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REVIEW

Replanting challenges among Indonesian oil palm smallholders: a narrative review

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Abstract

Three decades after their establishment, many smallholder oil palm plantations are overmatured and will require replanting soon. Replanting offers a unique opportunity to redesign plantations, close yield gaps, boost farm productivity, and secure livelihoods. However, replanting requires knowledge, inputs, and financing. If postponed or done sluggishly, replanting could further exacerbate existing socioeconomic and environmental challenges in smallholder oil palm cultivation. We collected literature relevant to the replanting of oil palm and created a narrative literature review to highlight the challenges that smallholders face during replanting. We identified access to inputs, finances, and knowledge as paramount challenges that might influence smallholders' decisions about when, how, and what to replant. Barriers to successful smallholder replanting in Indonesia are a lack of knowledge on replanting and proper training, uneven access to high-quality seedlings, as well as uneven eligibility for public replanting funds. We finish the review with recommendations for policymakers and researchers on how to overcome the challenges replanting holds and emphasize the opportunities replanting offers.

Keywords Oil palm · Indonesia · Farmers · Decision making · Replanting

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1 Introduction

Before the Indonesian government launched a transmigration program in the 1980s, its palm oil production was practically non-existent, and the cultivation area only covered 1.6 Mha (Wicke et al., 2011). After the program, Indonesia's palm oil production grew rapidly over the past decades, and today the country is the largest global producer (Naylor et al., 2019; Statista, 2021). The transmigration program aimed at relocating volunteers in order to fight overpopulation in some regions. But there was also the purpose of boosting the economy and reducing poverty by giving transmigrants land to cultivate oil palm in smallholding plantations (Kunz et al., 2017; Rival & Levang, 2014; Schleicher et al., 2019).

These smallholders became an important pillar of Indonesia's palm oil production (Kubitza, 2018; Naylor et al., 2019; Qaim et al., 2020). They now cultivate 41% of the Indonesian oil palm plantation area (Herdiansyah et al., 2020) and produce one-third of Indonesia's palm oil (Statista, 2021). In the 1990s, the number of smallholder oil palm plantations skyrocketed (Naylor et al., 2019), particularly in rural regions like the Jambi province (Euler et al., 2015).

Despite oil palm's ambivalent reputation, its cultivation has been a success in poverty reduction (Qaim et al., 2020). Three decades into this oil palm boom, many plantations have reached the end of their economic lifecycle (Corley & Tinker, 2016). The literature agrees that after 25 years, the productive economic cycle of an oil palm comes to an end for two main reasons: (1) the palm's height exceeds the 10-m mark, which makes harvesting more difficult, thus increasing the harvesting costs; and (2) the palm's fruit production decreases (Corley & Tinker, 2016; Ferwerda, 1955; Ismail & Mamat, 2002). Now, old palms have to be replanted (replaced by new seedlings). According to Mongabay Environmental News (2020), two-fifths of Indonesian smallholder plantations requires replanting. Other sources estimate that 30% (Glenday & Paoli, 2015) to 50%—or 2.4 Mha (Ompusunggu & Gunawan, 2018) of Indonesian smallholder plantations will need replanting within this decade.

The replanting process offers the opportunity for smallholders to increase the productivity of their plantations, thus narrowing yield gaps to company-managed plantations (Lee et al., 2014; Woittiez et al., 2017). Potential higher productivity can also translate into higher incomes for smallholder households. Additionally, plantation redesigning could also be done during the replanting process. Besides these opportunities, replanting can present a challenge to smallholders. Replanting is linked to high costs, and difficult management practices. Pest control as well as correct fertilizing become more crucial (Corley & Tinker, 2016; Goh, 2005; Nurfatriani et al., 2019). While there are different methods of replanting (Corley & Tinker, 2016), some may not be feasible for smallholders, given high capital and information requirements.

There is currently very limited research on smallholders' replanting choices, their challenges, and potential measures to support them. Yet, this knowledge is urgently needed to harness the opportunities offered by replanting and avoid the exclusion of large parts of smallholder farmers. In this review, we collect data from relevant studies, identify research gaps and offer policy recommendations concerning the difficulties and opportunities of smallholder-managed replanting.

This paper aims to collect and connect current available literature on smallholder oil palm replanting to identify the challenges Indonesian smallholders are facing. To do so, we reviewed scientific publications on oil palms smallholders and the replanting process which were available up until April 2022. We provide information on heterogeneity of Indonesian

oil palm smallholders, which is essential to assess the opportunities and risks of the smallholder replanting process. We discuss the necessity for replanting, the techniques, and the feasibility for smallholders. Next, we focus on opportunities and constraints of replanting for smallholders. Then, we discuss the guiding questions and highlight areas of importance for future research. Finally, we elaborate potential policy recommendations and potential future research opportunities.

2 Typology of Indonesian oil palm smallholders

Oil palm smallholder farmers are defined as farmers who have less than 25 ha of oil palm plantations (Glenday & Paoli, 2015). To assess how the replanting process will affect smallholders and how they can be supported, it is crucial to address the socioeconomic heterogeneity. Based on literature, we distinguished Indonesian oil palm smallholders into four types (Table 1).

Scheme smallholders emerged in the 1980s as part of the transmigration program. They were usually given around 2 ha of land to cultivate oil palm and received official land certificates (Gatto et al., 2015). Land certificates prove land ownership and are crucial as collateral for bank loans and other subsidies. Furthermore, transmigrant smallholders were supported by companies that provided knowledge and training as well as facilitating access to input materials like fertilizer and seedlings (Glenday & Paoli, 2015; Jelsma et al., 2017; McCarthy, 2010; Rival & Levang, 2014). Similar schemes followed but with less government influence (Jelsma et al., 2017; Rist et al., 2010). For example, the Credit for Primary Cooperative Members, (Kredit Koperasi Primer Anggota—abbreviation: KKPA) also included local farmers. In this scheme, smallholders entrust a company with parts of their land for large-scale oil palm cultivation. In turn, the company establishes a plantation for the smallholders. However, the smallholders have to bear the costs for establishing these plantations, for which they have to take out loans (Feintrenie et al., 2010; Rist et al., 2010).

Beginning with Indonesia's decentralization policy in the mid-1990s, smallholders gradually started to cultivate oil palm independently, with no formal affiliation to a company (Naylor et al., 2019). Additionally, former scheme smallholders became independent in their oil palm cultivation. They were able to keep their land certificates and draw on the established infrastructure (Euler et al., 2015). During that time, farmers with no prior experience also started oil palm cultivation. Some were migrants, and many were locals. Local farmers in particular faced many challenges. One of the main drawbacks was that local farmers strongly relied on their customary laws with which they handle land access in their communities. As customary law was not aligned with state law, this led to the establishment of many smallholder plantations in state-declared forest areas, making these plantations de jure illegal. As these plantations are formally located in contested land, attaining official land certificates is nearly impossible for smallholders (Kunz et al., 2017; Riggs et al., 2016).

