Policy in Emerging Markets

Project on Circular Economy

Establishing a Circular Economy for Palm Oil Fiber

Case of the Indonesian Palm Oil Sector

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Abstract

This study aims to recommend policymakers on the establishment of a circular economy in the Indonesian palm oil industry, more specifically for palm oil fiber waste. Despite the industry's crucial role in the country's economy, concerns over deforestation and sustainability have led to regulatory interventions, posing a dilemma for policymakers. The research proposes an alternative approach, leveraging circular economy principles and the Multi-Level Perspective framework, to transform palm oil waste, particularly fiber waste, into value-adding circular products. The study explores the potential of circularity in the Indonesian context, providing policymakers with insights, recommendations, and a scanning tool for data collection. The implications extend beyond the sector itself, with the transition to circular practices potentially fostering economic development and advancing overall socio-economic well-being in Indonesia.

Keywords: Circular economy, Waste-to-value, Palm oil sector, Palm oil fiber, MLP framework, Indonesia

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List of Abbreviations

BMC: Business Model Canvas

CPO: Crude Palm Oil

EFB: Empty Fruit Bunch

EIA: Environmental Impact Assessment

FFB: Fresh Fruit Bunch

GAPKI: Gabungan Pengusaha Kelapa Sawit Indonesia/ The Indonesian Palm Oil Association

IFC: International Finance Corporation

NES: Nucleus Estate Smallholders

MNE: Multinational Enterprise

OPEFB: Oil Palm Empty Bunch

OPF: Oil Palm Fronds

OPKS: Oil Palm Kernel Shell

OPT: Oil Palm Trunk

PKO: Palm Kernel Oil

POF: Palm Oil Fiber

POME: Palm Oil Mill Effluent

PRC: People's Representative Council

PV: Photovoltaic

UNDP: United Nations Development Program

RCCC: Research Center for Climate Change Indonesia

RSPO: Roundtable on Sustainable Palm Oil

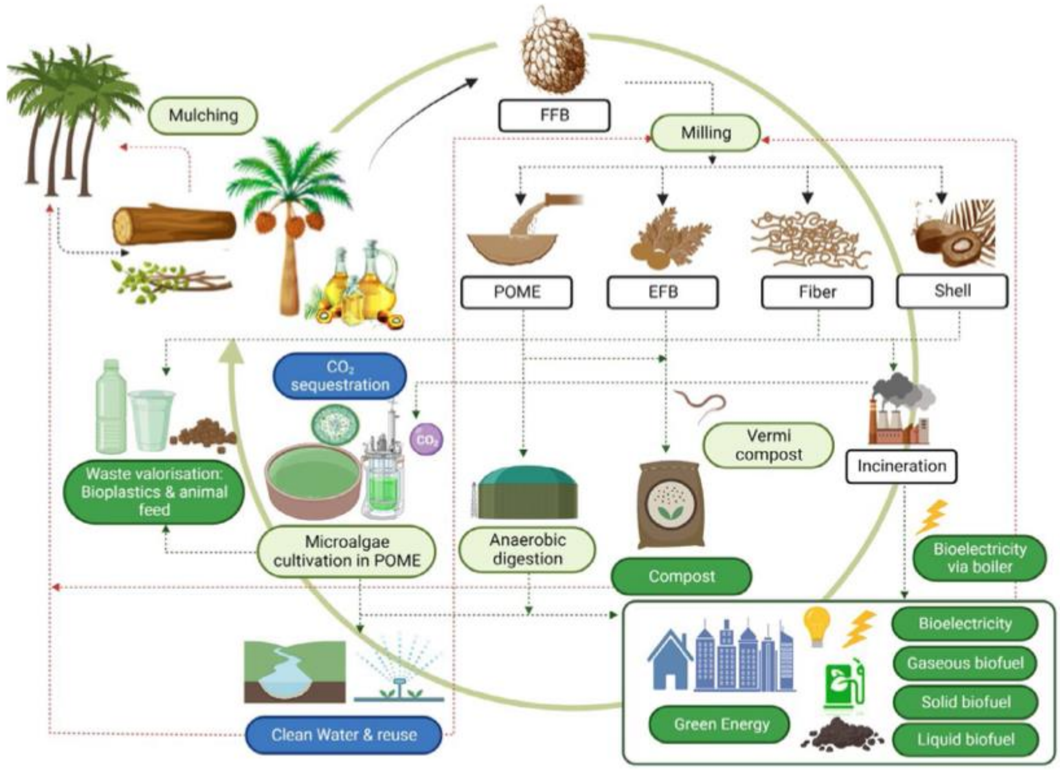
1. Introduction

Palm oil has the highest production and consumption share among all alimentary oils worldwide in front of soybean, rapeseed, sunflower and other oils. Almost 60% of global palm oil production is located in Indonesia (Ritchie, 2021). The industry is of high economic importance to the country as it accounts for 3.5% of GDP (GAPKI, 2022). In addition to that, oil palm plantations have played a crucial role in the country’s poverty reduction programs and lifted millions of Indonesians out of poverty since the 1950s. The sector provides jobs for 12 million people and contributes to the livelihood of 21 million citizens (ISPO, n.d.). Despite its higher productivity than most other edible oils, palm oil has gained a negative reputation due to its linkage to deforestation practices, land degradation, and the displacement of local communities and wildlife (Wicke et al., 2011). In recent years, palm oil imports have been regulated by the European Union due to its association with deforestation (Reuters, 2023) and dealignment with a number of Sustainable Development Goals such as SDG 15 (Life on Land) and SDG 12 (Responsible Consumption and Production) (United Nations, 2015). The question arises whether regulations are the right solution as many Indonesian citizens and smallholders are reliant on palm oil to make a living. Such regulations could therefore offset progress in other Sustainable Development Goals such as SDG 1 (No Poverty) and SDG 2 (Zero hunger). An alternative way to make palm oil more sustainable could be to maximize the utilization of palm oil waste generated in the production process. This waste could be used to create circular products which are in line with the Sustainable Development Goals.

Circularity is defined as the process of sharing, leasing, reusing, repairing, refurbishing and recycling existing materials to extend their (economic) life cycle (European Parliament, 2023). Previous research on circularity in the palm oil industry shows that Indonesia's neighboring country Malaysia has already established circularity in the palm oil industry to some extent (Cheah et al., 2023). Figure 1 illustrates this process of circularity, including examples of value-adding products made of palm oil waste. At this stage, Indonesia is mainly using the palm oil waste as a heating source or waste-to-energy source in the form of biofuel, on which the existing studies, like those from Mukherjee & Sovacool (2014) and Obidzinski et al. (2012) have been primarily focused. However, these forms of reusing the waste are less circular since they simply entail the incineration of palm oil waste. Fiber by-products on the other hand, could extend the (economic) life cycle of the palm oil waste for a longer period of time, which is of relevance to the Indonesian economy and policymakers as a result. This leads to the following research question: How to establish circular economy for palm oil fiber in the Indonesian palm oil industry? The scope of this research is on fiber by-products since these extend the (economic) life cycle of the palm oil waste for a longer period of time. The main frameworks which have been used are the circular economy principles and the Multi-Level Perspective (MLP) framework of Geels (2002). The key findings from this research include the favorable traits of palm oil fiber for repurposing in construction and composites, leveraging niche technologies to boost sustainability. The Indonesian palm oil industry tackles energy challenges, exploring biogas, solar PV, and geothermal options. The complex legal framework involves national policies, ministries, local governance, and village-level participation, encountering transparency issues. These findings have been transformed into a series of recommendations. A decentralized agency integrated with ISPO is proposed, ensuring top-down and bottom-up policy integration. ISPO should expand its role in the industry, helping palm oil mills in certifications, enforcing circular waste management standards. The government should provide the necessary infrastructure and establish collection centers as well as an online platform for palm oil fiber. On top of that, financial incentives such as subsidies for solar power or mechanical extraction technologies are recommended. Moreover, ISPO should pilot grants for circular product development. Education initiatives, like partnering with research institutes and monthly seminars by GAPKI, are also recommended to foster a sustainable future. Finally, a policy guide has been created to help policymakers in collecting data on palm oil producers and adopt efficient and targeted policies to stimulate circularity in the palm oil sector.

The second section of this paper (after this introduction) gives a literature review on the theoretical conceptual frameworks which have been used throughout the research. Section 3 introduces the case study which has been used as a research method and section 4 elaborates on this case study. This particular section assesses the current value chain, technological niche, stakeholders, and regulations which are of great importance when evaluating the possibilities of circularity regarding Indonesian palm oil fiber waste. Finally, the results are translated into policy recommendations in the 6th and final section of this paper.

Figure 1 - *Circularity practices in the palm oil industry*



Note: From Circular bioeconomy in the Malaysian palm oil industry: Current practices and future perspectives by (Cheat et al., 2023)

2. Theoretical Conceptual Framework

2.1 Circular Economy Framework

The narrative of the consumption over the century has shifted in a way that quality got associated with newness instead of being associated with long-term usage and resourcefulness (Stahel, 2016). Today's industrial economy is dominated by the linear economy, with a shift towards performance-based approach in some sectors. Linear economy is described by the model of take-make-use-dispose with the aim of obtaining revenue.

The main difference between the linear economy and the circular economy is that the prior doesn't consider how material has been, and further can be utilized, because it addresses raw materials from a one-use perspective (Marino & Pariso, 2016). The latter aims at turning goods at the end of their life cycle into resources for others, closing industrial ecosystem loops and thus minimizing waste (Stahel, 2016). The third type is the performance economy, which is selling the goods as services (Stahel, 2008). The trajectory of this paper is focused on turning linear economic practices into circular ones. Walter R. Stahel (2016) describes that capitalism, the driving force of linear economy, fosters this mindset that quality is associated with newness instead of long-term use and resourcefulness. However, circular economy aims to expand that product's lifecycle while also maximizing the value of the products at every point of its life. The motto of this new approach is "reuse what you can, recycle what cannot be reused, repair what is broken, remanufacture what cannot be repaired" (Stahel, 2016). It is important to shed light and emphasize the importance of circular economy in economic development in the sense of the capability approach (Szirmai, 2015), because its value creation is not captured in the measures of GDP. GDP measures the financial flow over a period of time (Sverko Grdic et al., 2020), however the value generated by circularity is not necessarily captured as an artifact of financial flow in its entirety, often new jobs and systems are created for preservation of the physical stock. A generally broader approach towards development and wellbeing has led to overall concerns both in the academia and the business environment over resource, security, ethics, safety, and greenhouse-gas reductions leading towards a more conscious consumer behavior valuing preservation and waste minimization (Stahel, 2018). These view shifts amplified the number of studies examining the positive effects of circular economy. A study done with seven European countries has found that a shift to circular economic practices would reduce each nation's greenhouse-gas emission up to 70% (Stahel, 2016). We are using the definition of circular economy by Piero Morseletto (2020) stating that it's an economic model for efficient resource usage through waste minimization, long-term value creation and reduction of primary resources by closing the loops of material, product parts and products to enhance environmental protection and socioeconomic benefits for the society. It creates positive development cycles that help preserve natural resources, enrich natural capital, optimize the yield, and manage the finite stocks of resources thus reducing system risk (Ari & Yikmaz, 2019). Therefore, leading to sustainable development and economic growth without the negative consequences (Goddin, 2020).

