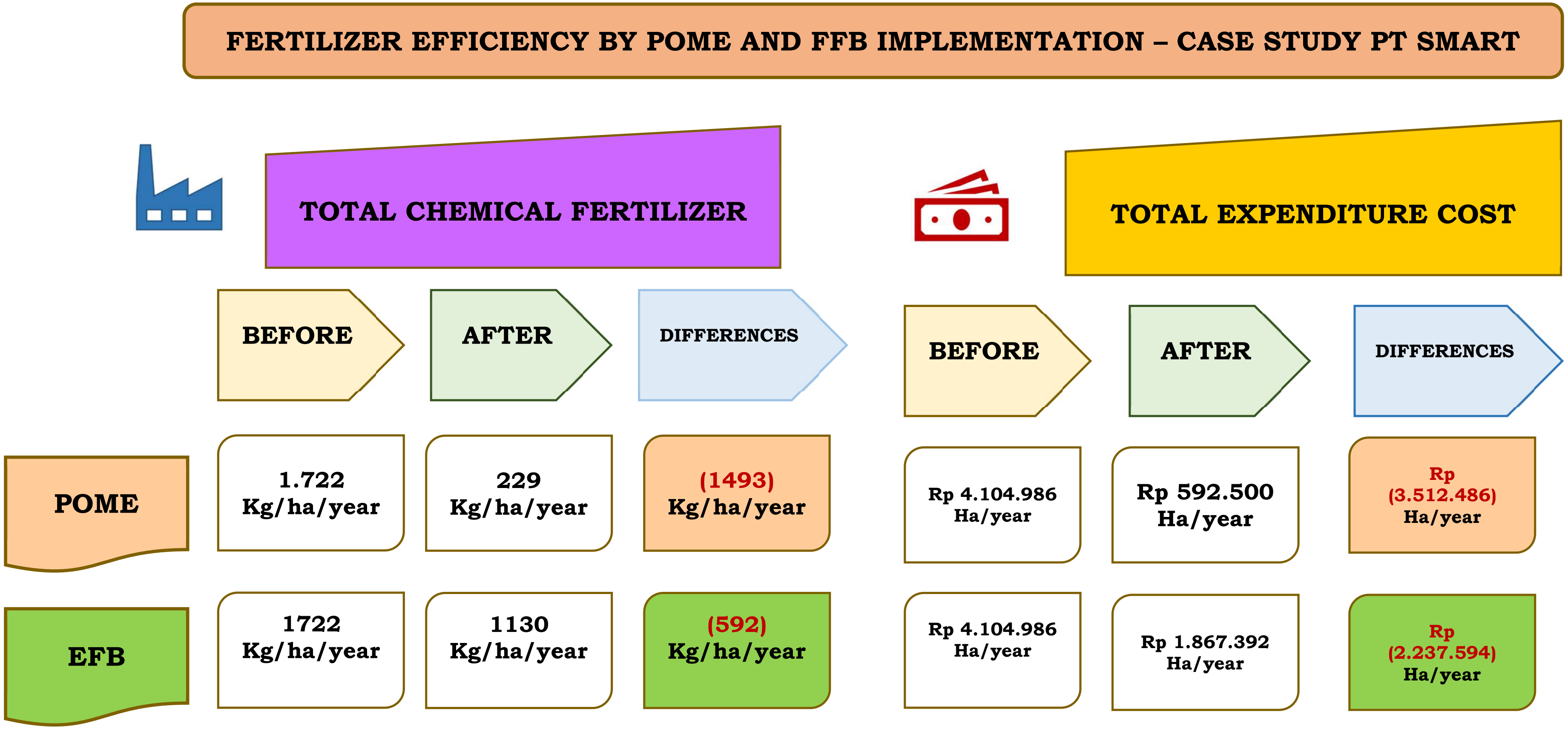


Figure 6.3 Fertilizer Efficiency by Pome and FFB Implementation – Case Study PT. Smart (Source: Septiawan et al. 2014)

Material resource efficiency by using owls as rat pest natural predators

In addition to chemical fertilizer utilization by circular economic implementation, palm oil farmers also implement other economization by bio-economy implementation using owls as natural predators to monitor rat pests. Owl utilization is proven to economize the expenditure cost by 83.33% in smallholder farmers and 89.58% in corporate oil palm plantations compared to rodenticide utilization or chemical monitoring (Table 6.5). Subiantara et al.[153] explained the rat pest attack decreases the production by 5% or more than 240 kg palm oil/ha/year if the rat population achieves 206 rats/ha. Rat pests do not just attack the growing point or 'umbut' (edible topmost and innermost frond) of immature palm oil, but also attack the producing palm oil tree by gnashing the fruits, both young fruits and elder fruits. Moreover, rat pest attacks affect negatively because of production decrease that affects economic loss.

Compared to chemical monitoring by rodenticide, rat pest monitoring uses natural predators such as owls has some benefits, i.e., more economized or cheaper, environmentally friendly, easy to conduct, and not need to monitor tightly because owls naturally hunt rats for fulfilling their eating needs, and the rat population is monitored below the economic threshold along the year. Otherwise, rat pest monitoring using owl predator has a weakness, i.e., it cannot be implemented in immature plants. Therefore, it can be just implemented to mature palm oil trees that have produced[154]. The research result of Sipayung et al.[155] mentioned rat pest monitoring until below the economic threshold in a 30-ha palm oil land area which just needs a pair of owls. Therefore, if converse the expenditure cost per ha per year will be more economical compared to chemical monitoring. An owl lives 10 to 12 years in wild nature. Table 3 provides prices, specifically the price of monitoring by using owls which is a purchasing price based on resources on the internet. The rodenticide expenditure cost in people's plantations is a result of an in-depth interview with a Riau farmer. Meanwhile, rodenticide expenditure cost in companies' plantations is based on the analysis of Mahendra et al.[156] who analysed the case study in Tritunggal Sentra Buana Inc. about the rat pest comparison efficiency and monitoring effectivity chemically and biologically. Through retrenchment of more than 80% by using owls, does not just obtain economic profit, but also social and environmental benefits.