To compensate for lacking support and diversify financing possibilities (Prokopy et al., 2008; Schoneveld et al., 2019), smallholders can get organized in farmer groups or farmer-managed cooperatives. Some of the cooperatives provide financial aid, but usually groups and cooperatives help to distribute tools, farming inputs, and provide training. Some even established replanting funds through member contributions (Anwar & Sunesti, 2021; Glenday & Paoli, 2015). An evaluation of their success proves difficult due to lack of information. Being a member of a farmer group is also a pre-requisite to apply for the state

Table 1 Types of smallholders in Indonesia (Glenday and Paoli, (2015)

	Type of Smallholder	Characteristics
1	Scheme smallholders	Hold land certificates Access to inputs, knowledge and finances through company affiliation Originally mainly transmigrants
2	Former plasma scheme, now independent	Hold land certificates Knowledge and access to inputs established during company affiliation Easier access to loans and funding Often transmigrants
3	Independent	Often no official land certificates Often sell fresh fruit bunches through middlemen Limited access to credits and subsidies, knowledge and other resources Often locals
4	Farmer groups/farmer-managed cooperatives	Coalition of independent farmers Can provide financial aid Better network Usually have legal documentation

replanting fund PSR (Peremajaan Sawit Rakyat) (BPDPKS, 2019a; Nurfatriani et al., 2019).

Even though smallholder oil palm cultivation has reduced poverty (Qaim et al., 2020), there is still a potential to increase their productivity and thus ensure smallholder livelihoods. Studies have shown that smallholders generate significantly lower yields compared to large-scale company-managed plantations (Euler et al., 2016; Lee et al., 2014; Woittiez et al., 2017). According to Lee et al. (2014) the yield gap can be up to 40%. These studies have also shown that independent smallholders produce significantly less than scheme smallholders. In the study by Lee et al. (2014) the yield gap between independent and scheme smallholders was 38%. Closing this yield gap will not only increase smallholders' income and improve their livelihood but could also reduce further land-use changes.

3 The replanting process

3.1 The necessity to replant

Oil palm becomes productive after approximately three years. After a rapid increase of productivity, the prime time of maximum yields lasts for about 15 years. After this, oil palms get less and less productive (Fig. 1), until they reach the phase of economic unprofitability. This typically occurs 25 years after planting (Corley & Tinker, 2016; Ferwerda, 1955; Ismail & Mamat, 2002). The harvesting process of oil palm fresh fruit bunches (FFB) still has a low degree of mechanization. Once the palm exceeds 10 m in height, harvesting becomes even more labor intensive. In combination with decreasing yields of the

palms and increased need for fertilizer, oil palm production becomes economically unprofitable at this stage.

Since the major expansion of Indonesian smallholder oil palm cultivation started in the 1990s, many farmers are currently dealing with overmatured plantations. According to Mongabay Environmental News (2020), two-fifths of the plantations are already 25 years or older. 30–50%, which would accumulate to 2.4 Mha, of the smallholder plantation area will need replanting within this decade (Glenday & Paoli, 2015; Ompusunggu & Gunawan, 2018). If replanting is not conducted timely, yield gaps are bound to increase.

Consequences of delayed replanting can already be observed in Malaysia. Here, the production cost of crude palm oil (CPO) increased by more than 70% between 1997 and 2008. One of the main reasons for this increase was traced back to low productivity per area unit, to which progressively aging oil palms contributed substantially (Wahid & Simeh, 2009). Despite of the steady growth of the oil palm area, Malaysia's FFB yield per hectare has shown a slight downward trend in the last 30 years, and the proportion of unprofitable old palms grows faster than the replanting rate can compensate (Kushairi et al., 2018; Wahid & Simeh, 2010). Due to the decrease of the yield over the past 30 years, a steady growth of the oil palm area is a potential consequence to cover for increased demands.

Another potential problem with delayed replanting is that a replanting backlog might occur: if replanting is stalled to the point where it can no longer be deferred, many smallholders will replant large proportions of their plantations simultaneously. This would increase the demand for replanting materials (seedlings, fertilizers, machinery, etc.), causing price increases, and possibly even material shortages (see also Wahid & Simeh, 2010). Another major issue is that oil palms produce no fruits in the first few years after plantation (Fig. 1). The duration of the unproductive phase varies depending on environmental conditions, planting skills, and seedling quality. But in general, productivity losses must be expected in the first 3–5 years (Schleicher et al., 2019). This could act as a deterrent and start a vicious cycle where decreasing yields impact farmers' financial buffer, making replanting even more difficult. Even though the area under oil palm, as well as production

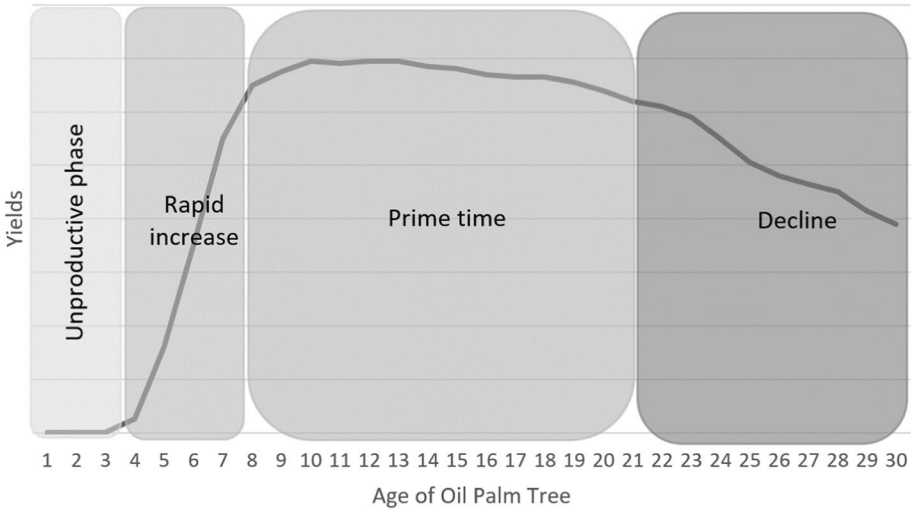

Fig. 1 The productivity of an oil palm over time (USDA, (2012)

volumes, are still increasing in Indonesia (Statista, 2021), the Indonesian government expects a decline in CPO productivity from 2024, if replanting is not properly done.

3.2 The different replanting methods

There are different methods to replant oil palm plantations. According to Corley and Tinker (2016), replanting should be a continuous process with a replanting rate of 4% of the plantation per year to secure stable yields and incomes. However, the observed overageing of smallholder plantations suggests that this rate is not being met.