The circular economy as a business framework on a macro level, can be separated into three higher level groups based on product usage which can be further divided into ten actionable strategies (Figure 2). One feasible approach is to create a smarter use of the product or manufacture a new product out of the old one, this is referred to as refuse, rethink and reduce. Another possible approach is to extend the lifespan or the product itself or part of it, this includes reusing, repairing, refurbishing, remanufacturing, and repurposing it. The last resort in terms of the attempt for circularity is the useful application of the materials of the products by recycling or recovery, which is incineration. Most of the existing targets and practices in the economy are aiming towards an increase of the last two practices, however these don't necessarily promote circularity, even though they are environmentally friendly solutions, because these practices destroy the products and thus are no longer part of the economy and do not create value for the society. It is possible however to connect the different circularity practices (Figure 2) first, by trying to refuse, rethink or reduce followed by the further expansion of the product lifespan (R3-R7 strategies). Only when that product has run its course, recycle, and start the process again, or incinerate it for energy production. (Morseletto, 2020; Potting et.al, 2017).

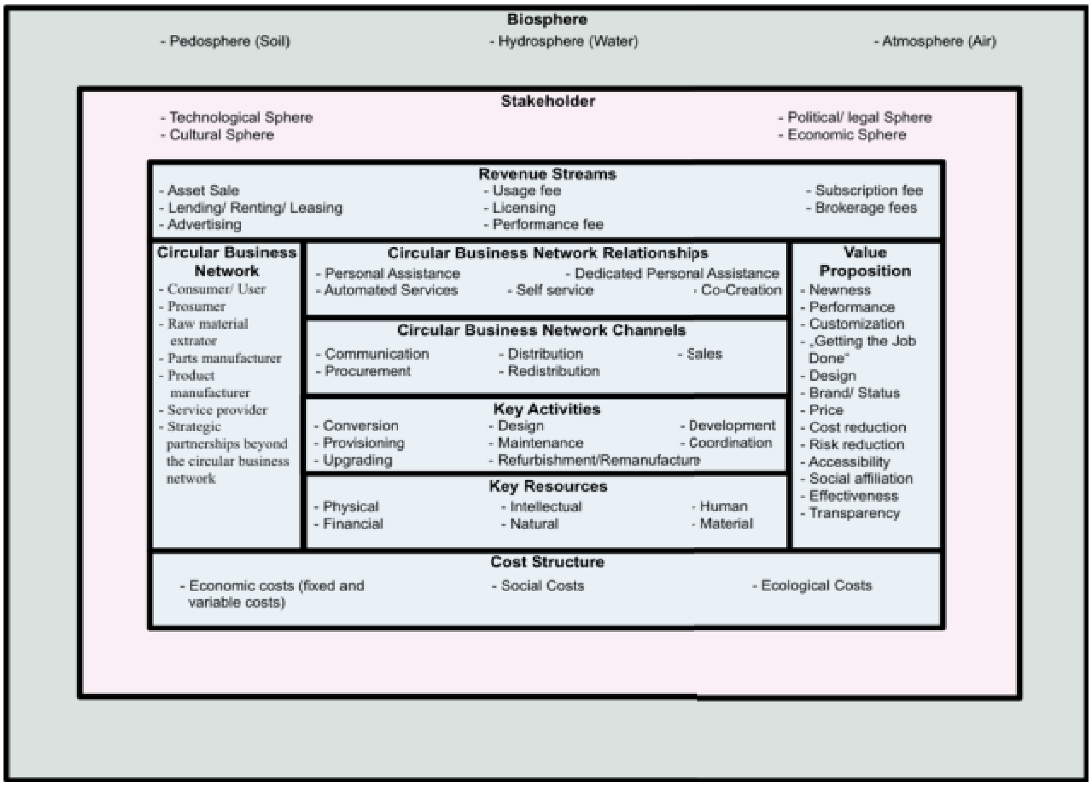
Figure 2 - *Circular framework strategies with correlating policy targets*

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. through sharing products or by putting multi-functional products on market).
	R2	**Reduce**	Increase efficiency in product manufacture or use by consuming fewer natural resources
Extend lifespan of product and its parts	**R3**	**Reuse**	Re-use 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 products or its part 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	**Recovery**	Incineration of material with energy recovery

Note: The first column is the categorization, the second ones shows the strategies and the third one sets the targets for policy recommendations. (Morsetto, 2020)

The Morseletto (2020) study also present policy targets for every strategy, because previous studies have shown that setting targets has a fundamental role in solidifying transitions to circular economy and can serve as a starting point for policy recommendations (Parris and Kates, 2003; Becker et al., 2013; Rotmans et al., 2001). This is the first study thus far that has looked at these targets in a systematic way. It suggests that governments should aim to extend the lifespan of products and increase both smart product use and manufacturing instead of only focussing on the recovery and recycle targets, because those are not the most circular practices. Policies supporting repairs, extended warranty products, design and system improvement for longevity, disassembly, spare part usage, modularization, creating inner remanufacturing circles and zero disposal should be made to promote repurposing, remanufacturing, refurbishing, repairing and reusing the products. Policies focusing on reduce, rethink and refuse elements should aim for increasing phase-out products, intensifying product usage and decreasing levels of production by promoting lightweight design, scrap and dissipative uses. The increase of these policies will automatically reduce the need for introducing new policies for recycling and waste management (Morseletto, 2020). It is important to mention that not all policies can be implemented at the same time and focusing on one will lead to trade-offs, however this slow transition from linear economy to a circular or more circular one can only be done through government level guidance. If we are looking at the micro and firm level, it is possible for the firms themselves to create circular business designs, through fostering innovation. The circular business model focuses on creating, offering, delivering value to their customers through converging their scarce resources in a sustainable, dematerializing way on top of profit and market share gains. Therefore, these firms are usually heavily involved in the product usage phase, offering used, refurbished, remanufactured modular products that have already gone through several usage cycles or they generate their revenues from the provision and optimization of the product service system instead of selling the physical product. Hofmann et. al. (2017) proposes the C3 Business Model Canvas (C3BMC)(Figure 3) as an ideal business design for operating an enterprise in a circular way. The C3 refers to integration of ecological, social and economic development into a circular use of the already existing BMC model. It means strong sustainable commitment, through preservation of biodiversity, natural resources regenerating capabilities, advocating for human development, and establishing more sustainable, better functioning social systems. The original BMC tool helps to create business models and show value creation by identifying value propositions, customer segments, customer channels, customer relationships, key activities, key resources, key partners, cost structure, and revenue streams (Joyce & Paquin, 2016; Upward & Jones, 2016). The expansion with the C3 component pushes the firms to think about ways to add value to their surrounding building block of the environment which are the circular economic operation, leading to economic development, the stakeholders helping the understanding of the social dimension and the biosphere which refers to the ecological aspects (Hofmann et. al., 2017). The circular economic operation is based on the following five elements: closing loops – creating multiple values – choosing appropriate business strategy (C3BMC) – designing an entity that can organize between parties (stakeholder dimension) – developing circular earning models (Patwa et al., 2021). Generating value on all three levels allows the firm to generate continuous growth and stay ahead of the continuously changing environment. (Hofmann et. al., 2017)

Figure 3 - *Circular (C3) Business Model Canvas for choosing firm strategy for operation and value creation*



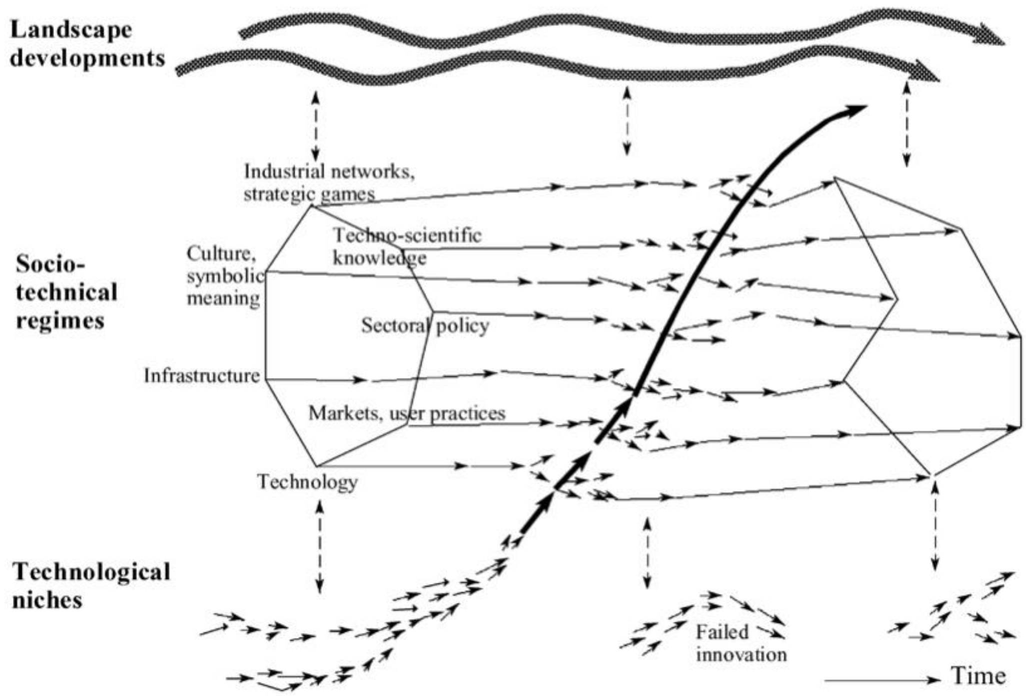
Source: (Hofmann et. al., 2017)

Empirical evidence suggests developing countries face increased challenges in terms of resource availability, varying government policies and consumer behavior compared to developed ones (Patwa et al., 2021; McMillan et. al., 2017). These countries require high economic growth, they usually have high or growing populations, must deal with enormous amounts of waste and the adding strains on their ecological environments by depleting their resources, to stay competitive in global markets and satisfy consumer needs (Patwa et al., 2021). Developed countries have been piling up their waste and dumping it in developing countries (Ferronato & Torretta, 2019), therefore, it has become clear that they cannot take the same approach as developed countries did throughout history. To overcome the listed issues one possibility for the developing countries is to take the circular economy approach, which is widely viewed to promote economic growth by generating new job opportunities, dampening price volatility, increasing the security of supplies, saving material juts while also minimizing environmental impacts and pressures (EMF, 2023). Emerging economies rely mostly on primary sectors of the industry however this approach would move them towards secondary sectors promoting to reuse part of products for remanufacturing to create new ones, instead of extracting material from the natural environment thus saving energy, reduces CO2 emissions and increasing the value added of the output (Paul et al., 2021). The circular economy also creates an opportunity to overcome the challenges of the disruption of the value chains – which stayed apparent after COVID-19 pandemic – because important products with sufficient technology can be substituted by end-of-life items (Paul et al., 2021). The study by Patwa et. al (2021) confirmed that what Morsetto (2020) stated on government policies stands true in the emerging economy perspective. Also, government policies highly influence the adoption of a circular economy, by fostering cooperation between industries through legislation or platform creation and by increasing mass awareness on the topic. Government policies also highly influence the adoption of extended lifecycle products, ecological protection, and balance through deforestation regulations. Overall, it can been clearly seen from the literature that many barriers exist in the process of implementing circularity and it requires some radical changes alongside with government intervention (Paul et al., 2021) The transformation process is slow and complex due to the required changes in both the production and consumption system, because companies need to change how they address creating offering and delivering value and also stakeholders need to change how they view quality and value creation (Joustra et al., 2013; Lacy & Rutqvist, 2015).