Table 6.5. The comparison of expenditure cost using rodenticide and owl

	Rodenticide (smallholder farmers)	Rodenticide (Corporate oil palm plantation)	Owl (Rp/ha/year)
Needs	10 kg/ha/year		1 pair/30 ha

[153] Subiantara, A., Hakim, A. R., Diana, R., Wijaya, N. C., Yusuf, M., & Arianti, S. (2022, September). Analisis Kerugian Serangan Hama Tikus Di Perkebunan Kelapa Sawit (Studi Kasus Di Pt. Sakti Mait Jaya Langit). In *Prosiding Seminar Nasional Universitas Pgri Palangka Raya* (Vol. 1, Pp. 63-67)

[154] Dhamayanti, A. (2009). Kalian Social Ekonomi. Pfd. In Seminar Nasional Perlindungan Tanaman (Pp. 439-445). Pusat Pengendalian Hama Terpadu Departemen Proteksi Tanaman Fakultas Pertanian Insitus Pertanian Bogor. Retrieved From ARGOEKOSISTEM. In Prosiding Seminar Nasional Penelitan Pengabdian (PP.1-5)

[155] Sipayung, A. S., & Dan Thohari, A. L. (1990). Prospek Pemanfaatan Burung Hantu Tyto Alba Untuk Pengendalian Tikus Pada Perkebunan Kelapa Sawit. *Jakarta, Kongres HPTI I.*

[156] Mahendra, M.I., Jamaluddin, Jumri.(2022) "Perbandingan Efisiensi Dan Efektivitas Pengendalian Hama Tikus (Rattus Tiomanicus) Dengan Cara Kimiawi Dan Biologi Di PT.Tri Tunggal Sentra Buana", Jurnal Agriment, 7(1)

Price	Rp 50,000	Rp 200,000 /ha/ 3 months	Rp 1,000,000 per pair
Total Cost	Rp 500,000		Rp 33,333 /ha/year
Maintenance Cost	-		Rp 50,000 /year
Total Cost/year	Rp 500,000	Rp 800,000	Rp 83,333
Total Retrenchment Cost/ha/year	**Rp 416,667**	**Rp 716,667**	
Retrenchment Cost Percentage/ha/year	**83.33%**	**89.58%**	

Source: primary data, Mahendra et al 2022, and Adidharma 2022.

THE COMPARISON OF EXPENDITURE COST USING RODENTICIDE AND OWL

	Rodenticide (smallholder farmers)	Rodenticide (corporate oil palm plantation)	Owl
TOTAL COST	Rp 500,000 ha/year	Rp 800,000 ha/year	Rp 83,333 ha/year

Figure 6.4 The Comparison of Expenditure Cost Using Rodenticide and Owl

6.2.Carbon Emissions Reduction in Palm Oil Plantations

The carbon emissions in both smallholder and corporate palm oil plantations mostly come from two main sources: materials used in the cultivation process and energy in the plantation operational process.

Smallholder palm oil plantations

Our simulation results show that the amount of carbon emissions produced by smallholder palm oil plantations in the cultivation process before carrying out CE practices is around 2.17 tons of CO 2-eq per ha/year each (Table 6.6). The implementation of CE in the cultivation process through palm oil-cattle integration (POCI) system contributes to reduce the use of fertilizers and ultimately contributes to emission reduction. The amount of carbon emissions after practicing CE in the cultivation process decreases by 19.2% to 1.75 tons of CO 2-eq per ha/year (Table 6.7).

The assumption used to calculate carbon emissions in the cultivation process in both smallholder and corporate palm oil plantations refers to the emission factors from Chase and Henson (2010) : (a) every 1 ton of urea produces 1340 kg of CO2-eq; (b) every 1 ton of NPK produces 360 kg of CO2-eq; (c) every 1 ton of KCL produces 200 kg of CO2-eq- (d) every 1 ton of RP produces 43.7 kg of CO2-eq- (e) every 1 ton of Kieserite produces 200 kg of CO2-eqp (f) every 1 ton of pesticide produces 17257 kg of CO2-eq. The detailed calculation of emissions in the cultivation process is put in the table below:

Table 6.6. Estimated carbon emissions from materials use in smallholder oil palm plantation without CE practices

Fertilizer							
Types of Emission	**Materials**	**Unit size**	**Realization/ Year**	**Emission Factors**		**Emission/ Year**	**Emission Unit**
CO2	Urea	ton	0.30	1.34	kg CO2-eq/kg Urea	0.40	ton CO2-eq
CO2	NPK	ton	0.60	0.36	kg CO2-eq/kg NPK	0.22	ton CO2-eq
CO2	KCl	ton	0.30	0.2	kg CO2-eq/kg KCL	0.06	ton CO2-eq
CO2	RP	ton	0.30	0.0437	kg CO2-eq/kg RP	0.01	ton CO2-eq
CO2	Kieserite	ton	0.50	0.2	kg CO2-eq/kg Kies	0.10	ton CO2-eq
		ton	2.00			0.79	
Pesticides							
Types of Emission	**Materials**	**Unit size**	**Realization/ Year**	**Emission Factors**		**Emission/ Year**	**Emission Unit**
CO2	Pesticide	ton	0.1	17.257	kg CO2-eq/kg Pesticide	1.38	ton CO2-eq
				TOTAL		**2.17**	**ton CO2-eq**

Source: Consultant team's calculation

Table 6.7. Estimated carbon emissions from materials use in smallholder oil palm plantations with CE practices (POCI system)

Types of Emission	**Materials**	**Unit size**	**Realization/ Year**	**Emission Factors**		**Emission/ Year**	**Emission Unit**
CO2	Urea	ton	0.15	1.34	kg CO2-eq/kg Urea	0.2	ton CO2-eq
CO2	NPK	ton	0.10	0.36	kg CO2-eq/kg NPK	0.0	ton CO2-eq
CO2	KCl	ton	0.15	0.2	kg CO2-eq/kg KCL	0.0	ton CO2-eq
CO2	RP	ton	0.15	0.0437	kg CO2-eq/kg RP	0.0	ton CO2-eq
CO2	Kieserite	ton	0.50	0.2	kg CO2-eq/kg Kies	0.1	ton CO2-eq
		ton	1.1			0.4	
Pesticides							
Types of Emission	**Materials**	**Unit size**	**Realization/ Year**	**Emission Factors**		**Emission/ Year**	**Emission Unit**
CO2	Pesticide	ton	0.1	17.257	kg CO2-eq/kg Pesticide	1.4	ton CO2-eq
					TOTAL	**1.75**	**ton CO2-eq**

Source: Consultant team's calculation

The implementation of CE in the cultivation process through POCI system reduces the use of fertilizers (Urea, NPK, KCI, and RP)

In a different case of smallholder farming, the way to improve material efficiency is conducted through replacing chemical fertilizers with POME. Assuming that the chemical fertilizers are entirely replaced by POME, our simulation shows that the carbon emission decreases from 1.85 to 0.65 tons of CO2-eq per ha / year, equaling 65% reduction in the emission.

In the plantation operational process, the main sources of carbon emission come from the solar used by car trucks for the purpose of transporting FFB from the plantation to the Palm Oil Mill (PKS). In some plantation, they also use solar to fuel generator engines to produce electricity in the plantation keepers' house. Before carrying out CE practices, our simulation results showed that the carbon emissions are about 2.48 tons of CO2-eq per ha / year. After implementing CE, carbon emissions from plantation operations decrease by 49.2% to 1.26 tons of CO2-eq per ha/year. The CE practice in the operational process of smallholder palm oil plantations is mainly to replace the use of generators with solar panels.