The conventional method to replant is the felling and chipping method in combination with prior poisoning of the palms. Poisoning the palm trunks accelerates their decay (Virdiana et al., 2020), facilitating the next step: felling the palms. Companies usually use heavy equipments to fell the old stand (Zulkifli & Khalid, 2008). Among smallholders, it is common to use a chainsaw, which is cheaper but more labor-intensive and time-consuming. Next, the felled palms are chipped by heavy machinery or chainsaws. Pulverization with special machines is also possible (Bayona Rodríguez et al., 2015; Corley & Tinker, 2016; Ooi & Heriansyah, 2005; Virdiana et al., 2020). The chipped material can be spread on the plantation and used as initial fertilizer (Corley & Tinker, 2016). Yet, according to Ávila et al. (2014) the risk of pest infection of the new stand increases if the residue material is not buried. Burying the residues is likely to increase the replanting costs, although Ávila et al. (2014) provide no information on that matter. Pulverization reduces pest infection, but is less suitable for smallholders, given the necessity to use special machines (Ooi & Heriansyah, 2005).

If the whole plantation is felled and chipped at once, income losses will be 100% in the first years (Novra et al., 2021). Partial replanting increases fixed costs and could thus be unprofitable for smallholders with only one or two plots and small plantation sizes. Therefore, income diversification becomes more crucial (Siswati et al., 2020). Usage of heavy machinery is more efficient, but high fixed costs might prevent smallholders from using them. Machinery could be shared or rented through farmer groups and farmer-managed cooperatives; however, we found no studies to support this consideration. Also, we found no information on the toxicity of the poison used for the environment, nor on possible health risks for farmers.

An alternative replanting method is underplanting. The exact procedure varies, but generally, the plantations can be replanted entirely within three years. It is common to replant 50% of the plantation and the rest after 24 months or 25% each in years 2 and 3. The old stand can be removed by either heavy machinery, chainsaws, or poisoning (Corley & Tinker, 2016; Ooi & Heriansyah, 2005; SPKS, 2016). If done correctly, short-term income losses can be reduced, and overall yields might even increase. Underplanting is, however, considered to be more challenging to implement. Initial shading from the old stand might hamper the development of the young palms, increasing the risk of pest infection and slowing down the growth of the new stand (Corley & Tinker, 2016). The only study we found on smallholder underplanting was by Ernawati et al. (2019). The study suggests that the acceptance of underplanting among smallholders in Jambi is considerably lower when compared to the conventional technique of felling and chipping. Maintenance costs were said to be higher due to the different age patterns of the palms. The income of smallholders who implemented this technique was also lower. Higher maintenance costs and lower

incomes suggest that underplanting requires a higher level of management skills to maximize plantation yields and profits.

Additionally, the replanting process could be used to redesign the new plantations to improve their productivity, for example, by increasing the palm density (Ernawati et al., 2021) or selecting higher-yielding varieties. Biodiversity enrichment measures could also complement the methods. Experimental studies have shown that integrating native trees into oil palm plantations can positively affect biodiversity and ecosystem services while at the same time having little effect on oil palm yields (Gérard et al., 2017; Teuscher et al., 2015; Zemp et al., 2019). As these experiments were conducted on medium-sized plantations, it is unclear to what extent results can be applied to smallholder plantations.

4 Impeding factors in smallholder replanting

4.1 Replanting financing

During the productive phase, oil palm provides a relatively stable income for smallholder farmers (Mehraban et al., 2021). Income from oil palm cultivation can be up to ten times higher compared to rice cultivation (Rival & Levang, 2014). At the same time, replanting can represent a substantial financial burden for smallholders. Replanting costs are estimated to be between 3200 € and 3800 € per hectare (Nurfatriani et al., 2019). These costs might further increase if best management practices are not applied and/or if biodiversity enrichment measures are implemented. Studies on smallholder income are rare, but the four we found (Table 2), clearly indicate the necessity for longstanding savings before replanting can be financed. In the study by Ramadhana et al. (2021) smallholders generated an annual net income of 1660 € per hectare with their oil palm plantations, while their household expenditures amounted to 1500 €. Lee et al. (2014) show that income among independent smallholders could be significantly lower when compared with scheme smallholders. Furthermore, it can take up to 18 years, for smallholders to repay their loans for the initial plantation establishment (Rist et al., 2010). This impedes their ability to invest in replanting.

Besides the necessary investments for replanting, smallholders also have to cope with reduced income during the unproductive phase of the new stand. Depending on their replanting method, they lose their income from the plantation partially or entirely for a few years. In two case studies conducted in Jambi Province, potential and actual household income losses during the non-productive phase were 75% and 71%, respectively (Novra et al., 2021; Yanita et al., 2021a, 2021b). This would increase the off-farm income dependency of smallholders and could lead to a long-term reallocation of labor.

Most smallholders will need financial support. In another case study from Jambi, 93% of the interviewed smallholders reported the need for financial aid. Access to financing is a major problem for Indonesian smallholders, particularly local smallholders, who often have no official land certificates, and are thus excluded from the formal banking sector. Consequently, many smallholders rely on informal credits at detrimental conditions (Glenday & Paoli, 2015; Krishna et al., 2017; Sahara et al., 2017).

In 2015 the governmental Oil Palm Plantation Fund Management Agency (Badan Pengelola Dana Perkebunan Kelapa Sawit—abbreviation: BPDPKS) was established to collect and distribute oil palm funds via the replanting program PSR to support smallholders in their replanting efforts (BPDPKS, 2019a). Even though the application procedure was

Table 2 Income of smallholders

Study	Study area	Income measure (per hectare)	Smallholder type	Amount (€)
Rival and Levang (2014)	Sumatra	Annual income	Not specified	2100
Lee et al. (2014)	Sumatra	Annual gross income	Not specified	1200
		Annual gross income	Independent	720
Yanita et al., (2021a, 2021b)	Sumatra	Annual net household income	Not specified	860
Ramadhana et al. (2021)	Sulawesi	Annual net household income	Not specified	1900

simplified in 2019 (BPDPKS, 2019b), the success of this program can still be improved. Applicants have to prove that their plantation is not in dispute, and hold official land certificates, which continues to be a major burden for local smallholders. As elaborated above, some plantations are located in state forest areas or other areas with contested land ownership, and thus they cannot receive official land certificates. Applicants must further be members of a farmer group or cooperative. We did not find representative evidence on the prevalence of farmer groups and cooperatives, but in another Jambi-based case study, 35% of the farmers had no membership (Yanita et al., 2021a, 2021b). Against this background, the requirement to be part of a farmer group or cooperative could be another obstacle to receiving state funding.

According to the Indonesian Oil Palm Smallholders Union (Serikat Petani Kelapa Sawit – abbreviation: SPKS), many smallholders do not even know that the PSR exists (SPKS, 2016). And those who know the program seem overwhelmed by the application process (Syarfi et al., 2019a, 2019b). Finally, even if a smallholder receives PSR funding, it is limited to 1,600 € per hectare and capped at 6,370 € in total (Nurfatriani et al., 2019). The rest of the costs must be paid with savings and/or bank loans, which, again, is a problem, particularly for smallholders with no land certificates. It is not surprising that some smallholders state that they prefer keeping their non-profitable plantations and have no plan to replant (Syarfi et al., 2019a, 2019b). So far, the 180,000 hectares yearly replanting goals have not been met (Ardana, 2022). Since late 2017 until the end of 2022, only 278,000 hectares have been replanted (Reuters, 2023).