2.2 Multi-Level Perspective Framework

The academic work of Frank W. Geels (2002, 2004) emphasizes the importance of socio-technical systems in fostering innovation. Geels argues that instead of focusing merely on technical aspects, societal aspects from both the supply side as well as the demand side should be carefully considered when establishing or restructuring systems. Incorporating a societal approach is of high importance in the Indonesian palm oil sector, which involves a broad scale of stakeholders and interests. Geels also stressmentions the importance of rules and regulations when establishing socio-technical systems. Rules and regulations are not solely formed formally by government bodies, but are also constituted within social groups, companies, and within a culture as a whole. Changing a system means looking at all existing rules and rule systems and by acknowledging that only adapting government regulations might not immediately bring the desired results. The influential Multi-Level Perspective (MLP) framework from Geels provides a comprehensive outlook for all of these stances, with three distinct tiers: landscape developments (macro), socio-technical regimes (meso), and technological niches (micro). The micro-level fosters radical innovations, the meso-level focuses on actors to maintain stability and developmental paths in technology, and the macro-level forms the backdrop with slowly changing external factors. Even though this framework traditionally revolves around technological innovation, it adapts effectively to broader societal contexts, serving as a valuable tool to understand how radical innovations within sheltered niches can propel more extensive societal transformations. Figure 4 exhibits the MLP framework from Geels and demonstrates the 3 dimensions and their interconnectedness in the process of fostering innovative systems.

Figure 4 - *Multi-Level Perspective framework*



Source: (Geels, 2002)

The MLP framework can be an important aid in establishing circularity in the palm oil industry in Indonesia as it helps to conceptualize the different elements and actors. The technological niche dimension could assist in framing the usage of palm oil fiber waste as a source for circular products in Indonesian industries. The socio-technical regime dimension could be of value in clustering and mapping out the relevant stakeholders and regulations in the Indonesian palm oil sector. Furthermore, landscape developments could be investigated to get a comprehensive idea of the external factors influencing systems of palm oil fiber waste, such as the current value chain and practices.

In relation to circular economy, to make circularity mainstream, structural changes within the economic system and society are imperative (Geels, 2002). Recycling certain residual materials, for example, may be hindered by existing regulations, which are not tailored to circular products. Additionally, establishing fresh collaborations between companies from various sectors is not always a seamless process. Challenges related to regulations, cultural differences, and unfamiliarity often surface. Besides, investors might be reluctant in investing in circular business activities due to their unfamiliarity with the concept of circularity or concerns about profitability. To realize new forms of recycling, reuse, repair, and product-as-a-service, new collaborations are vital. However, these collaborations don't naturally evolve, and they may encounter challenges due to disparities in culture, language, and a lack of familiarity. This underscores the need for the government to recognize the importance of these new collaborations and actively support them, and is in line with the theories covered in Section 2.1. Key players and government authorities can initiate and try out these new collaborations, with the government providing specific arrangements to help initiators, permit-issuing bodies, and municipalities in launching innovative circular initiatives.

3. Case, data, and methodology

This research uses a case study method to get extensive insights in the potential of circular economy of palm oil fiber waste in the Indonesian palm oil industry[1]. Case studies are extensive studies of a single unit with the aim to be generalizable across a larger set of units. Case study methods are useful in exploring complex issues and gaining insights into real-world contexts (Gerring, 2004). Case studies are especially useful for policy-related research according to George & Bennett (2005) because they allow for a more nuanced understanding of a problem and can provide insights into broader phenomena around the topic. This case study focuses on circular economy for palm oil fiber waste, specifically focused on the Indonesian palm oil industry. The MLP framework of Geels (2002) has been used to structure the course of this case study in 3 dimensions: landscape development, technological niches, and socio-technical regimes. These MLP dimensions have been further divided into the following case study specific factors: the palm oil value chain, the qualities of palm oil fiber, the choice of three different industries, possible substitutions for biofuel, the regulatory frameworks, the Indonesian market and end user, and a stakeholder analysis. The data used for these subsections includes secondary data from academic papers about (circular economy) in the Indonesian palm oil industry.

[1] The initial aim was to adopt a qualitative research design, employing semi-structured interviews with palm oil companies. In these interviews, data would be collected on the current waste production, waste management, and the openness of these firms in selling their waste to Indonesian construction companies. The palm oil companies were selected by consulting institutional and industry related websites. Along to that, the network of one of the authors was used to find respondents. A total of 33 palm oil companies were contacted through email and a follow-up phone call, however, none of them replied or wanted to cooperate in this research. Additionally, the Indonesian Palm Oil Association (GAPKI) was contacted through email, but this did not result in an interview either. Due to time constraints and an unfortunate low response rate, the choice had been made to re-assess the design of this research and switch to a case study approach.

Additionally, a number of technical papers about fiber extraction have been incorporated as well as grey literature from governmental bodies and institutions like the United Nations Development Program (UNDP) and Indonesian Sustainable Palm Oil (ISPO). A multidisciplinary approach in terms of existing data collection. The intention of this case study is to provide Indonesian policymakers with an extensive view on the potential of palm oil fiber circularity in the Indonesian palm oil sector. The outcome could be to some extent generalizable to palm oil industries in other large palm oil producing countries like Thailand and Malaysia. This multi-country application is reflected in the policy guide which has been created as part of the recommendations and translated in the languages of the most notable palm oil producing countries. The function of this policy guide is to provide Indonesian policymakers with the necessary data in order to adopt efficient and targeted policies to stimulate circularity for palm oil fiber. Palm oil producers would be encouraged to fill in a questionnaire, after which the data would be collected and forwarded to the policy guide ready for assessment. The questionnaire employs a structured approach since concrete questions are imposed to the palm oil producers. The questions are centered around topics such as palm oil waste (management) and more practical topics such as localization, in order for policymakers to shape policies in a more targeted way.

4. Case Analysis Palm Oil Industry Indonesia

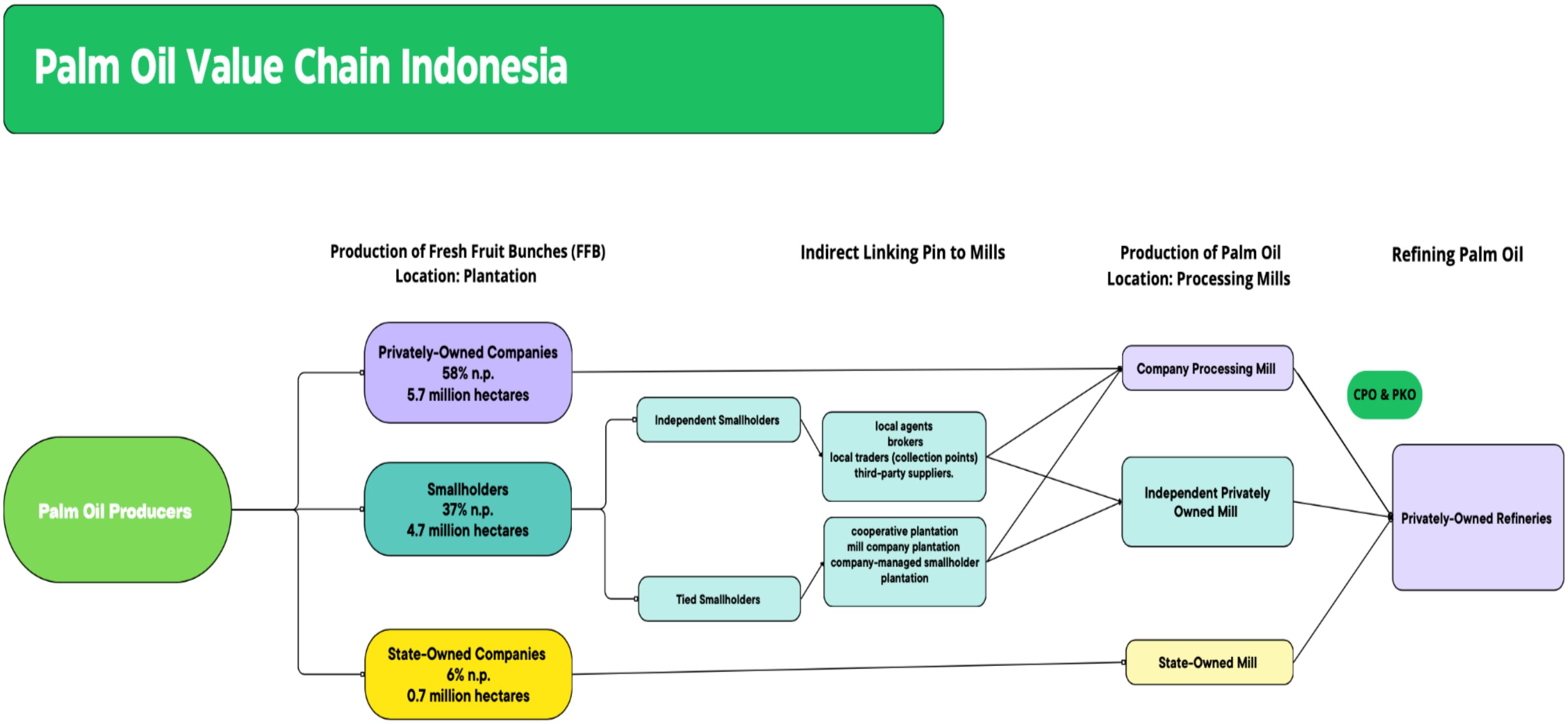
4.1 MLP Landscape : Palm Oil Value Chain in Indonesia

It is necessary to establish the palm oil value chain in Indonesia to give a representation of the social systems’ framework (Geels, 2004). Geels uses the term landscape to include the relative “hardness” and material aspect of society such as spatial arrangements of cities, factories, high-ways and electricity infrastructure, but also technical systems and belief systems (Geels, 2004). “Changes on the landscape level may put pressure on the regime and cause internal restructuring” (Geels, 2004). In the case of the palm oil industry in Indonesia, climate change and changing belief systems towards climate change is putting pressure on existing regimes to trigger the creation of more sustainable and circular policies.

However, It can be hard to deviate from certain existing landscapes as people adapt their lifestyles, and industrial supply chains emerge making it part of an entire economic system. Geels states that “landscapes are beyond the direct influence of actors, and cannot be changed at will (Geels, 2004).” Radical novelties might have a ‘mis-match’ with existing regimes and the feasibility of adaptation can be heavily constrained. Therefore, it is imperative to fully understand the current landscape as to ensure how novelties are to be implemented and accepted within the broad landscape and socio-technical regime.

The process of palm oil production starts with harvesting the oil palm's fresh fruit bunch (FFB) which happens every 10-15 days in a cycle on palm oil plantations (Cheah et al., 2023). The FFB contains all palm oil and is transported to palm oil milling factories and processed into both crude palm oil (CPO) and palm kernel oil (PKO). In a linear value system, the palm oil would be distributed to customers and the chain would stop here. However, several residue parts are collected during the process that can be used to create new value-added and circular products. These waste parts include the empty fruit bunch (EFB), palm oil mill effluent (POME), fiber, and shell (Cheah et al., 2023). The EFB is the part of the FFB which is leftover after stripping it. The EFB contains a high caloric value and carbon content and therefore it is perfectly suitable for energy generation and as a fertilizer. POME is the waste water of the palm oil production process. It is essential to have adequate waste water management systems to ensure the POME is not discharged in the sea or rivers but instead filtered and transformed into clean water which can be reused for irrigation. Mesocarp fiber and shell, which account for 18% of the FFB, is used for energy generation and animal feed, but can also make textiles, furniture, sustainable packaging and can even be used in construction as we will discuss in the next chapter (Cheah et al., 2023). Oil palm plantations and milling plants commonly use self-generated bioenergy as primary energy source to operate self-sufficiently. Due to the abundant availability of oil palm biomass, the required energy for production processes is generated from the combustion of oil palm biomass. However, the majority of biomass is not further used and abandoned on site (Cheah et al., 2023).