The assumption used to calculate the carbon emissions in the operational process of smallholder palm oil plantations refers to the Revised 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Volume 2 Energy, Chapter 3 where the emission factor for CO2 is 74.1 kg CO2-eq/GJ HV and 1 liter of diesel = 0.0387 GJ HHV. In this calculation it is also assumed that carbon is 100% oxidized. Another assumption used in the calculation above is that the energy in the plantation keepers' house uses a mini generator with a capacity of 450 watts. The number of solar needs for fueling the mini generators is calculated by the formula 0.21 x p x t, where 0.21 is the constant factor of solar consumption per kilowatt per hour; p = generator power (the power of mini generator used in this calculation is a 450 watt); t = unit of time (use of lighting per day 12 hours, used for 30 days).

Table 6.8. Estimated carbon emissions from plantation operation in smallholder oil palm plantations without CE practices

Information on the use of solar fuel (in Liters) in the farm operations:								
Source	Engine efficiency							
Machine	70%							
Truck	80%	*238.2* Liters						
Generator Set	80%	424.2 Liters						
	Transportation							
	Type of emission	Sources	Unit	Real/ Year	Emission Factors		Emissions/Year	Emission Unit
	CO2	Solar	liter	238.2	74.10	kg CO2-eq/GJ HV	0.96	ton CO2-eq
			Ton	0.2025				
	Generator Set							
	Type of emission	Sources	Unit	Real/ Year	Emission Factors		Emissions/Year	Emission Unit
	CO2	Solar	liter	424.2	74.10	kg CO2-eq/GJ HV	1.5	ton CO2-eq
			Ton	0.36057				
						TOTAL	**2.48**	**ton CO2-eq**

Source: Consultant team's calculation

Note: The process of emission calculation refers to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Volume 2 Energy, Chapter 3 where the emission factor for CO2 is 74.1 kg CO2-eq/GJ HV and 1 liter of diesel = 0.0387 GJ HHV. The uint of emission is ton CO2-eq

Table 6.9. Estimated carbon emissions from farm operation in smallholder oil palm plantations with CE practices

Information on the use of solar fuel (in Liters) in the farm operations:								
Source	Eff. Mesin							
Machine	70%							
Truck	80%	*238.2*						
Generator Set	80%	*84.0*						
	Transportation							
	Type of emission	Sources	Unit	Real/ Year	Emission Factors		Emissions/Year	Emission Unit
	CO2	Solar	liter	238.2	74.10	kg CO2-eq/GJ HV	0.96	ton CO2-eq
			Ton	0.2025				
	Generator Set							
	Type of emission	Sources	Unit	Real/ Year	Emission Factors		Emissions/Year	Emission Unit
	CO2	Solar	liter	84.0	74.10	kg CO2-eq/GJ HV	0.301	ton CO2-eq
			Ton	0.0714				
						TOTAL	**1.26**	**ton CO2-eq**

Source: Consultant team's calculation

The CE practice in the operational process is mainly to replace the use of generators with solar panels.

<u>Box 1</u>

Energy Use and Carbon Emissions in Plantation Activities

The basic information built in this calculation comes from the results of interviews with oil palm smallholders. Energy use at the oil palm plantation level is carried out by using vehicles to transport palm oil. The vehicle used to transport FFB is a diesel-fueled colt pickup. For one trip, the amount of fruit that can be transported is around 8-11 tons; with a transport fee of around IDR 70/kg (for a distance of around 20 Km) and IDR 100/kg for a distance of up to 55 Km. This fee includes the driver, fuel (BBM), and benefits for the vehicle owner.

If it is assumed that one trip can transport 10 tons of FFB with about 55 km, then the costs incurred are:

- Total cost = 10 tonnes x 1,000 (tons to Kg conversion) x IDR 100/kg = IDR 1,000,000
- Work money for drivers IDR 150,000; and the rest to buy diesel and vehicle owners.

Assuming fuel consumption is around 5 km/liter157, and the price of Pertamina biodiesel is IDR 6,800/liter158, the fuel costs are:

IDR 6,800 / liter x [55 Km : 5 Km / liter] = IDR 74,800

If the consumption of 11 liters of biodiesel, for 55 km, the energy consumption is equivalent to 143,220 BTU159; emission conversion constant for biodiesel (2,524 BTU equivalent to 10.84116 Kg CO2 Emissions). Thus, the total emission is [(143,220 / 2,524) Kg Emissions X 10.84116] = 615.16 Kg CO2/10 tons FFB. Because there are 10 tons of FFB in a vehicle or the emission is around 0.06-ton CO2/ton FBB.

Comparing with conditions in large companies, such as PT. DSN, it is known in the Sustainability Report, in 2022, FFB transport emissions of 0.00377 tCO2/Ton FFB. Thus, it appears, the emission level of transporting FFB for large companies is much lower than conditions at the farm level. Based on this calculation, the reduction in carbon emissions for each FFB unit will decrease if there is an increase in the amount of FFB that can be transported (scale effect), and the proximity of the distance to the palm oil processing factory (distance effect).

Likewise, regarding spraying activities, farmers usually use generator or genzet. For one spraying attempt, 1 liter of iron is usually used and done for ½ day for a land area of about 1 ha. A total of 1 liter of gasoline is equivalent to 700 grams of CO2. Thus, the CO2 emission for spraying per hectare is 700 grams. In a year, it is assumed to spray 2 times. So that the total emission from spraying activities in 1 year is 1.4 Kg CO2/Ha. Usually, in 1 Ha, there are 138 oil palm trees in an oil palm plantation.

[157] Https://Www.Oto.Com/Truk-Baru/Mitsubishi/Fuso-Fn-527-Ml/Faq/Berapa-Konsumsi-Bbm-Per-Kilometer
[158] Https://Mypertamina.Id/Fuels-Harga
[159] Https://Hijauku.Com/Kalkulator/Transportasi/

Corporate oil palm plantations

Our simulation results show that the amount of carbon emissions produced by corporate palm oil plantations in the cultivation process before carrying out CE practices is around 0.990 tons of CO 2-eq per ha/year each. After practicing CE by replacing the use of chemical fertilizers with POME, the amount of carbon emissions decreases by 96.4% to 0.035 tons of CO 2-eq per ha/year. We can see here that a corporate palm oil plantation produces much lower carbon emission than that of smallholder plantation. One of the main reasons is because corporate plantation companies apply fertilization technology based on leaf analysis, which enables them to use more efficient fertilizers.