4.2 Access to input materials and knowledge

Large oil palm corporations with abundant land, financial, and human resources, as well as technical knowledge, can make optimal decisions to maximize profits. On the contrary, smallholders might have limited financial resources and knowledge for best management practices (Aguilar et al., 2022).

Smallholders typically only have access to low-quality fertilizer, and its application is often suboptimal. Furthermore, smallholders tend to use less productive seedlings which have inferior germination rates, and ripen irregularly, which increases harvesting costs. This is particularly common among independent smallholders. It has also been reported that smallholders use seedlings from their own nursery based on seeds from their current palms, which is often associated with low-quality seedling material (Jelsma et al., 2017; Soliman et al., 2016; Woittiez et al., 2017). There is no evidence of smallholders' access to heavy machinery, but the fact that smallholders resort to using chainsaws for replanting indicates a lack of more efficient alternatives.

Another constraint is the knowledge gap between independent and plasma smallholders (Kannan et al., 2017). While plasma smallholders can rely on their company's expertise and possibly exchange knowledge with other scheme smallholders, independent smallholders often do not have a similar network. Especially local independent smallholders usually have no prior experience with oil palm cultivation. Independent smallholders appear to rely on informal farmer groups and their input suppliers for information (Jelsma et al., 2017).

5 Discussion

5.1 The necessity for changes

The shortcomings mentioned in the previous section will negatively impact smallholders' ability to replant and affect their willingness to do so in the first place. Smallholders are usually not in the position to think about maximizing profits, but their decisions are made to satisfy and suffice (Cordaro & Desdoigts, 2021). Bounded rationality due to limited information and knowledge may cause smallholders to inaccurately assess the replanting costs, miss out on opportunities for support, and overlook improvement potentials. Previous studies have shown that smallholders tend to be risk averse (Clough et al., 2016; Sarwosri & Mußhoff, 2020). In the absence of proper knowledge about the replanting process and without access to affordable funding and high-quality input materials, risk-averse farmers will likely delay investments in replanting.

Studies have shown that replanting is connected to high investment costs and potentially severe income losses. Underplanting is suitable to buffer income losses, but only if implemented correctly; otherwise, it can negatively affect income and plantation productivity. The concern of being unable to cope with the additional burden of replanting seems to be prevalent among smallholders, causing a delay in the replanting process (Napitupulu et al., 2021). This effect could be further amplified by the increasing CPO prices, that might compensate for decreasing plantation productivity (Zainal et al., 2018). Eventually, economic productivity will decrease and the associated income losses will threaten smallholders' livelihoods.

In another scenario, smallholders might be tempted to burn their old stand to reduce the clearing costs, which accounts for half of the replanting costs (Yanita et al., 2021a, 2021b). Although burning leads to significant carbon dioxide emissions and has been illegal since 2015, it is still practiced (Goldstein et al., 2020; Hartmann et al., 2018; Silvianingsih et al., 2020). Without support, there is also higher chance for expansion of oil palm area as well as more potential land conflicts. Smallholders could also be forced to sell their land and thus lose their main income source.

Farmer groups and cooperatives could be of help in the replanting process by providing financial, technical, and material support. However, many farmer groups are inactive, and some cooperatives need to be more transparent. Groups and cooperatives often seem overwhelmed with their responsibilities (Syarfi et al., 2019a, 2019b; Yanita et al., 2021a, 2021b). Results by Jelsma et al. (2017) suggest that cooperatives and farmer groups only play a minor role as a provider of fertilizer, which makes it questionable how important they are in terms of material supply. Furthermore, there needs to be more reliable evidence on how prevalent they are.

State efforts to accelerate replanting and to support smallholders have had limited success so far. The dissemination and distribution of the program needs to be improved. One

of the main problems is that the program automatically excludes those who need the funding the most: mainly local, independent smallholders without land certificates. They have the lowest yields, lower income and the most limited access to finances and quality seedlings. Finally, in addition to liquid funds, smallholders additionally require training in best management practices to increase productivity and be able to establish more sustainable oil palm plantations.

5.2 Recommendations

5.2.1 Provide training, improve information flow

Replanting requires timely and thorough planning. Pest control becomes more critical, and the proper use of fertilizer is crucial to optimize palm growth and reduce farm expenditures. In the past, training offers have proven to increase smallholders' knowledge of best management practices (Ishak et al., 2020; Romero et al., 2019; Syahza et al., 2018) as well as the productivity of oil palm plantations (Elias et al., 2013). Proper training could support smallholders' decision making (Moser & Barrett, 2006).

The BPDPKS suggests that smallholders should diversify their income sources during replanting, for example, by cultivating other cash crops (BPDPKS, 2020) or pond fish farming (Siswati et al., 2020). If done correctly, the additional income can compensate for the income losses from replanting. Naturally, such improvements would require new investments, new skills, and the opening of new markets, for which support, information and training would be necessary.

Furthermore, smallholders need support regarding new plantation designs. Underplanting is better than replanting the whole plantation at once but requires a higher level of management skills. Replanting offers the opportunity to make replanted plantations more environmentally sustainable, but it will also make plantation management more complex. Up to 2.4 Mha of smallholder plantations need replanting within this decade. This offers a unique chance to significantly improve oil palm's sustainability, using enrichment planting with native trees (Gérard et al., 2017) or alley cropping (Slingerland et al., 2019).

Once again, farmer groups and cooperatives can play an essential role in providing and/or organizing training, information, and support. Nevertheless, the little amount of data that exists suggests that their potential is far from being exhausted.

5.2.2 Push the use of high-quality seedlings and facilitate access to markets

Next to information flow, practical support may prove useful. Smallholders, particularly independent ones, do not have the same access to the oil palm supply chain as large-scale companies. With better seedlings, smallholders may increase their oil fruit production by 30% (Jelsma et al., 2017). Therefore, policymakers should find ways to guarantee easy and affordable access to high-quality seedlings.

For the initial phase of replanting, when the palms are unproductive, the BPDPKS suggests that smallholders should expand their income sources. For example the felled trunks can be used to produce brown sugar or sold to the timber and furniture industry. Oil palm fronds could be utilized for craftsmanship (BPDPKS, 2020). Studies have shown how oil palm residues, like the trunks, can be used as additional income sources (Fakhri et al., 2020; H`ng et al., 2011; Hambali & Rivai, 2017). But again, political decision-makers

must facilitate access to these markets and establish an infrastructure where the smallholders can sell their goods. The same applies to other agricultural products that smallholders might produce as part of their income diversification.