Figure 5 - *Current Palm Oil Value Chain of Indonesia*



Note: Self established using data of UNDP from 2020

As is illustrated in Figure 5, privately-owned companies, state-owned companies, and smallholders are the three actors involved in oil palm plantations in Indonesia. With more than 2.1 million smallholders in Indonesia in 2020, they manage almost 40% of Indonesia's palm oil plantations and occupy almost 4.7 million hectares. (UNDP, 2020). In the country, smallholders can be divided into two categories: independent smallholders and plasma or tied smallholders. Independent smallholders have their own system of financing, management and equipment and are not part of a particular mill. Plasma smallholders are farmers who operate under the Nucleus Estate Smallholders (NES) project. This project has been created by the government to create partnerships between large companies and smallholders (Ngadi, 2019). Smallholders are linked to a particular mill by a contract or credit agreement and receive management assistance from the mill managers and generally have easy access to cooperatives, government agencies and companies (Musim Mas Group, 2023). The FFB from both tied and independent smallholders is transported to independent mills and privately-owned mills, where the palm oil is extracted. State-owned plantations have a relatively small role as compared to large private-owned plantations. Yet they do have an important role in increasing state revenues from the palm oil sector, and by functioning as a technical, social, and economic role-model for others (UNDP, 2020).

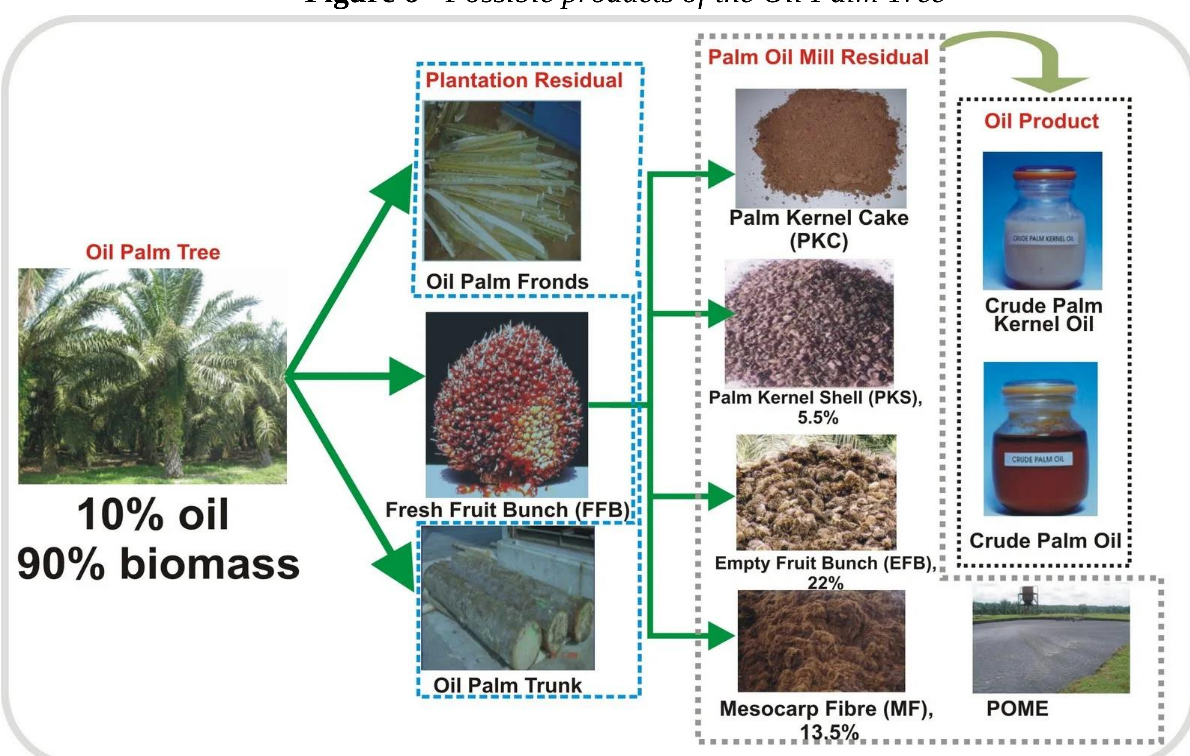
Privately-owned companies make up the larger share of palm oil producers. They often have their own inhouse mills and manage all palm oil plant waste within their own facilities (UNDP, 2020). The private sector is strategic, having large agricultural lands, high productivity, and collaboration with smallholders. After the crude palm oil is harvested from the FFB, the oil is often sold to other large privately-owned refineries and exporters that further refine the oil for different purposes and sectors (Pirard et.al., 2020). There is little vertical integration from upstream on the value chain (plantation and mill) to downstream (refinery and export), and companies are rarely owned by the same corporate entity. This means that sustainability commitments at the refinery and trader level often have a considerable impact on the behavior of upstream suppliers (Pirard et.al., 2020). A small number of large corporate groups control the refineries and export market and the five largest groups control around two-thirds of the of the total export volume (Pirard et.al., 2020).

The most important finding from the visualization of this value chain, is that only the mills manage the FFB waste. Therefore, when looking at the waste management of FFB, our research on establishing circularity in the palm oil industry does not apply to smallholders, but merely to independent mills, state-owned mills, and privately-owned palm producers with their own respective mills. Smallholders and all other palm oil plantations do produce other palm oil production wastes such as oil palm trunks and oil palm fronds, yet these types of waste do not contain mesocarp fiber and are therefore not further developed in this research (Cheah et al., 2023).

4.2 MLP Technological Niches

4.2.1 The Qualities of Palm Oil Fiber

Figure 6 - *Possible products of the Oil Palm Tree*



Source: (Zafar , 2022)

In the framework of Geels (2004), establishing circularity for palm oil fiber will be the innovative technological niche. As we have established at the previous section, the scope of our study is limited to the fiber extracted from the fresh fruit bunch (FFB), therefore this section will focus on the extraction process, the qualities, and characteristics of the fiber and why this study focuses on fiber waste out of all the waste generated during palm oil production. Research has found that the two fiber components originating from the fresh fruit bunch are mesocarp fiber and palm kernel shell, and together they make up for 18% of FFB (Hamzah et al., 2019; Yeo et al., 2020) (Figure 6) , which we will refer to in this section paper as the POF (Palm Oil Fiber). According to GAPKI, the Indonesian Palm Oil Association, palm oil production in 2022 has reached 51,8 million tons and the industry is continuously growing (GAPKI, 2022). The International Council of Clean Transportation's 2020 report has found that out of the complete palm oil production 0,8 ton per hectare fiber waste is produced, and at the same year the UNDP accounted for 4,7 million hectare of land for palm oil cultivation , which results in an overall 3,76 million ton of fiber waste in Indonesia. In recent years due to the increased social awareness of sustainable development, a growing number of studies has outlined the need for diversification and improved utilization of the increased number of by-products and waste produced in the palm oil industry across the world (Santosa, 2008).

Out of all the potential by-products from Figure 7 (OPEFB, OPF, OPT, OPKS, POME), the fiber extracted from OPEFB and OPKS has the highest potential for remanufacturing and repurposing, because it's fiber concentration is above 75% (Wirjosentono et al., 2004). The extraction of OPF happens through the retting process, which can be done in four ways: mechanical, chemical, vapor, and water retting. Mechanical retting refers to hammering which is done with machinery. The difference between chemical, water and vapor retting is that the first one refers to chemical treatment, the second soaking and the third steaming. The traditional way of separation is water retting and that is still currently the most commonly used method in Indonesia (Raju et al., 2008; Obuka et al., 2018). Shinoj et al. (2011) in their review paper about palm oil fiber establishes that mechanical extraction would be the most environmentally friendly approach, because that would eliminate polluted wastewater (POME). However, the transition requires capital investment, thus it should be incentivised by the authorities or the market itself. Research has found that the OPF by-products can be utilized in several different ways; as energy source, animal feed, paper production, fertilizer, concrete, polymer, composite, bioplastic just to mention a few (Santosa, 2008). A list of how the individual by-products of the palm oil production could be utilized can be seen in Figure 7. However currently the mesocarp fiber and the kernel shell is mostly used for generating electricity through incineration (Vijaya et al., 2008; Dewi et al., 2022), which we established at the circularity framework (Section 2.1.). Even though it's a sustainable practice, it is not the most circular, because it's not generating higher value added.

OPF has many positive characteristics, in addition to its abundant availability, which will be covered now. OPF is hard and has a porous surface morphology which makes it suitable for improving mechanical properties of materials used for repairs and to be used for mechanical interlocking for composite fabrication (Shinoj et al. 2011; Ismail, 2009). The fiber has low-density, high-energy absorption, low-velocity impact, it's non-abrasive and 100% biodegradable making composites more sustainable (Yaro et al., 2021; Faizi et al., 2016; Arya et al., 2015). OPF is considered a lignocellulosic material, for which the demand has been increasing over the years (Hariharan & Khalil, 2005). In this sense it's similar to other plant fiber like flax-sisal or coconut fiber both of which has been used in the automotive, machinery and the textile industry- Mercedes benz has been using these fiber to build a mat in their door panels and create their seatings, because they have great deformability, high strength and easy to recycle thus making contribution to the carbon budget easier (Shinoj et al. 2011). The OPF also shows potential usage for eco-friendly solid fuel, adsorbent for wastewater treatment and biofertilizer for plant growth (Liew et al., 2018).

The biggest body of research has been done over the utilization of palm oil fiber in the construction industry, because it can be used as a construction material for buildings, partition boards, ceilings, panels and in concrete. In terms of concrete it has better structural performance than crushed granite, it's more resilient towards humidity and high temperatures causing less deformation and due to its natural absorption capabilities it's able to absorb water (Shinoj et al. 2011; Ismail, 2009) These technologies are a very early stages of adoption therefore they can be characterized as technological niches, which are according to Geels (2004) potentials for innovations and therefore due to their novelty need to be kept as "protected spaces" to shield them from market selection for which he proposes government subsidies and strategic investment. It's especially crucial in an emerging economy context because these technological niches in general face "harnesses"' and path dependency. The latter makes it hard for both producers and users to deviate from existing practices and functioning systems while hardness refers to the resistance towards change, which is amplified by the need for stability in both economic and social context in emerging countries (Geels, 2004; Khanna et al., 2014). However if this technological niche gets established but can break through existing regimes creating a new innovative social technical system leading to landscape developments and opening the door for further circularity practices in Indonesia (Geels, 2004).

Figure 7 - *By-products of palm oil production*

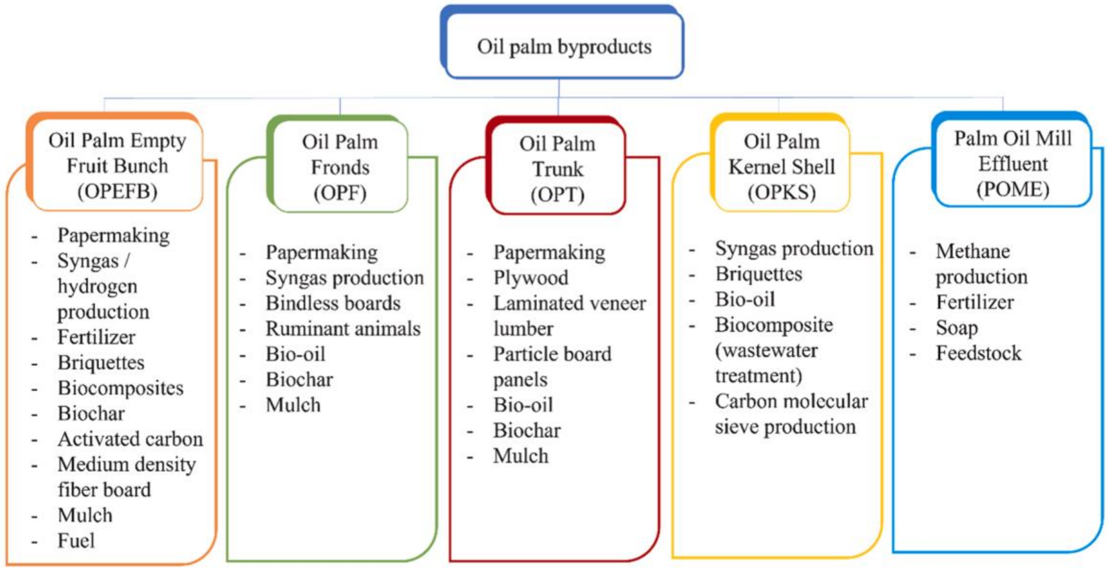


Fig. 4. Current applications of various oil palm by-products.
Source: Elbersen et al. (2005); Onoja et al. (2018).