Table 6.10 Estimated carbon emissions from materials use in corporate oil palm plantation without CE practices

Fertilizers							
Types of Emission	**Materials**	**Unit size**	**Realization/ Year**	**Emission Factors**		**Emission/ Year**	**Emission Unit**
CO2	Urea	ton	0.619	1.34	kg CO2-eq/kg Urea	0.829	ton CO2-eq
CO2	NPK	ton	0.000	0.36	kg CO2-eq/kg NPK	0.000	ton CO2-eq
CO2	KCl	ton	0.634	0.2	kg CO2-eq/kg KCL	0.127	ton CO2-eq
CO2	RP	ton	0.369	0.0437	kg CO2-eq/kg RP	0.016	ton CO2-eq
CO2	Kieserite	ton	0.087	0.2	kg CO2-eq/kg Kies	0.017	ton CO2-eq
		ton	1.709			0.990	
Types of Emission	**Materials**	**Unit size**	**Realization/ Year**	**Emission Factors**		**Emission/ Year**	**Emission Unit**
CO2	Pestisida	ton	0.0	17.257	kg CO2-eq/kg Pestisida	0.0	ton CO2-eq
				TOTAL		**0.990**	**ton CO2-eq**

Source: Consultant team's calculation

Table 6.11 Estimated carbon emissions from materials use in corporate oil palm plantation with CE (POME fertilizer)

Fertilizers							
Types of Emission	**Materials**	**Unit size**	**Realization/ Year**	**Emission Factors**		**Emission/ Year**	**Emission Unit**
CO2	Urea	ton	0.000	1.34	kg CO2-eq/kg Urea	0.000	ton CO2-eq
CO2	NPK	ton	0.000	0.36	kg CO2-eq/kg NPK	0.000	ton CO2-eq
CO2	KCl	ton	0.078	0.2	kg CO2-eq/kg KCL	0.016	ton CO2-eq
CO2	RP	ton	0.051	0.0437	kg CO2-eq/kg RP	0.002	ton CO2-eq
CO2	Kieserite	ton	0.087	0.2	kg CO2-eq/kg Kies	0.017	ton CO2-eq
		ton	0.171			0.035	
Pesticide							
Types of Emission	**Materials**	**Unit size**	**Realization/ Year**	**Emission Factors**		**Emission/ Year**	**Emission Unit**
CO2	Pestisida	ton	0.000	17.257	kg CO2-eq/kg Pestisida	0.0	ton CO2-eq
				TOTAL		**0.035**	**ton CO2-eq**

Source: Consultant team's calculation

6.3.Carbon Emissions Reduction in the Palm Oil Milling

Carbon emissions produced by palm oil milling companies come from three main sources: (a) the process of transporting FFB from plantation to mill; (b) FFB processing in the factory; (c) production of liquid and solid waste. CE practices in milling for the purpose of resource efficiency and reducing carbon emissions have been carried out through energy saving mechanisms and methane gas utilization. Energy saving practices are more widely applied in the FFB processing phase at the factory, for example, replacing solar with palm oil processing waste (shells) for fueling boiler operations.

Operating a boiler that only uses solar diesel without using shells at all will produce carbon emissions of 0.165 tons of CO 2-eq per ton of FFB / year. The largest contribution of carbon emissions is from POME liquid waste, which is as much as 97.6%. By practicing a CE through the use of FFB processing shells as fuel, the total carbon emissions in boiler operations can be reduced by 2.31% to 0.161 tons of CO 2-eq per ton of FFB / year. Fiber and shell can replace 90% of the function of solar in operating the boiler, the remaining 10% still uses diesel to produce steam in the first hour when the boiler starts operating. Therefore, the use of fuel to generate the engine for processing every 1-ton FFB can be reduced from 0.9 liter (without CE) to only 0.1 liter (with CE).

Table 6.12. Estimated carbon emissions in milling company without CE practices

Information about milling company							
- FFB processed:		1	ton/year		% Shell for boiler:		95.0%
- % Liquid Waste Production:		58.3%	FFB processed		% Fiber Production :		14.4%
- % Shell Production:		6.4%	FFB processed		% Machine Efficiency:		70.0%
Fuel needs	Machine Efficiency						
Solar process	70%	0.68					
Solar idle day	70%	0.00					
Solar needs in holiday	50%	0.26					
TOTAL		0.93	0	0	0	0	0
Liquid Waste							
Types of Emissions	**Source**	**Unit**	**Real/year**	**Emission Factors**		**Emissions/Year**	**Unit**
CH4	Liquid Waste	ton	0.6	1.24%	CH4	0.007	ton CH4
Conversion CH4 to CO2							
Types of Emissions	**Source**	**Unit**	**Real/year**	**Emission Factors**		**Emissions/Year**	**Unit**
CO2	Liquid Waste	ton	0.58	22.25	CO2-eq/CH4	0.161	ton CO2-eq
Engine Fuel							
Types of Emissions	**Source**	**Unit**	**Real/year**	**Emission Factors**		**Emissions/Year**	**Unit**
CO2	BBM Solar	litre	0.9	74.1	kg CO2-eq/GJ HV	0.004	ton CO2-eq
		Ton	0.0007946				
Transportation Fuel							
Types of Emissions	**Source**	**Unit**	**Real/year**	**Emission Factors**		**Emissions/Year**	**Unit**
CO2	BBM Solar	litre	-	74.1	kg CO2-eq/GJ HV	-	ton CO2-eq
					TOTAL carbon emission	**0.165**	**ton CO2-eq**

Source: Consultant team’s calculation

Table 6.13 Estimated carbon emissions in milling company with CE practices

Information about milling company							
- FFB processed:		1	ton/year		- % Shell for boiler		95.0%
- % Liquid Waste Production:		58.3%	FFB processed:		- % Fiber Production :		14.4%
- % Shell Production:		6.4%	FFB processed:		- % Machine Efficiency:		70.0%
Fuel needs	Machine Efficiency						
Solar Process	70%	0.07					
Solar Idle Day	70%	0.00					
Solar needs in holiday	50%	0.03					
TOTAL		0.09	0	0	0	0	0
Liquid Waste							
Types of Emissions	**Source**	**Unit**	**Real/year**	**Emission Factors**		**Emissions/Year**	**Unit**
CH4	Liquid Waste	ton	0.6	1.24%	CH4	0.007	ton CH4
Conversion CH4 to CO2							
Types of Emissions	**Source**	**Unit**	**Real/year**	**Emission Factors**		**Emissions/Year**	**Unit**
CO2	Liquid Waste	ton	0.58	22.25	CO2-eq/CH4	0.161	ton CO2-eq
Engine Fuel							
Types of Emissions	**Source**	**Unit**	**Real/year**	**Emission Factors**		**Emissions/Year**	**Unit**
CO2	BBM Solar	litre	0.1	74.1	kg CO2-eq/GJ HV	0.000	ton CO2-eq
		Ton	0.0007946				
Transportation Fuel							
Types of Emissions	**Source**	**Unit**	**Real/year**	**Emission Factors**		**Emissions/Year**	**Unit**
CO2	BBM Solar	litre	-	74.1	kg CO2-eq/GJ HV	-	ton CO2-eq
					TOTAL carbon emission	**0.161**	**ton CO2-eq**