5.2.3 Clarify the ambiguous land tenure regulations and reform the PSR

Indonesia has a long history of legal and institutional pluralism regarding land tenure regulations (Kunz et al., 2017). The local use of customary laws was long tolerated. Locals used them to regulate land access and land use in their communities—including the establishment of oil palm plantations. Many of these plantations are now located in a state-declared forests. The affected local smallholders own officially illegal plantations and cannot receive land certificates. Without these, the smallholders are practically excluded from official loans. They must rely on informal loans at poor conditions, directly affecting their ability to save money and make investments. Therefore, clarifying ambiguous land tenure regulations is essential to support smallholder replanting.

Indeed, this is a huge task and will likely take time to complete. In the meantime, government support needs to be reformed to support smallholder replanting. Since those who do not have land certificates are the ones that need support the most, the requirements for access to funding support programs should be adjusted. Furthermore, the funding amount should be increased. Currently, it only covers half of the expenses at maximum, with limited possibilities for other financing sources. Lastly, the funding program should expand its responsibilities and organize training, for example, regarding best management practices or income diversification, and provide or at least facilitate access to materials, particularly high-quality seedlings and machinery.

6 Conclusion

In this article, we reviewed the literature on smallholder replanting of oil palm plantations and identified the challenges Indonesian smallholders will likely face before, during, and after replanting. The purpose of this review is to combine the key information in this study area and understand the state-of-the-art of smallholder oil palm replanting. Further, we revealed several crucial research gaps that should be addressed in future studies. We also derived several policy recommendations. Our study has a limitation. This review is purely qualitative by design, therefore, there is no meta-analysis. A meta-analysis would give more structure to the study. However, given the limited availability of literature on smallholder replanting, we opt for a narrative review to open this field to future research.

Our review showed that up to 50% of smallholder oil palm plantations in Indonesia need to be replanted within this decade. When replanting becomes imminent, smallholders face several challenges, which past literature has not adequately addressed. The failure to engage in replanting will result in decreasing yields, entailing income losses, and deteriorating livelihoods. As a consequence, some smallholders will likely be forced to sell their plantations, or will continue to work on plantations that are becoming less and less productive. Environmental deterioration is also likely, for example, if new land is cleared to meet increasing demands or old plantations are burned to save money. On the contrary, with proper support, smallholders' risk aversion of replanting could be reduced, leading to increased income, ensuring their livelihoods, and increasing environmental sustainability

of oil palm plantations. However, this can only happen when smallholders receive substantial support.

From a policy perspective, it is critical to address the issue of smallholder replanting due to the expected environmental and socioeconomic implications and to provide support measures. Smallholders need to receive training and information on why replanting is important, when and how it is done, and where they can get technical and financial support. Here, it becomes crucial that sustainable replanting methods and measures are included in the training. It will be essential to show the benefits of these sustainable measures to increase their acceptance among smallholders. Only then can the replanted oil palm plantations increase their environmental sustainability and ensure smallholders' income. Research can help to identify specific problems smallholders face when replanting occurs and, based on these insights, design proper training concepts. Making such trainings accessible to smallholder farmers should be a priority for policymakers. One way to achieve easy access is to reform the PSR program by including training measures. Furthermore, the different smallholder types need to be acknowledged in the process. Particularly the perspective and needs of local independent smallholders, who are typically most deprived of access to resources and information, have to be considered.

Policymakers should further facilitate access to materials, such as high-quality seedlings, funding schemes, and new markets for income diversification. An efficient way to facilitate access to funding schemes is to reform the PSR, mainly by solving the issue of ambiguous land tenure regulations, making the application for the program more appealing to smallholders. Research can help to determine how smallholders can be provided most effectively with access to supply chains and funding schemes by analyzing smallholder needs.

Farmer groups and cooperatives can function as a mediator between individual smallholders and policymakers. They can provide support for smallholders in many ways. However, their maximum potential has yet to be utilized. Smallholders have mixed opinions with regard to trust toward farmer groups and cooperatives. Both institutions should aim to benefit their members and communities by communicating more transparently and promoting community-based activities. Future research must gather data on their prevalence and their difficulties. They should receive support in organizing and optimizing themselves.

Future research should guide the implementation of the above-mentioned suggestions. Potential pathways to resolve land-title disputes need to be assessed. Access to public programs like the PSR can be optimized but requires in-depth reviews of the process and smallholder experiences with it. The prevalence of replanting methods needs to be documented and connected to environmental and socioeconomic pre-requisites and consequences. And finally, the implementation of replanting policies should be tested experimentally in different designs to ensure a good fit to smallholder needs.

Addressing the challenges associated with replanting can improve both socioeconomic and environmental conditions and help transform Indonesia's smallholder oil palm sector in Indonesia toward more sustainability.

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Declarations

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References

Aguilar, F. X., Hendrawan, D., Cai, Z., Roshetko, J. M., & Stallmann, J. (2022). Smallholder farmer resilience to water scarcity. *Environment, Development and Sustainability, 24*(2), 2543–2576.

Anwar, M. Z., & Sunesti, Y. (2021). Vulnerable people and sustainable livelihoods in the face of replanting phase in oil palm industry in Jambi - Sumatra. *IOP Conference Series: Earth and Environmental Science, 716*(1), 12112. https://doi.org/10.1088/1755-1315/716/1/012112

Ardana, I. K., Wulandari, S., & Hartati, R. S. (2022) Urgency to accelerate replanting of Indonesian oil palm: A review of the role of seed institutions. *IOP Conference Series: Earth and Environmental Science, 974*(1), 012104. https://doi.org/10.1088/1755-1315/974/1/012104

Ávila, R. A., Bayona, C., Ricón, Á., & Romero, H. M. (2014). Effect of replanting systems on populations of Strategus aloeus (L.) and Rhynchophorus palmarum (L.) associated with the oil palm OxG interspecific hybrid (Elaeis oleifera × Elaeis guineensis) in Southwestern Colombia. *Agronomía Colombiana, 32*(2), 224–231. https://doi.org/10.15446/agron.colomb.v32n2.43011

Bayona Rodríguez, C. J., Ávila Diazgranados, R. A., Rincón Numpaque, Á. H., & Romero Angulo, H. M. (2015). CO2 soil emission under different methods of oil palm replanting. *Revista Facultad Nacional De Agronomía Medellín, 68*(2), 7619–7625. https://doi.org/10.15446/rfnam.v68n2.50949

BPDPKS. (2019a). *BPDPKS in Brief*. http://www.bpdp.or.id/en/bpdpks-in-brief

BPDPKS. (2019b). *Govt Makes Procedures Easier to Replant Oil Palm*. http://www.bpdp.or.id/en/govt-makes-procedures-easier-to-replant-oil-palm

BPDPKS. (2020). *Potential Income Sources for Oil Palm Farmers During Replanting Seasons*. http://www.bpdp.or.id/en/potential-income-sources-for-oil-palm-farmers-during-replanting-seasons