Source: (Gan et al., 2023)

4.2.2 Alternative Energy Generation Solutions for Producers

Palm oil producers profit from the abundance of OPF biomass and utilize it, among other uses, to generate valuable energy for in-house production purposes. When a more circular approach is implemented, a substantial part of the OPF biomass will be utilized for other purposes, thereby diminishing the biomass available for generating thermal energy. This shows the necessity of an alternative source of energy for palm oil producers. A potential technological niche within the circular economy framework includes the treatment of the highly polluting waste-water POME. It is detrimental to the environment as it pollutes groundwater and releases methane gas into the atmosphere. However, the reutilization of POME offers great potential. The primary treatment for POME is based on anaerobic digestion[2]- a process in which liquid effluent is converted into biogas. This process is widely adopted in the industry to meet water quality standards for industrial effluent. However, the emerging biogas that could be used to generate power through gas turbines or gas-fired engines often remains unused and is flared off (Obuka et al., 2018). The unutilized potential of biogas can be attributed to the considerably high investment costs. The costs of setting up a standard biogas facility is projected to range from 800.000 € to 1.2 million € (based on the current exchange rate of 1€ to approximately 16,740 IDR) (Kaniapan et al., 2021). The relatively high initial investment translates into a competitive advantage for the largest palm oil producers and mills. Another valuable alternative is solar energy. Due to the abundance of sunlight, the country identifies solar PV—the most common and cost-efficient form of solar energy—as the primary energy source for its energy transition. By 2060, Indonesia aims to reach net-zero emissions, with solar PV expected to constitute the great majority (Hasjanah, 2022). For businesses

[2] Anaerobic digestion is a process in which bacteria breaks down organic matter (i.e. residual biomass from the production process of palm oil) in the absence of oxygen (EPA, 2023)

aiming to generate energy more sustainably, considering solar energy is a logical step. However, despite Indonesia's ambitious long-term goals, the country still falls behind internationally, with less than 1% of electricity generated through solar PV, and the prices for businesses are higher than in Europe, China, and India. To supply a regular Indonesian household with rooftop PV including a battery storage system, an initial capital of $2500-$3000 is required with an additional payment plan (Hasjanah, 2022). After 10-15 years the investment reaches net zero and starts paying off. For businesses, this number can be scaled up, but not linearly, because the cost per unit of solar PV decreases with larger purchases (Hasjanah, 2022). High initial costs currently pose an obstacle for palm oil producers and mills. The tropical climate also poses challenges for deploying solar PV in Indonesia in the form of tropical typhoons, cyclones, and sand and dust, which can cover the panels and reduce efficiency. Nevertheless, the future looks promising with technologies tailored for tropical conditions gradually being introduced into the market (Salaman et al., 2013). Moreover, the costs of employing solar technologies have plummeted globally in the last decade, including in Indonesia. The average cost for solar PV purchase agreements has fallen by around 78% between 2015 and 2022 in Indonesia and is forecasted to further decrease as the technology continues to advance (Hasjanah, 2022). Given the current challenges and the positive outlook for solar PV in Indonesia, especially in the long run, this technology has the potential to become a viable alternative for Indonesian palm oil producers and mills. Another unique alternative for Indonesia is geothermal energy. The country's geography, characterized by very active seismic activities and volcanoes, translates into the highest geothermal energy potential globally. However, identifying underground hot water reservoirs, which geothermal energy sourcing depends on, requires sophisticated exploration and expensive drilling processes. Those are hindered by Indonesia's infrastructure deficits in rural areas. While the country has vast predicted resources, the costs and uncertainties associated with geothermal energy deployment depict a key challenge and have prevented larger deployment of this energy source so far (Chipman Koty, 2022). The sophisticated technology required typically associates this energy source with large-scale projects, and the feasibility for individual businesses is therefore limited. However, the Indonesian government continues its R&D efforts on small-scale projects, and various efforts and pilot projects on smaller-scale geothermal projects have been reported in recent years (Richter et al., 2021). Depending on their location, palm oil producers and mills might be able to benefit from Indonesia's unique geographic conditions in the future.

In conclusion, biogas, solar PV, and geothermal energy represent viable sustainable energy alternatives for the Indonesian palm oil sector. As these technologies evolve, it is anticipated that the initial costs will decrease, making their adoption more practical. Solar PV, in particular, shows considerable promise for businesses.

4.2.3 Industries

Fibers have a wide range of uses, some of which are presented in the following part. Presenting them here gives an insight into how fibers are used in different Indonesian industries.

Firstly, they can be used to feed livestock, particularly ruminants. This practice is briefly analyzed here since it offers benefits. We do however consider this practice to be outside the scope of the circular, as it does not significantly extend the product life cycle (R9 of the circular framework). A presentation of fiber use in the paper industry is also proposed. In our view, this practice is more akin to recycling (R8 of the circular framework), but it does offer some interesting prospects. Using fibers to make bioplastics is part of a circular practice (R7 of the circular framework). However, according to our research, this approach is not yet sufficiently developed to offer products that meet consumer expectations and for large-scale production. On the other hand, the use of fibers in the manufacture of products for the construction sector is part of a circular system and allows fibers to be used in a way that increases the efficiency, quality and therefore longevity of the products to which they are added and could be implemented (R7 of the framework). As a result, we have presented this use in more detail.

Construction sector

A study analyzed the carbon emissions of the construction sector in 41 countries and concluded that it is not unreasonable to say that the construction sector is the biggest carbon emitter. In 2009, construction activities produced 5.7 billion tonnes of CO2 emissions, representing 23% of global emissions from economic activity. The same article mentions that emerging economies are responsible for 60% of C02 emissions (Huang et al., 2017). Indonesia ranks among the countries with the highest construction investment in Asia, leading the Southeast Asian countries by a wide margin. Construction investment has been driven by the rapid development of all sectors of the economy, as well as rising domestic demand for public services (Soemardi & Pribadi, 2012). According to a 2023 article, the nation's three biggest obstacles to adopting sustainable practices are a lack of knowledge, bad design choices, and budgetary limitations (Fitriani & Ajayi, 2023).

Several studies have shown that palm oil fibers, due to their properties, can be used in the manufacture of composite materials such as earth blocks and mortar. Products with added fibers offer thermal stability and conductivity, qualities that are in high demand in the construction sector. A study has shown that the use of natural plant fibers in cement composites reduces the weight by 10%, reduces the energy required for the production process by 80% and reduces the cost of the elements used by 5% compared to a glass fiber based concrete (Momoh & Osofero, 2020).

Moreover, the addition of fibers in the production of concrete also increases the sound absorption improving acoustical capacities. (Hussain et al., 2022). The fibers could also be used in the manufacture of concrete beams. This usage could greatly reduce the risk of transmitting diseases such as asbestosis, cancer, tumors and malignant pleural disease (Momoh & Osofero, 2020). Furthermore are significant financial costs, environmental impacts and excessive energy consumption associated with the production and use of synthetic fibers. Research has demonstrated the low cost and low energy consumption of natural fibers, as well as their favorable environmental properties, such as biodegradability, bio renewability, non-hazardous nature, zero carbon footprint and reduced pollutant emissions (Joshi et al., 2018). Nevertheless this technique still has room for improvement since fibers increase water absorption and could cause certain problems on technical properties (Gan, et al., 2023). From Table 7 we can see that EFB contains the highest amount of cellulose, which is a necessary component for better strength (Momoh & Osofero, 2020).

Bioplastic

Natural fibers and bioplastics are now being extensively studied in many products due to the long term decline in the use of petroleum and growing concerns about the use of synthetic plastics. Scientists and engineers are interested in fiber-polymer bioplastics because of their widespread availability, low carbon emissions and biodegradability (M.R.M et al., 2022). With remarkable thermal properties, insulation, strength, flexibility and electrical resistance, palm fibers can be used in the fabrication of those new types of plastics (Gan, et al., 2023). Nonetheless, certain properties of the products created still need improvement, such as resistance to mold and weathering, and require further research (Gan, et al., 2023).

The paper industry

Recent concerns about environmental issues, particularly deforestation, are driving the paper industry to find alternatives. OPT, OPF and OPEFB could be potential substitutes with excellent technical properties. With usage in almost all traditional paper applications, this solution could be a potential alternative to single-use paper (Indriati et al., 2020). Oil palm fiber has been used by the pulp and paper industry for the past decade as an alternative to expensive and scarce wood-based materials, as the resulting papers are of similar quality. On the other hand, because oil palm fiber contains less lignin than other natural fibers such as coconut or pineapple leaves, it has a thicker wall, shorter fiber length and less stiffness and toughness (Gan, et al., 2023. However, the main barrier to making this revolution a reality has been the cost of producing paper from OPB, as it would increase operating costs associated with updating and modifying current machinery and production lines. (Gan, et al., 2023).

Animal feeding sector

The oil palm fibers could be converted into pellets but lacks protein, which prevents it from being used to feed all types of animals . Studies have demonstrated the caloric values of palm oil fiber pellets but have also shown the poor digestibility of the products. Therefore, using these pellets to feed ruminants could be adapted and could reduce management and operating costs (Gan, et al., 2023). As arable land for animal feed becomes increasingly scarce, this alternative could be based on waste from palm oil production. This solution would be suitable especially for ruminants which need roughage (Santosa, 2008).

4.3 MLP Socio-Technical Regimes

Geels explains socio-technical regimes “as the linkages between elements necessary to fulfill societal functions”(2004). Integral to understanding such a system, is understanding the relationships and interlinkages between seller (palm oil producer and mills), buyer (the circular industries), government and social groups. These groups consist of human actors that share similar characteristics and roles and have distinct social rules. Therefore, it is crucial to establish the different groups and the different motives they share.

4.3.1 Indonesian Market

As previously mentioned, the reputation of palm oil has faced significant challenges, particularly in Europe, where it is frequently associated with deforestation and adverse impacts on biodiversity. However, these concerns did not affect global consumption figures, which reached a record high in the previous year (Statista, 2023). It is evident that the palm oil industry will continue to be a cornerstone of Indonesia's economy. Consequently, there will be a continuous flow of by-products and residues available for further processing in the relevant industries within Indonesia. This section aims to analyze the socio-technical regime of the domestic market, and its potential for the implementation of OPF fiber in these industries.