Source: Consultant team's calculation

The assumptions used in calculating the amount of carbon emissions from the FFB processing process are: (a) conversion factor emission derived from anaerobic waste ponds is 1.24% (Yacob S, Hassan MA, Shirai Y, Wakisaka M, & S., 2006); (b) the conversion of CH_4 to CO_2 considering the global warming potential (kg CO_2-e/kg CH_4) is 22.25 (Schmidt, 2007 in Chase & Henson, 2010); (c) emission factor for CO_2 is 74.1 kg CO_2-eq/GJ HV and 1 liter of diesel = 0.0387 GJ HHV (IPCC, 2006); (d) solar used to process FFB is 0.676 liters/ton FFB. This figure is obtained by calculating the average diesel need in the mill with an engine efficiency of 70%; (e) the percentage of liquid waste, shell and fiber production refers to the 2022 Palm Oil Processing Mass Balance.

Box 2
Bioenergy from POME

Based on the information submitted by PT. DSN in the 2022 Sustainability Report. POME waste, which is processed into methane capture, can produce 13,435,401 kWh of electricity or equivalent to a reduction of 3,749,977 liters of diesel. The reduced diesel is equivalent to 10,003 tons of CO2e.

At the first Bio-CNG plant, the company processed 104,513 m3 of POME waste into biomethane with 7,703,401 kWh of energy (27,732 GJ). Biomethane is used for kernel crushing plant operations, and compressed gas is in the form of CNG. Biogas which is further processed in the form of Bio-CNG, is used to fuel vehicles. Currently, 8 trucks are already fueled with Bio-CNG and the company is able to reduce emissions by 5,355 tCO2.

The second Bio-CNG plant was built with a capacity of 10,296,000 kWh or the equivalent of 37,066 GJ. The company has issued an investment of IDR 146.7 billion for the Bio-CNG 2 investment, IDR 8.4 billion for Bio-CNG trucks, and IDR 1.52 billion for solar to Bio-CNG converter kits.

Conditions for the use of renewable energy based on the source are divided into shells and fibers, Bio-CNG Plant, and Biogas engine, respectively 8,050,301 GJ, 27,732 GJ and 20,700 GJ.

6.4.Circular Economy Practices in Palm Oil Refinery

The number of palm oil refinery industries in Indonesia has reached 86 units with a capacity of 56 million tons/yea. In addition, there are also 19 units in the biodiesel industry with a capacity of 12 million kilolitres/year, and 21 units in the oleochemical industry with a capacity of 11.3 million tons/year[107]. The refinery companies produce solid waste in the form of Spent Bleaching Earth (SBE), which still contains 20 – 40% oil[160].The amount of bleaching earth is added to as much as 1.5 – 3 percent of the total CPO processed[161]. SBE contains a chemical compound, namely SiO2 reaching 83.05 percent.

While SiO2 or silica dust could be harmful to the surrounding environment, SiO2 can be used as a mixture of Portland cement. Concrete with a mixture of SBE waste that achieves the design compressive strength is 10% SBE of 34.16 MPa and 20% SBE of 29.06 MPa. Based on the results of the TCLP (Toxicity characteristic Leaching Procedure), the concentration of heavy metals in concrete with a mixture of 10% SBE is below the TCLP quality standard. These results prove scientifically that concrete with a mixture of 10% SBE

[160] Utami, S., & Indrasti, N. S. (2020). Pemulihan Minyak Sawit Dari Spent Bleaching Earth Dengan Metode Ekstraksi Refluks. *Jurnal Teknologi Industri Pertanian*, *30*(1).
[161] Nuryanto, E., & Askasari, D. R. (2018). Pemanfaatan Arang Tempurung Kemiri (Aleurites Moluccana (L.) Willd.) Sebagai Adsorben Pada Pemurnian Minyak Kelapa Sawit Mentah/Crude Palm Oil (Cpo). *Jurnal Penelitian Kelapa Sawit*, *26*(2), 49-58.

is technically and environmentally feasible [162]. SBE also contains a phosphoric acid component derived from the degumming process[151].

In addition to supporting infrastructure development through the provision of materials, the remaining oil in SBE can be recovered for industrial applications (for example as raw material for oil refinery biofuels, lubricants, oleochemicals, animal feed, and fertilizers)[163] (Arpornpong et al., 2018). Recovered oil can also be processed into methyl ester (biodiesel), this is because oil is no longer food grade[164] [165].Recovery of palm oil from SBE using the reflux extraction method was able to produce an oil yield of 88.31 percent[151].

SBE waste can also be used as organic fertilizer. The inclusion of organic agricultural waste and waste from palm oil milling can transform SBE trash into an organic fertilizer. The combination of these three ingredients has an impact in the form of significant biomass growth and productivity of up to two times that of crops that have been given fertilizer[166].CE practices in the process of refining CPO have a relatively large impact. The use of hot steam can reduce costs by up to 39.29 percent and the use of electricity can reduce costs by up to 13.47 percent[50].

Processing results SBE waste through recovery oil Biodiesel is a recycling process that reduces waste and emissions carbon at most[167]. Based on Appendix I PP No. 101 of 2014, ‘SBE is included in the list of B3 waste from specific sources’ with hazard category 2 and SBE is not included in the category of corrosive materials if it has a neutral pH. However, the change in SBE status as non-B3 waste in PP 22/2021 brings great hopes for investors to develop an SBE processing industry in palm oil[107] (Sawit Indonesia, 2022). In the PP, SBE is included in the category of non-hazardous waste with the criteria of being the result of an embryonic oleochemical industrial process and/or animal or vegetable oil processing which produces extracted SBE (Extracted SBE) with an oil content of less than or equal to 3 percent. Thus, SBE waste that has an oil content of more than 3 percent is still in the B3 waste category.

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[162] Dermawan, D., & Ashari, M. L. (2018). Studi Pemanfaatan Limbah Padat Industri Pengolahan Minyak Kelapa Sawit Spent Bleaching Earth Sebagai Pengganti Agregat Pada Campuran Beton. Jurnal Presipitasi, 15(1), 7 – 10. Https://Doi.Org/10.14710/Presipitasi.V15i1.7-10.