Clough, Y., Krishna, V. V., Corre, M. D., Darras, K., Denmead, L. H., Meijide, A., Moser, S., Musshoff, O., Steinebach, S., Veldkamp, E., Allen, K., Barnes, A. D., Breidenbach, N., Brose, U., Buchori, D., Daniel, R., Finkeldey, R., Harahap, I., Hertel, D., & Scheu, S. (2016). Land-use choices follow profitability at the expense of ecological functions in Indonesian smallholder landscapes. *Nature Communications, 7*, 13137. https://doi.org/10.1038/ncomms13137

Cordaro, F., & Desdoigts, A. (2021). Bounded rationality, social capital and technology adoption in family farming: Evidence from cocoa-tree crops in Ivory Coast. *Sustainability, 13*(13), 7483. https://doi.org/10.3390/su13137483

Corley, R. H. V., & Tinker, P. B. (2016). *The oil palm* (Fifth edition). John Wiley & Sons. http://search.ebscohost.com/login.aspx?direct=true&scope=site&db=nlebk&AN=1079110

Elias, A., Nohmi, M., Yasunobu, K., & Ishida, A. (2013). Effect of agricultural extension program on smallholders' farm productivity: Evidence from three peasant associations in the highlands of Ethiopia. *Journal of Agricultural Science, 5*(8), 163.

Ernawati, H. D., Saputra, A., Alamsyah, Z., Napitupulu, D. M. T., Yanita, M., & Fauzia, G. (2021). Analysis of independent oil palm farming income after replanting in Muaro Jambi District. *IOP Conference Series: Earth and Environmental Science, 782*(3), 32055. https://doi.org/10.1088/1755-1315/782/3/032055

Ernawati, H. D., Suandi, Yanita, M., & Qoirina, N. (2019). The impact of replanting oil palm plantations on the farming income of the Sungai Bahar community in Muaro Jambi Regency. *IOP Conference*

Series: Earth and Environmental Science, *336*, 12003. Doi: https://doi.org/10.1088/1755-1315/336/1/012003.

Euler, M., Hoffmann, M. P., Fathoni, Z., & Schwarze, S. (2016). Exploring yield gaps in smallholder oil palm production systems in eastern Sumatra, Indonesia. *Agricultural Systems, 146*, 111–119. https://doi.org/10.1016/j.agsy.2016.04.007

Euler, M., Schwarze, S., Siregar, H., & Qaim, M.. (2015). *Oil palm expansion among smallholder farmers in Sumatra, Indonesia* (EFForTs Discussion Paper Series No. 8). Göttingen.

Fakhri, F., Malik, A., Aldy, P., Elianora, E., & Zulkifli, Z. (2020). Pemberdayaan masyarakat melalui penerapan teknologi pengawetan dan pengolahan batang sawit untuk bahan baku mebel dekoratif. *Unri Conference Series: Community Engagement, 2*, 241–245. https://doi.org/10.31258/unricsce.2.241-245

Feintrenie, L., Chong, W. K., & Levang, P. (2010). Why do farmers prefer oil palm? Lessons learnt from Bungo district, Indonesia. *Small-Scale Forestry, 9*(3), 379–396. https://doi.org/10.1007/s11842-010-9122-2

Ferwerda, J. D. (1955). *Questions relevant to replanting in oil palm cultivation*. H. Veenman & Zonen.

Gatto, M., Wollni, M., & Qaim, M. (2015). Oil palm boom and land-use dynamics in Indonesia: The role of policies and socioeconomic factors. *Land Use Policy, 46*, 292–303. https://doi.org/10.1016/j.landusepol.2015.03.001

Gérard, A., Wollni, M., Hölscher, D., Irawan, B., Sundawati, L., Teuscher, M., & Kreft, H. (2017). Oil-palm yields in diversified plantations: Initial results from a biodiversity enrichment experiment in Sumatra, Indonesia. *Agriculture, Ecosystems & Environment, 240*, 253–260. https://doi.org/10.1016/j.agee.2017.02.026

Glenday, S., & Paoli, G. (2015). *Overview of Indonesian oil palm smallholder farmers: A typology of organizational models, needs, and investment opportunities.*

Goh, K. J. (2005). *Fertilzer Recommendation Systems for Oil Palm: Estimating the Fertilizer Rates*. http://barformula.com/assets/pdf/research_paper15.pdf

Goldstein, J. E., Graham, L., Ansori, S., Vetrita, Y., Thomas, A., Applegate, G., Vayda, A. P., Saharjo, B. H., & Cochrane, M. A. (2020). Beyond slash-and-burn: The roles of human activities, altered hydrology and fuels in peat fires in Central Kalimantan, Indonesia. *Singapore Journal of Tropical Geography, 41*(2), 190–208. https://doi.org/10.1111/sjtg.12319

H`ng, P. S., Wong, L. J., Chin, K. L., Tor, E. S., Tan, S. E., Tey, B. T., & Maminski, M. (2011). Oil palm (Elaeis guineensis) trunk as a resource of starch and other sugars. *Journal of Applied Sciences, 11*(16), 3053–3057. https://doi.org/10.3923/jas.2011.3053.3057

Hambali, E., & Rivai, M. (2017). The potential of palm oil waste biomass in Indonesia in 2020 and 2030. *IOP Conference Series: Earth and Environmental Science, 65*, 12050. https://doi.org/10.1088/1755-1315/65/1/012050

Hartmann, F., Merten, J., Fink, M., & Faust, H. (2018). Indonesia's fire crisis 2015: A twofold perturbation on the ground. *Pacific Geographies, 49*, 4–11. https://doi.org/10.23791/490411

Herdiansyah, H., Negoro, H. A., Rusdayanti, N., & Shara, S. (2020). Palm oil plantation and cultivation: Prosperity and productivity of smallholders. *Open Agriculture, 5*(1), 617–630. https://doi.org/10.1515/opag-2020-0063

InfoSAWIT.TV. (2021). *Meningkatkan Peranan Petani Sawit Rakyat Melalui Subsidi Replanting dan Subsidi Sarpras*. https://www.youtube.com/results?search_query=infosawit

Ishak, S. M., Aman, Z., & Taib, H. M. (2020). An evaluation on outcome of oil palm replanting scheme (TSSPK) and new planting scheme (TBSPK). *International Journal of Modern Trends in Social Sciences, 3*(14), 129–148. https://doi.org/10.35631/ijmtss.3140011

Ismail, A., & Mamat, M. N. (2002). The optimal age of oil palm replanting. *Oil Palm Industry Economic Journal, 2*(1), 11–18.