Construction Sector

The Indonesian construction industry has experienced substantial growth recently, driven by large scale infrastructure and projects and an overall emerging economy. Subsequently, fiber-reinforced concrete consumption in Indonesia is expected to rise robustly**,** thereby providing fertile ground for the introduction and implementation of fiber-reinforced concrete based on OPF waste (Mordor Intelligence, 2023). So far, the adoption of sustainable practices, which include the utilization of OPF reinforced concrete, remains very limited in Indonesia. The primary barriers to adoption are a lack of knowledge and awareness. The future shift towards greener practices in the sector is uncertain and appears to be a secondary consideration in Indonesia. However, the significant benefits of palm oil by-products, especially for concrete, cannot be overlooked. Increased recognition of this competitive edge could lead to broader industry adoption, even if environmental concerns are not the primary motivation. Budgetary constraints of businesses present another challenge. (Futami et al., 2021). Instead, we anticipate a gradual but steady growth. One way to catalyze this process could be in the form of direct investments from abroad. Although Indonesia has created a restrictive FDI policy environment in the last decades which impacts the construction sector, those restrictions are primarily dedicated to investments in low- and medium level technology and risk projects with limited value. Since 2017, the Indonesian government has been attempting to attract larger-scale projects with a minimum contract value of $3.8 million and associated with more sophisticated risks and technologies, by easing ownership regulations (Oxford Business Group, 2022). This shift presents a promising development for the implementation of OPF in the construction sector, although there hasn't been a significant change in the value of inbound FDI in the industry since then (Statista, 2023a).

Bioplastic Industry

Indonesia faces significant challenges with plastic pollution especially in marine environments. As reported by the Environment and Forestry Ministry, the country produced 68.5 million tons of waste in 2021, of which approximately 17% was plastic waste (Simangunsong, 2022). Since 2015, Indonesia has ranked as the second-largest contributor to marine plastic pollution globally, following China (The World Bank, 2021). In 2020, the Indonesian Government implemented taxes on single-use plastics, initially setting the rate at around USD 0.01 per bag, later increasing it to approximately USD 0.02 per bag (Kahfi, 2020).

These developments imply an increasing awareness in Indonesia regarding plastic solutions which gives rise to alternative solutions like OPF. Several small-scale companies started engaging in biodegradable plastic production but did not touch upon OPF yet. Despite relatively slow sales growth of these companies, the prospect of bio-based plastic in Indonesia is still promising and the niche industry is growing. Awareness deficits persist, but the direct negative impact of plastic pollution on the Indonesian communities has spurred more immediate action compared to the construction industry, as reflected in various educational awareness initiatives. (Global Business Guide Indonesia, 2017, CNS MEDIA, 2023).

Furthermore, GAPKI, a key stakeholder, has been explicitly advocating the potential of OPF based bioplastic in Indonesia. With substantial research advancements and market-ready technologies (GAPKI, 2023), the Indonesian government's support through a business-friendly environment and effective incentives, could facilitate the widespread diffusion of EFB fiber bioplastic. A first step is already taken as the government acknowledged that accelerated R&D activities to establish next generation biofuel and bioplastic capabilities should be emphasized (ADB, 2019).

Paper Packaging Industry

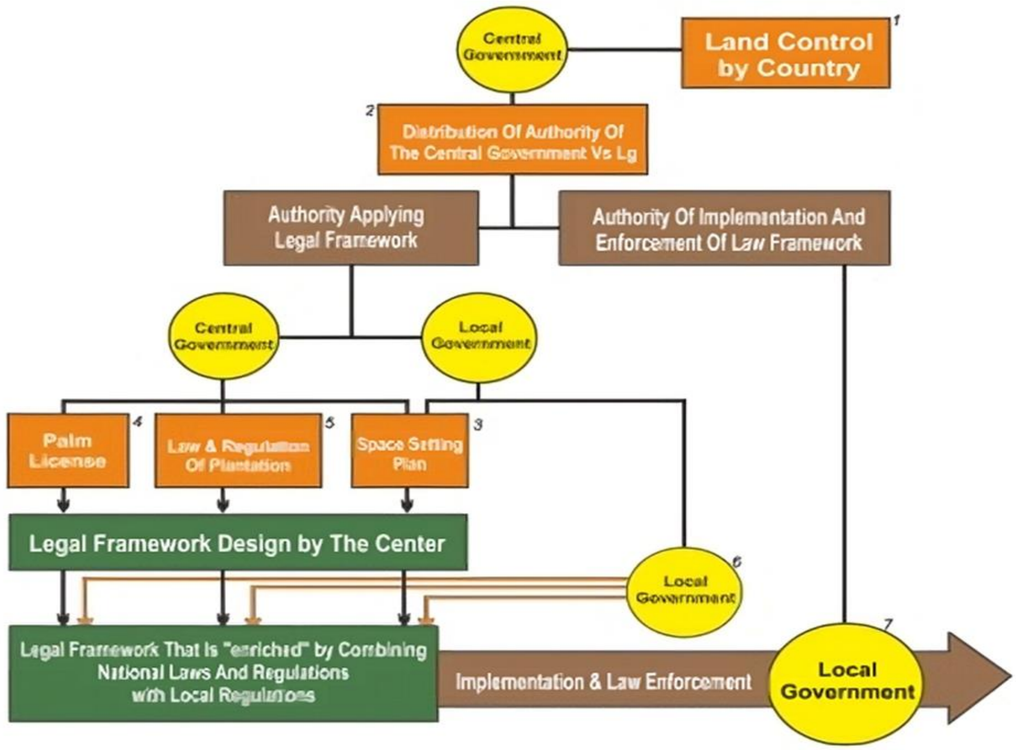
EFB fiber shows particularly promising qualities for packaging paper. In coherence with the aforedescribed plastic pollution problem in Indonesia and subsequent steadily increasing awareness, more environmentally friendly packaging options attained momentum within the last years in Indonesia. Consequently, the Indonesia paper packaging market size is expected to grow 6% annually from USD 13.46 billion (~ 1% of GDP) in 2023 to USD 18.08 billion by 2028. The global pandemic boosted the demand for paper packaging significantly and online shoppers tripled from 2017-2022 with further positive trend projections (Mordor Intelligence, 2023a).

In addition to domestic market growth, export projections also indicate growth but they represent a relatively small fraction with total exports amounting to $430 mio. in 2022. These promising growth projections have attracted many foreign investors (GII, 2023). The paper packaging industry in Indonesia is characterized by several major market players who control a significant market share. Recent times have seen the formation of new strategic alliances, both domestically and across the Asia-Pacific region (Mordor Intelligence, 2023a).

4.3.2 Regulatory Framework

The governance of oil palm development in Indonesia is a testament to the intricate balance of authority between the central and local governments. Officials of the central government and members of the People's Representative Council (PRC) are tasked with setting national policies, crafting laws and regulations, devising development strategies, managing the legislative workflow, creating budgetary guidelines, and sanctioning land use plans (Saleh et al., 2020).

Figure 8 - *Legal governance in Indonesia*



Note: A graphical presentation of coordinated legal governance for oil palm production in Indonesia (Saleh et al., 2020)

Figure 8 portrays how actors from both central government and local governments. The diameter of each circle signifies the significance of the involved actors at different phases. The orange marks a sequence of legal documents pertinent to the subject matter documented, while the dark green rectangle encapsulates the entirety of the overarching structure. A multifaceted legal structure is constituted by an array of legislative documents, ordinances, and ministerial edicts that are effective at different geographical extents and promulgated by diverse strata of governance and various ministerial departments.

The President of Indonesia, along with the central government, plays a pivotal role in shaping the palm oil industry through the formulation and implementation of comprehensive national policies (Paoli et al., 2013). This includes setting strategic goals, such as economic growth targets, sustainability objectives, and social welfare considerations. Following policy formulation, the central government develops legislation that provides the legal backing for the policies. For instance, the Regulation of the President of the Republic of Indonesia Number 44 of 2021 concerning the National Palm Oil Policy issued by President Joko Widodo (Badan Pemeriksa Keuangan, 2020). This regulation establishes rules on land allocation for palm oil plantations, ensuring adherence to sustainable land-use practices, and safeguarding environmentally sensitive areas. Several ministries play crucial roles in regulating and overseeing different aspects of the palm oil sector. The Ministry of Agriculture is responsible for formulating and implementing policies related to agricultural practices, including those in the palm oil sector. This ministry sets guidelines for cultivation practices, land use, and productivity. For instance, Regulation of the Minister of Agriculture Number 19 (Badan Pemeriksa Keuangan, 2011) concerning the Guidelines for Sustainable Palm Oil Plantation Management in Indonesia. This regulation sets out guidelines for sustainable palm oil plantation management in Indonesia, covering a wide range of issues, including cultivation practices, land use, environmental protection, and social responsibility. The Ministry of Trade is responsible for trade policies, including export and import regulations for palm oil. It is involved in negotiating trade agreements, managing international trade relations, and promoting Indonesia's palm oil industry globally. For instance, Regulation of the Minister of Trade Number 26 (Badan Pemeriksa Keuangan, 2018). This regulation establishes the requirements and procedures for the export and import of crude palm oil (CPO), refined palm oil (RPO), and palm oil derivatives in Indonesia covering a wide range of aspects, including export and impor permits, quality standards, labeling requirements, and monitoring and reporting. The Ministry of Environment and Forestry is responsible for regulating the environmental aspects of palm oil cultivation, such as deforestation, peatland management, and conservation. It issues permits for palm oil plantations and ensures compliance with environmental regulations. For instance, Regulation of the Minister of Environment and Forestry Number 5 (Badan Pemeriksa Keuangan, 2021) that sets out procedures for issuing technical approval and letter of operational eligibility in the field of environmental pollution including palm oil plantations in Indonesia. It covers a wide range of issues such as peatland management, conservation, environmental monitoring, and Environmental Impact Assessment (EIA).

Once the central government has established the national legal framework, the local government at provincial level takes the initiative to adapt it to the local context. The provincial government enriches the national legal framework by adding local regulations. These regulations are crafted to address local issues and may involve stricter environmental standards, guidelines for community engagement, or specific land tenure arrangements. According to Stolle et al. (2015) , the Provincial Agriculture Departments have a role in overseeing and managing palm oil activities within their respective provinces in aligning regional practices with national guidelines, providing guidance and support to local governments, and ensuring sustainable palm oil development at the provincial level. An example is the Governor's Regulation of Riau Province Number 9 of 2022 (Badan Pemeriksa Keuangan, 2022) that outlines the guidelines for sustainable palm oil plantation management in Riau Province.

Local governments at municipality level are responsible for implementing and enforcing regulations within their jurisdiction, ensuring sustainable palm oil development at the grassroots level (Stolle et al., 2015). They also have the power to issue permits for palm oil plantations. They also have a responsibility to monitor compliance with environmental and social standards, and to resolve conflicts arising from palm oil activities (Hidayat et al., 2017) . For instance, Regulation of the Regent of Rokan Hulu Number 42 of 2022 concerning Regional Action Plan for Sustainable Palm Plantation in the regent of Rokan Hulu (Jaringan Dokumentasi dan Informasi Hukum Rokan Hulu, 2022), and Regulation of the Regent of Sanggau Number 56 of 2022 concerning Regional Action Plan for Sustainable Palm Plantation in the regent of Sanggau (Jarimngan Dokumentasi dan Informasi Hukum Sanggau, 2022).

In rural areas where palm oil plantations are often located, village governments also play an integral role in shaping the course of palm oil development and its impact on local communities. They actively participate in land-use planning, ensuring that palm oil cultivation aligns with the village's needs and aspirations (Palm et al., 2019). Through engagement with palm oil companies, village governments strive to secure equitable benefits for local communities, including employment opportunities, infrastructure development, and profit-sharing mechanisms. Additionally, they oversee plantation activities to uphold environmental and social regulations, minimizing the negative impacts of palm oil production and protecting community rights (Palm et al., 2019). Nevertheless, there may be challenges and potential gaps in the regulatory framework at the village level in ensuring fair and transparent practices in the palm oil industry (Andrianto et al., 2019) .