[163] Arpornpong, N., Charoensaeng, A., Khaodhiar, S., & Sabatini, D. A. (2018) Formulation Of Microemulsion-Based Washing Agent For Oil Recovery From Spent Bleaching Earth-Hydrophilic Lipophilic Deviation Concept. Colloids And Surfaces A: Physicochemical And Engineering Aspects, 541:87–96. Https://Doi.Org/10.1016/J.Colsurfa. 2018.01.026

[164] Leung, D. Y., Wu, X., & Leung, M. K. H. (2010). A Review On Biodiesel Production Using Catalyzed Transesterification. *Applied Energy*, *87*(4), 1083-1095.

[165] Naser, J., Avbenake, O. P., Dabai, F. N., & Jibril, B. Y. (2021). Regeneration Of Spent Bleaching Earth And Conversion Of Recovered Oil To Biodiesel. *Waste Management*, *126*, 258-265.

[166] Loh, S. K., James, S., Ngatiman, M., Cheong, K. Y., Choo, Y. M., & Lim, W. S. (2013). Enhancement Of Palm Oil Refinery Waste–Spent Bleaching Earth (SBE) Into Bio Organic Fertilizer And Their Effects On Crop Biomass Growth. *Industrial Crops And Products*, *49*, 775-781.

[167] Hwang, J. Z. H., Andiappan, V., & Ng, D. K. S. (2022, October). Promoting Circular Economy Between Palm Oil Sector With Multiple Industries. In *IOP Conference Series: Materials Science And Engineering* (Vol. 1257, No. 1, P. 012005). IOP Publishing.

CHAPTER VII CONCLUSION AND RECOMMENDATION

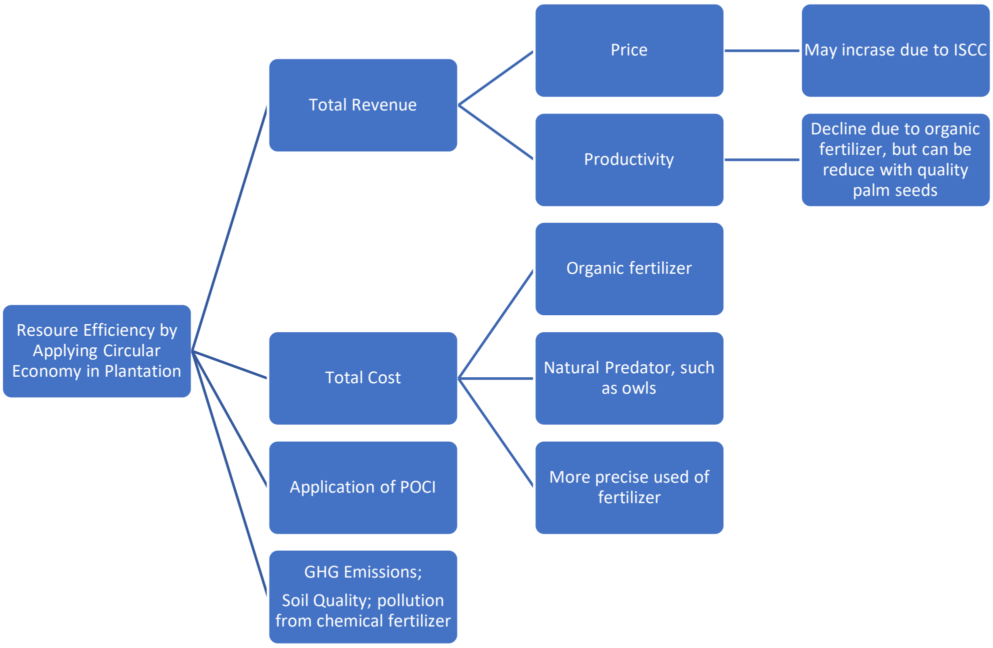
This study focuses on circular economy (CE) practices for resource efficiency in the palm oil sector, covering the plantation, milling, and refinery. Following UNIDO's framework, CE practices in the context of RECP are concentrated on materials, energy, water, waste, and emissions. The implementation of CE can be observed through seven paths, namely: (i) a change in mind set from resource use from linear design to circular; (ii) improve resource governance by applying a life cycle approach to minimize environmental impact; (iii) create a closed loop supply chain to allow materials to be used repeatedly; (iv) using renewable and sustainable resources; (v) utilize digital technology platforms to increase the level of precision of intervention and efficient use of resources; (vi) encourage collaboration and cooperation to build an increasingly efficient supply chain; and (vii) consistently conduct evaluations to achieve best performance.

The palm oil plantations, both smallholders and corporate plantations, have implemented resource efficiency through various CE practices. Farmers and companies have implemented circular economies to varying degrees. The condition of resources and capabilities affects the depth of CE implementation. The space for CE applications is still wide open and improving performance to achieve best practices still needs to be encouraged.

The informants said that they practice circularity in the materials with the mindset to create zero waste by utilizing all parts of the palm oil trees. The trunk, leaves, and empty fruit bunches are used as fertilizer within the plantation area. The level of CE loop in the material efficiency includes Refuse, Rethink, Reduce, Reuse, Remanufacture, Repurpose, Recycle, and Recover. A significant difference between smallholder and corporate plantations in material efficiency is that corporate plantations use sensor leaf-based fertilizing (foliar analysis). This technology significantly improves the effectiveness and efficiency of fertilizer use. To reduce the use of energy (oil fuel), instead of using oil-generated machines, some smallholder plantations apply conventional methods by sickle to control weeds in the plantation areas. Corporate palm oil plantations also use digitalization system to monitor the energy use in the plantation areas. Water use is optimized by utilizing rivers or wells altogether (Rethink) and reuse the wastewater (Reuse and Repurpose). The wastewater is also beneficial for maintaining soil fertility and decreasing chemical fertilizer. Relating to the emission, they have decreased the need for chemical fertilizers and then substituted them with organic fertilizers from biomass waste, livestock manure, and POME (Rethink).

By practicing CE in materials, the use of chemical fertilizers can be reduced by approximately 58.7% - 64.9% for smallholder plantations and 34.4% - 86.7% for corporate plantations. Practicing CE through materials and energy efficiency has also generated positive impacts on carbon emission reduction. The smallholder plantations could reduce the amount of carbon emissions by 19.2% (decreased from 2.17 to 1.75 tons of CO 2-eq per ha/year) after practicing CE in the cultivation process. In an extreme case where the chemical fertilizers are entirely replaced by POME, it is expected that the carbon emission decreases from 1.85

to 0.65 tons of CO 2-eq per ha / year, equaling 65% reduction in the carbon emission. Meanwhile, corporate plantations could reduce carbon emissions by 96.4% (decreased from 0.99 to 0.035 tons of CO 2-eq per ha/year). Furthermore, the key persons mentioned that by adopting CE practice, the company can apply for ISCC (International Sustainable & Carbon Certification). This can help the company to demonstrate the sustainability of their CPO product and allow it command a higher market price. In conclusion, the results of the analysis show that in the short term, the benefits increase through the application of a CE, and better environmental conditions, especially carbon and soil emissions. However, productivity was found to fall. This can be overcome by using superior palm seeds. Increases in revenue from ISCC certification could be used towards superior palm seedlings to improve productivity. A simple CE practice in the plantation value chain is illustrated as follows:



Resoure Efficiency by Applying Circular Economy in Plantation

The palm oil millings have also intensively practiced CE for the purpose of resource efficiency. CE applications in palm oil mills are closely related to the quality of the FFB to be processed. Palm fruit with a high yield rate is very important and the company ensures that the fruit to be further processed goes through a rigorous selection process, especially for FFB purchased from the community. This shows that in circular economic practice, the upstream and downstream sides are interdependent. For example, waste from PKS has been used as fertilizer in palm oil plantations. At the palm oil mill level, minimizing losses in the CPO and PKO processes is the main goal.