Jelsma, I., Schoneveld, G. C., Zoomers, A., & van Westen, A. (2017). Unpacking Indonesia's independent oil palm smallholders: An actor-disaggregated approach to identifying environmental and social performance challenges. *Land Use Policy, 69*, 281–297. https://doi.org/10.1016/j.landusepol.2017.08.012

Kannan, P., Peng, T. S., Ahmad, S. M., Seman, I. A., Rahman, A. K. B., Hashim, K., Bakar, H. A., & Omar, W. (2017). Knowledge assessment of basal stem rot disease of oil palm and its control practices among recipients of replanting assistance scheme in Malaysia. *International Journal of Agricultural Research, 12*(2), 73–81. https://doi.org/10.3923/ijar.2017.73.81

Krishna, V., Euler, M., Siregar, H., & Qaim, M. (2017). Differential livelihood impacts of oil palm expansion in Indonesia. *Agricultural Economics, 48*(5), 639–653. https://doi.org/10.1111/agec.12363

Kubitza, C. A. (2018). *Land-use change and rural development in Indonesia: Economic, institutional and demographic aspects of deforestation and oil palm expansion.*

Kunz, Y., Steinebach, S., Dittrich, C., Hauser-Schäublin, B., Rosyani, I., Soetarto, E., & Faust, H. (2017). 'The fridge in the forest': Historical trajectories of land tenure regulations fostering landscape transformation in Jambi Province, Sumatra, Indonesia. *Forest Policy and Economics, 81*, 1–9. https://doi.org/10.1016/j.forpol.2017.04.005

Kushairi, A., Loh, S. K., Azman, I., Hishamuddin, E., Ong-Abdullah, M., Izuddin, Z. B., Razman, G., Sundram, S., & Parveez, G. (2018). Oil palm economic performance in Malaysia and R&D progress in 2017. *Journal of Oil Palm Research, 30*(2), 163–195. https://doi.org/10.21894/jopr.2018.0030

Lee, J. S. H., Ghazoul, J., Obidzinski, K., & Koh, L. P. (2014). Oil palm smallholder yields and incomes constrained by harvesting practices and type of smallholder management in Indonesia. *Agronomy for Sustainable Development, 34*(2), 501–513. https://doi.org/10.1007/s13593-013-0159-4

markets.businessinsider.com. (2022). *Palm Oil PRICE Today | Palm Oil Spot Price Chart | Live Price of Palm Oil per Ounce | Markets Insider*. https://markets.businessinsider.com/commodities/palm-oil-price

McCarthy, J. (2010). Processes of inclusion and adverse incorporation: Oil palm and agrarian change in Sumatra, Indonesia. *The Journal of Peasant Studies, 37*(4), 821–850. https://doi.org/10.1080/03066150.2010.512460

Mehraban, N., Kubitza, C., Alamsyah, Z., & Qaim, M. (2021). Oil palm cultivation, household welfare, and exposure to economic risk in the Indonesian small farm sector. *Journal of Agricultural Economics*. https://doi.org/10.1111/1477-9552.12433

Mongabay Environmental News. (2020). *Indonesia aims for sustainability certification for oil palm smallholders*. https://news.mongabay.com/2020/04/indonesia-aims-for-sustainability-certification-for-oil-palm-smallholders/

Moser, C. M., & Barrett, C. B. (2006). The complex dynamics of smallholder technology adoption: The case of SRI in Madagascar. *Agricultural Economics, 35*(3), 373–388. https://doi.org/10.1111/j.1574-0862.2006.00169.x

Napitupulu, D., Alamsyah, Z., Ernawati, H. D., Yanita, M., Elwamendri, E., & Fauzia, G. (2021). Impact of oil palm plantation on household welfare in Jambi Province. *IOP Conference Series: Earth and Environmental Science, 782*(3), 32056. https://doi.org/10.1088/1755-1315/782/3/032056

Naylor, R. L., Higgins, M. M., Edwards, R. B., & Falcon, W. P. (2019). Decentralization and the environment: Assessing smallholder oil palm development in Indonesia. *Ambio, 48*(10), 1195–1208. https://doi.org/10.1007/s13280-018-1135-7

Novra, A., & Fatati, A. (2021). Preparing households for the oil palm replanting program: Is an empowerment program needed? *Journal of Southwest Jiaotong University, 56*(3), 179–195. https://doi.org/10.35741/issn.0258-2724.56.3.15

Nurfatriani, F., Ramawati, Sari, G. K., & Komarudin, H. (2019). Optimization of crude palm oil fund to support smallholder oil palm replanting in reducing deforestation in Indonesia. *Sustainability*, *11*(18), 4914. Doi: https://doi.org/10.3390/su11184914.

Ompusunggu, M., & Gunawan, A. (2018). *Independent oil palm smallholders neglected in sustainability efforts*. The Jakarta Post. https://www.thejakartapost.com/news/2018/04/05/independent-oil-palm-smallholders-neglected-in-sustainabilityeffort.html

Ooi, L.-H., & Heriansyah, H. (2005). Palm pulverisation in sustainable oil palm replanting. *Plant Production Science, 8*(3), 345–348. https://doi.org/10.1626/pps.8.345

Prokopy, L. S., Floress, K., Klotthor-Weinkauf, D., & Baumgart-Getz, A. (2008). Determinants of agricultural best management practice adoption: Evidence from the literature. *Journal of Soil and Water Conservation, 63*(5), 300–311. https://doi.org/10.2489/jswc.63.5.300

Qaim, M., Sibhatu, K. T., Siregar, H., & Grass, I. (2020). Environmental, economic, and social consequences of the oil palm boom. *Annual Review of Resource Economics, 12*(1), 321–344. https://doi.org/10.1146/annurev-resource-110119-024922

Ramadhana, A., Ahmed, F., & Thingrak, S. (2021). The impact of oil palm farming on household income and expenditure in Indonesia. *The Journal of Asian Finance, Economics and Business, 8*(4), 539–547. https://doi.org/10.13106/JAFEB.2021.VOL8.NO4.0539

Reuters. (2023). *Indonesia must achieve palm oil replanting target-senior official*. https://www.reuters.com/article/indonesia-palmoil-idUSKBN2V10EI

Riggs, R. A., Sayer, J., Margules, C., Boedhihartono, A. K., Langston, J. D., & Sutanto, H. (2016). Forest tenure and conflict in Indonesia: Contested rights in Rempek Village, Lombok. *Land Use Policy, 57*, 241–249. https://doi.org/10.1016/j.landusepol.2016.06.002

Rist, L., Feintrenie, L., & Levang, P. (2010). The livelihood impacts of oil palm: Smallholders in Indonesia. *Biodiversity and Conservation, 19*(4), 1009–1024. https://doi.org/10.1007/s10531-010-9815-z

Rival, A., & Levang, P. (2014). *Palms of controversies: Oil palm and development challenges.*

Romero, M., Wollni, M., Rudolf, K., Asnawi, R., & Irawan, B. (2019). Promoting biodiversity enrichment in smallholder oil palm monocultures: Experimental evidence from Indonesia. *World Development, 124*, 104638. https://doi.org/10.1016/j.worlddev.2019.104638

Sahara, Haryadi, & N., K. (2017). *Smallholder finance in the palm oil sector: Analyzing the gaps between existing credit schemes and smallholder realities*. Center for International Forestry Research (CIFOR). Doi: https://doi.org/10.17528/cifor/006582.