4.3.3 Stakeholder Analysis

Our value creation perspective requires a deliberate consideration on how to enhance the embedded resources and network connections within the Indonesian palm oil community, particularly in the context of repurposing palm oil industry waste into a more circular system. According to Geels (2004), in socio-technical regimes, actors that are involved in maintaining and changing the system, and rules and institutions should be carefully analyzed. Within technological niches, “actors need to put in a lot of “work” to uphold the niche, and work on the articulation of rules and social networks”(Geels, 2004). There are no clear role relationships between stakeholders that support this innovative niche. Thus, establishing robust relationships and promoting information sharing and close collaboration between stakeholders emerge as imperative components. In this stakeholder analysis, we focus on the social infrastructure that is necessary to develop, commercialize and use mesocarp fiber and we look further than just industry structures. Especially in the palm oil industry in Indonesia, coordination between government bodies, industries and social groups aimed at increasing sustainability in the sector is needed to establish this niche.

Regime - Government Bodies

In the previous section it is shown that the regulatory framework of Indonesia's palm oil industry involves various government policies aimed at ensuring sustainability and environmental friendliness. The country is mandated by constitution to conduct economic development under the principles of sustainability and environmental friendliness (Badan Pemeriksa Keuangan, 2020). However, it is clear from the analysis on the regulatory framework that all levels of government have different jurisdictions and different authority on palm oil producers, mills and the central planning and adherence to sustainability standards and processes. Therefore, to establish this niche, careful planning and integration between all levels of government is pivotal. We should be aware that policies that are implemented at the central government level might not trickle down towards local levels.

Environmental and Social Groups within Indonesia and Globally

There are multiple environmental and sustainable groups that focus on making the palm oil industry a cleaner and more efficient industry. These groups are important stakeholders as they influence development goals and certification criteria that are leading in making this industry more sustainable. For this particular niche, the support of these groups is pivotal, as they are in contact with most investors, large-scale producers and mills. They can influence the adoption of our policy advice and we can use their network to reach both palm oil producers as manufacturers of our proposed circular goods.

RSPO (Roundtable on Sustainable Palm Oil)

The RSPO is a global, non-profit organization with voluntary members that are focused on bringing stakeholders together throughout the whole palm oil supply chain (RSPO). They also implement and develop global standards for sustainable palm oil such as the RSPO Certification. Their RSPO certification is leading in the industry. The certification emphasizes the need for sustainability requirements on which the whole supply chain can rely on. The RSPO involves both individual consumers, small holders, and large-scale producers. Their main focus is targeted on the protection of worker's rights, smallholders' inclusion, reduction of greenhouse emissions and better waste management (RSPO).

Indonesian Palm Oil Association (GAPKI)

The GAPKI is a nation-wide Indonesian association that focuses on synergizing all national palm oil producers (GAPKI). The GAPKI acts as a linking pin between the central government and regional governments to formulate conducive sustainable policy. Additionally, their aim is to increase competitiveness of local farmers on the global scale. The palm oil producers within Indonesia that are connected to the organization, try to adhere to the ISPO certification (Indonesian Sustainable Palm Oil certification). Most of the ISPO criteria overlap with the RSPO criteria, yet the ISPO also provides financial support to smallholders. The ISPO is the government's commitment to producing good quality and competitive palm oil according to their own sustainable palm management standards.

UNDP (United Nations Development Program)

By ensuring the SDG's (United Nations sustainable development goals), the UNDP tries to support Indonesia by maximizing the development and economic benefits of this important commodity sector, while also minimizing the adverse social and environmental effects (UNDP). The UNDP, with their initiative the Green Commodities Programme, has also been pivotal in launching the GAPKI with the national government.

Palm Oil Producing Companies and Circular Industries

Privately-Owned Palm Producing Companies and Mills

Palm oil producing companies and mills might be more reluctant to alter their palm oil producing processes due to the necessary increased investment in their ability to extract the mesocarp fiber and to substitute the fibers' use as biofuel. There need to be clear market-based incentives or subsidies/fees for palm oil producing companies to be inclined to alter their processes. Also, companies might lack the necessary knowledge and technology to extract the fiber or get in contact with buyers, especially smaller independent mills. Larger privately-owned palm producers often have greater networks and capital to establish this niche (UNDP,2022).

Industries using Palm Oil Fiber

As for the industries that are indicated in section 4.2.3, it is only assumed that they have regular market incentives. It is important to create easy access to fiber producers, with regular and reliable provision rates at competitive prices.

5. Policy Recommendations

5.1 Policy Guide

In this case study of the Indonesian palm oil sector, we have thoroughly analyzed the production process of palm oil in the mills. We have visualized the current value chain and the opportunity for the creation of value-added products from palm oil fiber. The methodology that we used for our research has been primarily based on academic papers and secondary literature. On this basis, we have already been able to develop convincing policy recommendations and a first start towards a circular economy in the palm oil sector. However, we believe that additional quantitative data collection can provide a more extensive approach towards the following objectives:

- Locating the different amounts of palm oil waste in the regions in Indonesia.
- Understanding the knowledge and awareness of palm oil producers and mills regarding circularity and the willingness of them to establish circularity in their practices.
- Discern what palm oil producers and mills do with their waste. looking at incineration levels and other uses of waste.
- Learning if palm oil producers and mills already know about different palm fiber extraction methods and if they partake in this process.
- Establishing for what price they would be willing to sell their fiber.
- Establishing what clean energy sources are preferred in their respective mills in terms of cost and value.

Next to this case study, we have created an additional policy guide that includes a data collection tool programmed in Excel. We have translated the tool to Bahasa Indonesian to ensure inclusivity for all palm oil producers and mills as well as Indonesian policymakers[3]. This tool is especially made for policymakers to gather information on the objectives stated above. The data collection is through a short survey called The Green Cycle Survey (GoogleForms) with 25 multiple choice or short-answer questions[4], to develop an extensive understanding of the objections mentioned above. We recommend the central government to distribute the survey through different networks such as the GAPKI, ISPO and palm oil conferences to increase the reach and completed surveys. Within the guide, we have also developed a tool that can visualize the answers and help policymakers in their approach on writing effective policies. We also provide a brief overview of this case study and our recommendations. As we stated before, these recommendations follow after a thorough case study, yet we do recommend the central government to adapt the policies according to the quantitative results. For example, it can be the case that there is a need for an extensive awareness campaign, or that most mills already properly know how to extract the fiber in the most environmentally friendly way.

In the following section we propose our recommendations and how the data tool can help policymakers to approach these recommendations. We propose sending out the survey and waiting for enough responses before altering the policy recommendations. It is important to listen to the needs of one of the biggest stakeholders - the palm oil producers and mills- to ensure smooth adoption of the policies without too much resistance.

[3] We also translated the tool to Malay and Thai, to help add to circularity frameworks in other Southeast Asian developing countries.
[4] These questions are deducted from interview questions from our previous methodology (Appendix - Interview questions)

5.2 Policy recommendations

In this case study of the palm oil industry in Indonesia, we have established the innovative technological niche of palm oil fiber. We have located the industries that can use this product and how there is both local and global demand for buyers. With this information, we want to recommend the central government of Indonesia to facilitate this niche and spur the development of waste management and a circular economy. We believe that this niche has great innovative potential and can help diversify the Indonesian economy by promoting technological advancement, the move from primary commodities to the secondary sector and most importantly, ensuring more circular practices. The central government has been vocal in its commitment towards sustainability and the development of the palm oil sector. Therefore, we provide the following recommendations on how it can improve circularity in the sector:

1. **Policy Integration and Adherence**

One of the main goals should be to integrate policy decisions top-down and bottom-up. Indonesia's current governmental structure is highly complex, surpassing 500 provincial, district and municipal authorities and 34 different ministries (Saner, 2015). The adaptation of this technological niche needs effective and efficient policy coordination from the central government to the local level, making reporting and authority lines visible and transparent. Different elements of the value chain are linked to various Indonesian jurisdictions; thus, it is recommended that a decentralized agency is put into place with the main goal being to uphold the consistent application of the recommended policies and to promote cooperation between the distinct levels of government (European Union, 2023). Additionally, this agency has an advisory role, providing both the central government, as well as the local governments, with specialist expertise and knowledge from the plantation to technological advancements, and new policies.

It is recommended that the Indonesian government places this responsibility at the ISPO. The ISPO is already an initiative of the central government and is closely linked to both central government and palm oil producers. At this time, the ISPO has had an advisory role on ensuring sustainability standards by providing a certification scheme and helping support palm oil plantations on how to adhere to their certification (ISPO). However, we want to extend its reach by including palm oil mills in their certifications and by establishing a more profound partnership with the GAPKI. The GAPKI has a strong relationship with local governments and strong bargaining power with palm oil producers. Therefore, this association is pivotal in passing on sustainable commitments and establishing the necessary adherence to circularity. We are aware that the commitments of the central government do not necessarily align with the vision and incentives of local governments or producers. Therefore, the ISPO needs to take on a more active role, integrating in local governments, partnering with associations, providing policy feedback, and reporting back to the central government. This agency is crucial for adherence in a most complex governmental structure.

2. ISPO Requirement on Waste Management

Building on the responsibilities of the ISPO, we recommend that the ISPO integrates the independent palm oil mills in its certification framework next to palm oil producers. Palm oil mills form an integral part of the value chain and need to adhere to circular policies to make the sector more sustainable as a whole. Therefore, the ISPO should establish circular requirements for palm oil mills to increase the central governments' commitment towards sustainability upstream in the value chain. This also increases awareness at the level of refineries and traders of crude palm oil, who are increasingly supplying to markets with a demand for sustainably produced palm oil. In turn refineries and traders may choose only to opt for mills producing palm oil in a circular way, thus providing incentives for palm oil mills to invest in this niche. Additionally, we recommend the adoption of the following new ISPO standard for palm oil mills and producers (excluding smallholders) to be ISPO certificated; *Palm oil fiber needs to be extracted from the FFB and used in/sold to circular industries*. This new requirement should be adopted immediately, yet palm oil mills and producers can maintain their current ISPO certification for a maximum of five years in order to implement the necessary new technology for managing their waste. Yearly, the ISPO should be active in recollecting data (e.g. fiber supply contract information between producer and buyers) to see whether palm oil producers still produce up to standard.

3. Providing the Necessary Infrastructure

The central government should take on an active role in facilitating the essential infrastructure for this technological niche. A crucial element of establishing circularity is connecting the fiber suppliers (all palm oil mills) with the industries (paper-, bioplastics-, construction- industry). Unequal access of mills to these markets due to lack of infrastructure or lack of business networks decreases the likelihood that mills will adopt circular waste management practices. Therefore we recommend the central government to establish the following initiatives.

Collection Centers: With the help of the data survey that is provided in our *Guide Towards A Circular Palm Oil Industry*, it becomes clear in what regions in Indonesia the biggest palm oil waste flows are present and where there can be the highest supply of fiber. With the help of the new role of the ISPO, the central government and local governments should establish collection centers for fiber waste where suppliers are connected to buyers and place these centers at strategic locations. Of course, palm oil mills can choose to sell their fiber independently to different industries, but there should be the possibility to sell the fiber at a set price to these collection centers, who can directly sell it to the industries. This takes away some of the difficulty palm oil mills might face in establishing and fostering business relationships with industries and can create a fairer government set price that reflects the costs of palm fiber extraction. We also recommend the government to already think of facilitating the collection of fiber waste on site, yet this can be outsourced to third party transportation services.

Online Platform for Palm Oil Fiber: In collaboration with the ISPO and the GAPKI, we recommend establishing an online platform where palm oil producers and mills can connect with different companies in the circular industries directly. Both supplier and buyer can explain their particular industries and disclose prices, quantities and other objectives. This is supplementary on the collection centers as this platform creates a space for palm oil producers and mills to choose the industry independently and perhaps establish business connections with circular industries based on business values. The platform is beneficial for both increasing the enthusiasm of palm oil producers of partaking in a circular economy and can help circular industries locate their sources of palm oil fiber. Another suggestion would be to use this platform to provide information on the circular economy and inform both producers and industries on government incentives and new technologies.