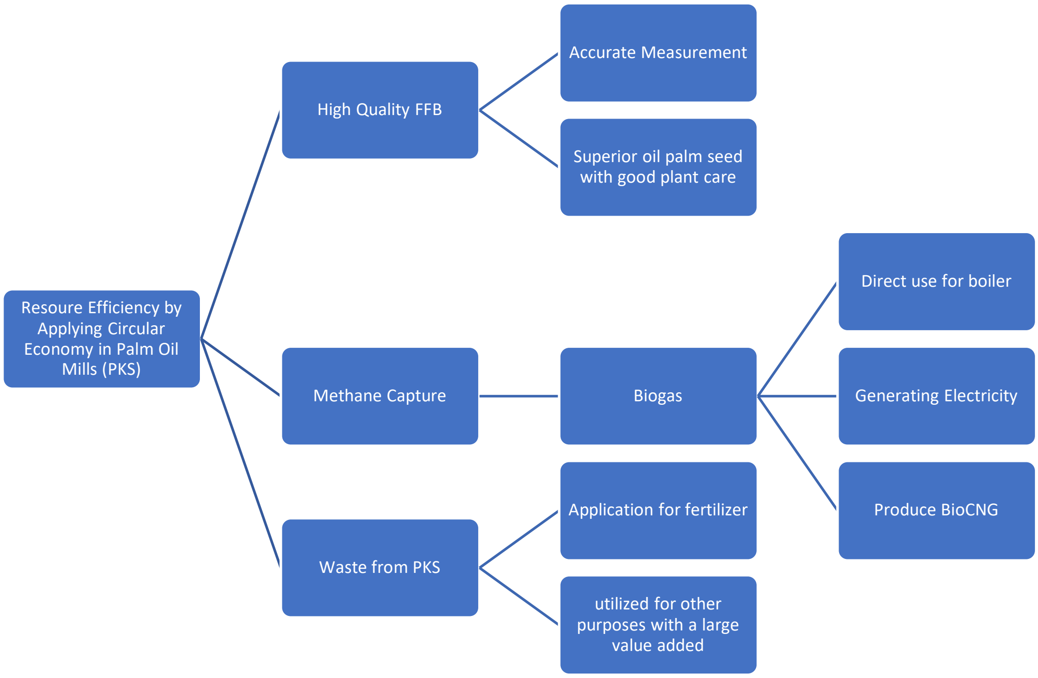
For the materials, they avoid the use of chemical substances in the process of separating the palm kernel and shell (Refuse). Many millings company adopt hydro cyclone technology for this purpose. Considering there some disadvantages of using this technology (need huge investment cost, wasteful of water, and high losses), some milling companies replace the hydro cyclone technology with clay bath technology. Another circularity practice in material use is Rethink, which controls the quality of FFB that goes to the milling processing. This is required to obtain FFB with a high yield rate. The milling companies also apply Repair principle to maintain the lifetime of machine components according to their technical age through certain techniques and maintenance. Another circularity practice in the material use is Recover principle by minimizing oil loss during the process.

For energy use, milling companies generally carry out circularity in the form of reduce the use of non-renewable energy such as solar in generating boilers (Reduce). In the current practice, the comparison of energy use for boilers is 90% renewable energy resources (shell and fibre) and 10% solar. Solar is only used at the initial stage to make steam within about one hour operation. PT PTN V has used methane gas or biogas to replace shell and fiber. Some big milling companies have been practicing CE to produce energy including electricity, through the methane capture process. It can save about 80% of fuel. For water optimization, the millings try to maintain normal standards of water use in the milling process to produce CPO, which is 1ton FFB will need 1 M^3 of water. It is a common practice in milling to create zero waste during CPO production. All wastes of palm oil products in the milling companies can be reused or recycled for their own use or sold to other firms or palm oil farmers.

The circularity process for waste in the milling company includes Repurpose principle by processing liquid waste into fertilizers and solid waste to be used back as fertilizer in the palm oil plantation. Solid waste from empty bunch, palm oil shell, and fibre are used to fuel the boilers. Energy saving technology in milling has contributed to significantly reducing the carbon emission. Another circularity of Reduce principle in milling companies is also implemented in the transportation, where some trucks to pick up the FFB from the plantation areas are fuelled by biodiesel. To quickly and precisely detect the problem of CPO production processes, many milling companies have applied digitalization or semi-digitalization to integrate, control, and enhance the efficiency of the production processes. This technology is connected to an Android-based cell phone.

The milling companies practicing CE are able to reduce carbon emission approximately 2.31% (decreased from 0.165 to 0.161 tons of CO 2-eq per ton of FFB/year). The waste from CPO processing, fiber and shell, may replace approximately 90 percent of the solar function in operating the boiler; the remaining 10 percent still requires oil fuel to make steam in the first hour after the boiler begins functioning.

Activities at the PKS level are already highly mechanized and dependent on technology. Therefore, technology that can detect loss is very important. One company mentioned the importance of the FOSS NIR DA1650 analyzer for detecting oil loss. With real time information, the problem can be immediately resolved. Thus, the application of CE in the palm oil mill value chain can be built in a simple way in two ways. First, it minimizes the loss of oil produced in each stage. Secondly, optimizing the waste of both methane gas for energy sources and others for organic fertilizer sources. Both strategies can improve resource efficiency.



Resoure Efficiency by Applying Circular Economy in Palm Oil Mills (PKS)

Palm oil refineries have practiced many different forms of CE. They generate solid waste in the form of Spent Bleaching Earth (SBE), which contains 20% – 40% oil. SBE contains chemical compounds, namely SiO2 reaching 83.05 percent. While SiO2 or silica dust could be harmful to the surrounding environment, SiO2 can be used as a mixture of Portland cement. The remaining oil in SBE can also be recovered for industrial applications (for example, as feedstock for oil refinery biofuels, lubricants, oleochemicals, animal feed, and fertilizers). The recovered oil can also be processed into methyl ester (biodiesel). Other use for SBE waste is organic fertilizers. Most waste and carbon emissions can be cut through the recycling process that is the result of SBE waste treatment through oil recovery into biodiesel. The CE practices in energy use, such as hot steam, can reduce costs by 39.3% and the use of electricity can reduce costs by 13.5%.