Sarwosri, A. W., & Mußhoff, O. (2020). Are risk attitudes and time preferences crucial factors for crop diversification by smallholder farmers? *Journal of International Development, 32*(6), 922–942. https://doi.org/10.1002/jid.3483

Schleicher, T., Hilbert, I., Manhart, A., Hennenberg, K., Ernah, Shella Vidya, & Fakhriya, I. (2019). *Production of Palm Oil in Indonesia: Country-focused commodity analysis in the context of the Bio-Macht project*. Freiburg. Öko-Institut e.V.

Schoneveld, G. C., Ekowati, D., Andrianto, A., & van der Haar, S. (2019). Corrigendum: Modeling peat- and forestland conversion by oil palm smallholders in Indonesian Borneo. *Environmental Research Letters, 14*(11), 119501. https://doi.org/10.1088/1748-9326/ab4870

Silvianingsih, Y. A., Hairiah, K., Suprayogo, D., & van Noordwijk, M. (2020). Agroforests, swiddening and livelihoods between restored peat domes and river: Effects of the 2015 fire ban in Central Kalimantan (Indonesia). *International Forestry Review, 22*(3), 382–396. https://doi.org/10.1505/146554820830405645

Siswati, L., Nizar, R., & Insusanty, E. (2020). Source of farmers income in the sustainable palm oil replanting in Riau province. *IOP Conference Series: Earth and Environmental Science, 515*, 12074. https://doi.org/10.1088/1755-1315/515/1/012074

Slingerland, M. A., Khasanah, N. M., van Noordwijk, M., Susanti, A., & Meilantina, M. (2019). Improving smallholder inclusivity through integrating oil palm with crops. *Exploring Inclusive Palm Oil Production, 59*, 147–154.

Soliman, T., Lim, F. K. S., Lee, J. S. H., & Carrasco, L. R. (2016). Closing oil palm yield gaps among Indonesian smallholders through industry schemes, pruning, weeding and improved seeds. *Royal Society Open Science, 3*(8), 160292. https://doi.org/10.1098/rsos.160292

SPKS. (2016). Standar Operasional Prosedur Manajemen Replanting.

Statista. (2021). *Palm oil industry in Indonesia.* Statista. https://www.statista.com/study/70058/palm-oil-industry-in-indonesia/

Syahza, A., Bakce, D., & Asmit, B. (2018). Increasing the awareness of palm oil plantation replanting through farmers training. *Riau Journal of Empowerment, 1*(1), 1–9. https://doi.org/10.31258/raje.1.1.1

Syarfi, I. W., Noer, M., & Utami, A. S. (2019). Replanting of smallholder palm oil plantations in Dharmasraya District, West Sumatera Province, Indonesia. *IOP Conference Series: Earth and Environmental Science, 250*, 12091. https://doi.org/10.1088/1755-1315/250/1/012091

Syarfi, I. W., Noer, M., & Utami, A. S. (2019b). Empowerment of the smallholders' cooperative for palm oil plantation replanting of Pir-Trans scheme in Dharmasraya District West Sumatera Province, Lectures of Socioeconomic Departement, Faculty of Agriculture. In *Proceedings of the international conference on innovation in research (ICIIR 2018) – section: Economics and management science.* Atlantis Press. Doi: https://doi.org/10.2991/iciir-18.2019.23.

Teuscher, M., Vorlaufer, M., Wollni, M., Brose, U., Mulyani, Y., & Clough, Y. (2015). Trade-offs between bird diversity and abundance, yields and revenue in smallholder oil palm plantations in Sumatra, Indonesia. *Biological Conservation, 186*, 306–318. https://doi.org/10.1016/j.biocon.2015.03.022

USDA. (2012). Malaysia: Stagnating palm oil yields impede growth. Commodity Intelligence Report.

Virdiana, I., Hasan, Y., Aditya, R., & Flood, J. (2020). *Testing the effects of oil palm replanting practices (windrowing, fallowing and poisoning) on incidence of Ganoderma*. https://www.gov.uk/research-for-development-outputs/testing-the-effects-of-oil-palm-replanting-practices-windrowing-fallowing-and-poisoning-on-incidence-of-ganoderma#citation

Wahid, M. B., & Simeh, M. A. (2009). Issues related to production cost of palm oil in Malaysia. *Oil Palm Industry Economic Journal, 9*(2), 1–124.

Wahid, M. B., & Simeh, M. A. (2010). Accelerated oil palm replanting the way forward for a sustainable and competitive industry. *Oil Palm Industry Economic Journal, 10*(2), 29–38.

Wicke, B., Sikkema, R., Dornburg, V., & Faaij, A. (2011). Exploring land use changes and the role of palm oil production in Indonesia and Malaysia. *Land Use Policy, 28*(1), 193–206. https://doi.org/10.1016/j.landusepol.2010.06.001

Woittiez, L. S., van Wijk, M. T., Slingerland, M., van Noordwijk, M., & Giller, K. E. (2017). Yield gaps in oil palm: A quantitative review of contributing factors. *European Journal of Agronomy, 83*, 57–77. https://doi.org/10.1016/j.eja.2016.11.002

Yanita, M., Alamsyah, Z., Napitupulu, D., Hamid, E., & Fauzia, G. (2021b). Can smallholder's oil palm income contribute to household expenses during replanting? *IOP Conference Series: Earth and Environmental Science, 716*(1), 12086. https://doi.org/10.1088/1755-1315/716/1/012086

Yanita, M., Napitupulu, D., Alamsyah, Z., Ernawati, H. D., Elwamendri, & Fauzia, G. (2021a). What is the priority pattern for replanting the independent smallholders oil palm in Jambi Province? *IOP Conference Series: Earth and Environmental Science*, *782*(3), 32059. Doi: https://doi.org/10.1088/1755-1315/782/3/032059.

Zainal, A. N., Dewi, A., Shri, & Faeid, M., Mohd, Z. (2018). Maximizing crude palm oil production in Malaysia: A search for an optimal policy using system dynamics and genetic algorithm approach. *The Journal of Social Sciences Research* (SPI6), 878–884. Doi: https://doi.org/10.32861/jssr.spi6.878.884.

Zemp, D. C., Gérard, A., Hölscher, D., Ammer, C., Irawan, B., Sundawati, L., Teuscher, M., & Kreft, H. (2019). Tree performance in a biodiversity enrichment experiment in an oil palm landscape. *Journal of Applied Ecology, 56*(10), 2340–2352. https://doi.org/10.1111/1365-2664.13460

Zulkifli, H., & Khalid, H. (2008). The effect of incorporating palm residues at replanting on phosphate dynamics in an inland soil in Malaysia. *Journal of Oil Palm Research, 20*, 559–570.