4. Entrepreneurial Support

From our stakeholder analysis it follows that we need a clear incentive structure for palm oil producers and palm oil mills to partake in a circular economy. At this time, while the Indonesian infrastructure on circular economy in the palm oil sector is still in the primary phases of development, we do not recommend legal punishment for palm oil producers that are unwilling. However, we recommend positive incentives such as subsidies on clean energy sources and mechanical extraction technology (Geels, 2004). Next to this, we believe in an integrated approach.The central government should make it its utmost priority to empower this crucial sector by establishing this technological niche and by using this opportunity to revitalize and innovate the entire socio-technical regime. As is established in the part on the qualities of palm oil and on alternative energy generation, mechanical extraction is the most environmentally friendly extraction method for palm oil fiber, also solar energy is currently the most promising source of clean energy. Therefore, we suggest two subsidies directed at palm oil producers and mills; an *Use of Solar Power Subsidy* and a *Mechanical Extraction Technology Subsidy*. The subsidy on solar power should fully cover the costs of the amount of solar panels that are needed to run the mills. We opt for a full subsidy due to the factor that otherwise mills will not be incentivized to switch to this energy source, and because Indonesia has already stated a strong commitment to its development of solar panels. The mechanical extraction technology should be partially covered, due to the future revenue stream of the fiber. Additionally, we recommend the "newly established" ISPO to pilot an initiative of giving out grants to palm oil producers that want to start developing a circular product themselves (e.g. construction blocks). We hope this increases engagement in the community and that it can help diversify the sector. The ISPO should also look at its partners, such as the UNDP and the International Finance Corporation

(IFC), to see if external funding is possible. Lastly, additional external financing for entrepreneurs can come from the private sector in the form of FDI. Restrictive FDI policies for smaller-scale and less technology-intensive projects depicts an obstacle for the diffusion of fiber into other industries. With eased ownership regulations, increased FDI can lead to highly effective knowledge transfer to a broader range of Indonesian companies, which ultimately helps to overcome knowledge deficits and diffuse innovative technologies.

5. Education on Circularity

For our last recommendation, we propose that the central government invests in the education of circularity on two levels; at schools, and at the palm oil sector level. If Indonesia is serious about its commitment to sustainability, the government should start at the source of new knowledge and at the source of the new labor force; the schools. Individuals between 6 and 18 years old are still in the process of developing their values and beliefs, which makes them more perceptive and open to messages about environmentalism and sustainability (UNICEF,2021). Therefore, by focussing on this age group, we can establish leverage for a circular economy in Indonesia. We recommend partnering with research institutes such as the RCCC UI (Research Center for Climate Change Indonesia), to develop short and yearly learning modules for children in this age range to expose them to sustainable theories adapted towards Indonesia. Engaging children in this manner can create a great knowledge base and a brighter more sustainable and circular future. Additionally, we propose that the GAPKI can open its regional branches to give monthly seminars on the circular transformation of the palm oil sector. The owners and personnel of oil producers and mills can join these seminars to gain information on the different ways in which the government can help them adapt their mills. These seminars can also be dedicated towards circularity on itself and the importance of advancing in this.

7. Implications and conclusion

The growth in global palm oil production has brought many benefits, helping to meet ever-increasing food demand. However, with this industrial expansion of production come environmental challenges in the form of deforestation, causing dealignment with the Sustainable Development Goals, particularly SDG 15 (Life on Land) and SDG 12 (Responsible Consumption and Production). Indonesian policymakers face a dilemma when considering the potential impact of regulations, as many workers and smallholders depend on palm oil for their livelihoods. Introducing strict regulations may hinder progress in other SDGs such as SDG 1 (No Poverty) and SDG 2 (Zero Hunger). An alternative approach to enhance palm oil sustainability involves optimizing the use of palm oil waste generated during production. Transforming this waste into circular products aligns with SDGs, offering a more balanced solution. At this stage, waste from palm oil production is generally not taken into account and is either used as fuel or discarded. Traditionally, residues are burned to generate the energy needed to heat palm fruit in the process of oil extraction. This study assessed the potential of circularity for palm oil fiber in the Indonesian palm oil industry. With the assistance of the MLP framework, it has established a new socio-technical system with palm oil fiber waste as a technological niche, operating in a landscape of circularity. There are some main conclusions which can be drawn from this study. First of all, POF possesses favorable characteristics for remanufacturing and repurposing in high-value industries like construction and composites. The successful adoption of niche technologies can enhance sustainability, mitigating carbon footprint and distrupting the current socio - technical regime of Indonesia allowing for teh creation of a more circular landscape. Additionally, the Indonesian palm oil industry faces energy challenges due to biomass competition. Alternatives include biogas, solar PV, and geothermal energy, with evolving technologies making sustainable options increasingly viable. The intricate legal framework governing Indonesia's palm oil industry involves national policies, ministries, local governments, and village-level participation, facing transparency challenges. The study has a number of implications for palm oil mills. In the first place, it provides them with a self-evaluation tool by filling out the questionnaire. This can enhance awareness among palm oil producers and educate them on the benefits of waste management. It also shows them the entrepreneurial potential of palm oil fiber waste, which might foster cooperation with other industries and institutions. Furthermore, this study has implications for Indonesian policymakers. It provides them with useful insights and policy recommendations which can help them in creating and conducting targeted policies to stimulate circularity. Additionally, it provides them with a policy guide which can help them in collecting data to ensure their policies are efficient and tailored to the right groups. The implications of establishing circularity in the Indonesian palm oil industry go further than just the sector itself. The transition could foster economic development by moving a primary sector towards a secondary sector in the form of palm oil fiber manufacturing. This could generate jobs, raise productivity, and benefit the overall socio-economic development of the country and its citizens.

8. Limitations and Future research directions

The initial setup of this research included a method of primary data collection in the form of interviews. However, eventually, this study has been predominantly backed with secondary data. Although this data has been valuable in mapping out the existing actors, practices, and regulations, new insights might have been gained by the application of primary sources. Future research could incorporate more primary data in order to add more value to the existing literature. The lack of cost-revenue data has also been a limitation in this research and has impeded the application of a cost-benefit analysis. Future research should aim to incorporate such a feasibility analysis. It is also important to note that this study has been focused on palm oil producers. Smallholders have not been considered due to a lack of available data, however, this group comprises a large proportion of Indonesian palm oil farming. Future studies could be aimed at smallholders in order to get a more complete image of circular feasibility in the sector. Another suggestion for future research could be to analyze the other end of the supply chain, i.e. the potential market and end user for palm oil fiber products, more in depth. This could be done by extending the scope of the potential customers from a domestic level to an international level or by zooming in on the Indonesian end consumer. On another note, future studies could be more concentrated on the technical aspects of circularity in the palm oil industry. This could be done by laying the emphasis on physics or chemistry, for example by performing a more detailed analysis of the different parts of fiber and their benefits. Transportation has also not been covered in depth in this research and deserves more attention in future studies, especially given the lack of infrastructure in order to adapt to circular practices optimally. Finally, it would be interesting to use this case study as a basis for similar research on palm oil fiber potential in other countries.

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Appendix I - Interview Questions

Interview questions palm oil producers

1. What are the by-products of your production process?
2. How much fiber waste do you produce?
    a. What is the regularity of your waste production (weekly, monthly, ..)?
3. What do you do with your waste? (Do you sell it? Incinerate it?)
4. What is the percentage composition of the total waste?

5. What is the weight of the waste? (Do you have any data that you could give us?)
6. How much does it cost you to manage your waste?
7. Are there any regulations you have to follow when managing your fiber waste?
8. Did anyone approach your company to propose recycling your fiber waste?
9. Is there an official organization that controls how you manage your biowaste?
10. Do you follow any international or local certification in your waste management?
11. Would you be open to expanding your business to use your fiber waste or sell it to other companies? (why?)
    a. What kind of support would you need to sell/utilize your fiber waste?
12. For what price (per kilogram or ton) would you be interested in selling your palm oil waste?
13. Do you have any ideas about the products that could be made from this fiber waste?
14. What could be the sectorial and market opportunities for these products locally?
15. What could be the sectorial and market opportunities for these products internationally?

16. Who else do you know/think could we interview on this topic? Could you provide us with the contacts?

Interview questions ISPO/RSPO

17. What are the by-products of the production process?
18. How much fiber waste do palm oil producers produce?
    b. What is the regularity of this waste production (weekly, monthly, ..)?
19. What do most palm oil producers do with their waste? (Do they sell it? Incinerate it?)
20. What is the percentage composition of the total waste?
21. What is the weight of the waste? (Do you have any data that you could give us?)
22. How much does it cost to manage their waste?
23. Are there any regulations producers have to follow when managing your fiber waste?
24. Are there already initiatives in place to propose recycling fiber waste?
25. Are there official organizations within Indonesia that control how producers manage their biowaste?
26. Are there any international or local certifications that incorporate waste management?
27. Would producers be willing to expand their business by selling their fiber waste to other companies? (why?) What kind of support would they need to sell their fiber waste?
28. Do you have any ideas about the products that could be made from this fiber waste?
29. What could be the sectorial and market opportunities for these products locally?
30. What could be the sectorial and market opportunities for these products internationally?
31. Who else do you know/think could we interview on this topic? Could you provide us with the contacts?

Appendix II - Best practices in other countries

Malaysia's fossil fuel reserves are declining therefore there is an increasing need for renewable energy sources. Being the second biggest palm oil producer in the word coupled with the above mentioned initiatives to make the palm oil production more sustainable to utilization of palm biomass has gained attention. Malaysia produces both biodiesel which can supplement diesel fuels and bioethanol which can supplement gasoline and fossil petrol, because the other renewable resources like solar and hydro are rather more expensive and in a very initial stage. The bioenergy production is done by a governmental agency to be able to produce internally the previously imported biogas from other countries (Thailand, Philippines). The country employs both traditional and modern methods, from which the second is more sustainable but the earlier is cheaper and helps to dispose of palm oil tree residuals. (Salleh, 2020) They aim to create high-value added products with high-value job creation to be able to be competitive in the international markets, however they have to face several challenges, namely: technological, economic, infrastructural, social and environmental. (Rashidi et al 2022)

Overall biogas production is an upward sloping trend in revenues therefore it can be seen that other countries employ bioenergy environmental policies. The leading in this sector is **Finland** and **Sweden**. Both introduced national prower programmas after the Paris climate Agreement to support biofuel production in an energy efficient sustainable way. The reason they were able to achieve their plans and become leading in this sector is the high level R&D invested, but more importantly the government support. In both countries the government introduced carbon taxes, investment support and subsidies in this sector. Sweden even managed to switch to bioenergy with regards to electricity, stopped the fossil fuel transportation in the countries and introduced regulation to place extra attention to biodiversity preservation and protection, thus stopping the industrial use of bioenergy from the potential negative effects on environment. (Rashidi et al 2022)

Nigeria also plans to capitalize on the palm oil mill effluent (POME) which is usually discharged into the environment without any treatment after the production of palm oil. There are three scale of processors in the country smallholder (traditional) , semi-mechanized and mechanized. The latter two only accounts for 20% of the productions and therefore the currently used thermophilic temperature approach (45 to 65°C) with neutral pH condition for turning POME into biomethane gas is highly inefficient, which results is a potential loss of 367 million m3 annually. The reason behind the inefficiency is the lack of technical knowledge and funding (Elijah et al., 2014)