It is evident that CE practices have positively impacted resource efficiency of the smallholder palm oil plantations. However, many of them are still facing various major challenges to further improve their resource efficiency through CE practices. These include: (a) price of chemical fertilizers and pesticides continuing to rise; (b) fertilizers scarcity; (c) have limited access to POME from milling companies; (d) lack of support from government to procure high quality palm oil seeds; (e) lack of training and socialization from the government to improve farmers capability in practicing CE for resource efficiency. In addition to these challenges, many smallholders palm oil plantations are also facing fundamental problems especially related to unclear status of land ownership, difficulty to obtain ISPO certification, long duration of fruitless season, and lack of financial support to palm oil replanting. Unlike smallholder palm oil plantations, the corporate plantations have no serious issues with the availability and price of chemical fertilizers and high-quality palm oil seeds. In addition, they can also easily access organic fertilizer (POME) from their integrated milling company.

For the milling companies, the major challenges and barriers to promoting a CE in the industry include: (a) insufficient FFB during fruitless season; (b) lack of capital to afford the cutting-edge technology for CPO processing and waste management; (c) lack of support from the government, especially in term of tax incentives. Considering the abovementioned condition of CE practices by palm oil plantations, millings, and refinery, their level of CE loop in the resource efficiency and the challenges they are facing, we propose recommendation as follow:

Policy Recommendation Based on Value Chain

Value Chain	Recommendations	Stakeholders
Plantation	1. Provide access to high quality/superior palm oil seed, if necessary, the government can provide subsidy. 2. Access to the fertilizer use technology to make it more precise (such as FOSS NIR DA2500), encouraging the use this technology more intensive especially for small farmer or cooperative. 3. Aid farmers to obtain Indonesia Sustainable Palm Oil (ISPO) with subsidies or incentives. 4. Encourage the application of Palm Oil Cattle Integration (POCI) in palm oil plantation, if necessary, government can provide incentives and facilitations 5. Provide trainings and counseling related to environmentally friendly cultivation techniques and CE applications to farmers. 6. Provide trainings and counseling and mentoring related to CE applications to farmers, such as the utilization of palm oil's waste in plantations: stick to be broom stick, leaf, trunk, frond, and empty fruit bunches to be organic fertilizer, etc	Ministry of Agriculture, Ministry of Environment and Forestry, Oil Palm Plantation Fund Management Agency, Ministry of Small and Medium Enterprises and Cooperatives, Palm Oil Grower Association, Research and Development Agencies Palm Oil Business Associations Palm Oil Farmers Cooperatives
Palm Oil Mills	1. Develop technology capable of detecting loss levels in oil processing at every stage of the production process 2. Develop technology that has a high level of precision in assessing FFB yield levels. 3. Develop methane capture technology to produce biogas. 4. Promote applying waste in PKS to substitute chemical fertilizers.	Ministry of Environment and Forestry, BRIN, Ministry of Industry, Ministry of Education, Research, and Technology, Oil Palm Plantation Fund Management Agency, Ministry of Energy and Mineral Resources

		Palm Oil Business Associations
Refinery	The direction of resource utilization will be closely related to utilizing waste both as an energy source and to produce other products. SBE has great potential for further utilization, but it is necessary to ensure that the waste that will be produced will not be harmful.	Ministry of Environment and Forestry, BRIN, Ministry of Industry, Ministry of Education, Research, and Technology, Ministry of Industry, Ministry of Trade, Oil Palm Plantation Fund Management Agency, Ministry of Energy and Mineral Resources Palm Oil Business Associations

Policy Recommendation Based on Cluster Based

List of Recommendations	Main Stakeholders
Cluster of governance	
a. **The availability of palm oil plantation materials needs to be consistently maintained, especially high-quality seeds, fertilizers, and pesticides.** b. **The distribution of chemical fertilizers, especially the subsidized fertilizers for smallholder farmers, has to be monitored continuously and strictly to ensure the availability of fertilizers in the palm oil-producing areas.** c. **Provide rewards and incentives in various forms (such as tax discounts) for smallholder and corporate palm oil plantations with high compliance in the environmental aspect, including those who have already obtained certifications such as Indonesia Sustainable Palm Oil (ISPO) certification and PROPER.** d. **Develop the guidebook CE implementations related utilizations of palm oil's waste for smallholder palm oil farmers, including strategies, methods, action plans, etc**	Ministry of Agriculture Ministry of State-Owned Enterprises (cq: state-owned fertilizers producers) Indonesian National Police Indonesian National Army Provincial and District governments Palm Oil Business Associations Palm Oil Farmers Cooperatives

e. **Provide the guidebook of POCI model development including strategies, methods, and action plans.**	
Cluster of people and CE awareness	
a. Offer regular CE training for smallholder palm oil farmers.	Ministry of Agriculture BRIN, Ministry of Education, Research, and Technology
b. Promote the utilization of palm oil waste to economically produce high value-added and creative products.	Ministry of SMEs and Cooperative
c. **Increasing the capacity of human resources especially for increasing the efficiency and effectivity of fertilizing process and handling B3 waste treatment.**	Ministry of Agriculture Palm Oil Business Associations Palm Oil Farmers Cooperatives
Cluster of R&D and innovation	
a. Promote intensive R&D to produce high quality palm oil seeds, especially to fulfill the needs of smallholder farmers. b. **Promote intensive R&D to develop waste utilization technology especially for processing B3 waste to recycled and reused materials.** c. Promote close collaboration between industry, academia, and research institutions in developing more advanced CE application models and techniques. d. **Develop innovative palm oil yield detection tools. This tool is important as one of the instruments to create a more transparent determination of the selling price of Fresh Fruit Bunches (FFB).**	BRIN, Ministry of Industry, Ministry of Education, Research, and Technology Ministry of Finance (cq: BPDPKS Sawit) Palm Oil Business Associations Palm Oil Farmers Cooperatives
Cluster of Environment	
a. The irrigation water system and its quality need to be monitored regularly. b. Promote the use of renewable energy such as bioenergy, solar panel, wind power, and hydro power to generate electricity for various purposes in the palm oil plantations. c. Promote the use of innovative technology to monitor and prevent deforestation from plantations. d. Monitor the appropriate treatment or final disposal of hazardous wastes, including SBE with high oil content.	Ministry of Agriculture Ministry of Public Works Provincial and District governments Ministry of Energy and Mineral Resources Ministry of Agriculture Provincial and District governments Palm Oil Business Associations Palm Oil Farmers Cooperatives

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