HUNGRY PALM OIL MILLS IN CENTRAL KALIMANTAN, INDONESIA

Key Players for Moving Towards Sustainability in the Palm Oil Supply Chain

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Cover Picture: Aerial footage of palm oil and the forest in Sentabai Village, West Kalimantan, 2017 (adapted from photo by Nanang Sujana, CIFOR).

ABSTRACT

Deforestation is at a high level and palm oil production is a significant driver for it. Still, investments in this industry are high but are outpacing the actual production volume by far. This results in having a lot of palm oil mills running below their installed capacity, and thus creating a need for more palm and increasing the risk for forest loss. In this thesis, these mills are referred to as *hungry mills* – hungry for more palm oil fruit bunches to process. An approach was developed to identify them within a palm oil landscape

These hungry mills were tried to be identified by calculating mill supply catchments based on the maximum transport time of the palm fruits of 48 hours to guarantee the best quality. The expected yield, approached through the palm stands age and a management factor (industrial or smallholder plantation), was summarized for these areas, and compared to the installed mill capacity. With this, mills and related actors could be prioritized for transformations towards sustainability. The methodological approach is based on a geographic information system (GIS) and supplemented with Python - programming scripts.

The findings for the research area of Central Kalimantan showed, that the whole province requires more palm, and the number of hungry mills is expected to be remarkably high. Up to 45 out of 110 mills were found to operate below their installed capacity. Only two-thirds of the needed plantation area is established, creating an urgent need for more plantation area, improved management strategies, and adapted certification schemes. Analyses with the available *degraded land* in the province showed, that deforestation would not be needed to get enough supply for all these mills. To achieve this, relevant actors, like local governments, owner groups, and certification systems were identified to drive appropriate transformations in the palm oil sector. These include changes in regulations, certification, and management strategies to promote better land-use allocation, forest conservation, and palm plantation management favourable for forest development.

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LIST OF ABBREVIATIONS

CPO	Crude Palm Oil
FAO	Food and Agriculture Organization of the United Nations
FFB	Fresh Fruit Bunch
FPIC	Free, Prior and Informed Consent
GIS	Geographic Information System
HCS	High Carbon Stock
HCV	High Conservation Value
IOPP	Industrial Oil Palm Plantation
OSM	Open Street Map
P&C	Principles and Criteria
RSPO	Roundtable on Sustainable Palm Oil
SDG's	Sustainable Development Goals
SHP	Smallholder
WRI	World Resources Institute

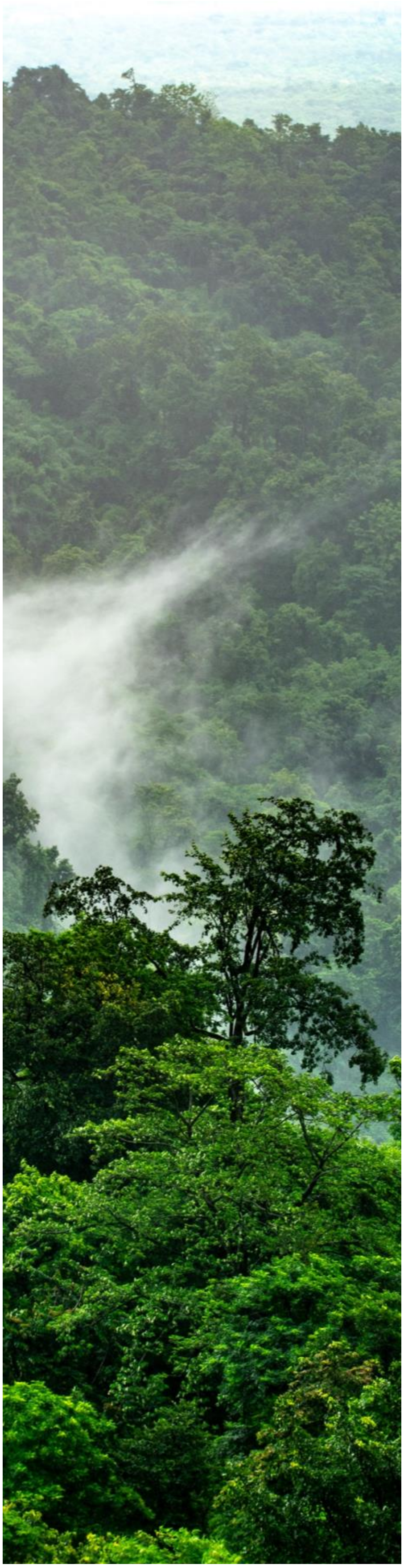


Figure 1: Rainforest in Tindharia, Darjeeling (Photo by Boudhayan Bardhan, Unsplash).

1 INTRODUCTION

1.1 PROBLEM STATEMENT AND RESEARCH FOCUS

“We Lost a Football Pitch of Primary Rainforest Every 6 Seconds in 2019”, titled the World Resources Institute in June 2020 (Weisse and Dow Goldman, 2020). Global deforestation is at a high level, the population is spreading, and more resources are needed. In our global system, forests are a main actor shaping climate, biodiversity, and social-ecological systems, providing the essentials of life on earth. It is in the air we breathe and in the food we eat.

Despite various efforts in reducing deforestation, we are still losing forest area, even it happens at a slightly slower rate from 2015 to 2020. Between 2001 and 2015, the reason for over one quarter of deforestation can be attributed to commodity-driven land use change. Palm plantations for palm oil production are among this, especially in Malaysia and Indonesia (Curtis et al., 2018). In the latter case, oil palms directly account for 23 % of the total deforestation between 2001 and 2015. There is an additional and remarkable part of forest conversion to grass- or shrubland which was later turned into oil palm plantations (Austin et al., 2019).

Nowadays, the oil of the oil palm is by far the most produced vegetable oil in the world (FAS, 2020). At the same time, it is the vegetable oil, using the fewest producing area. It yields ten times more per hectare than soybean oil, which is on the second place in the vegetable oil production ranking (Morel et al., 2016). Therefore, it is a very land-efficient product.

Mostly, oil palms are grown in monocultures. The conversion of forests to monocultural use leads to various direct and indirect effects on soil and biodiversity (Geibler, 2010). In addition to the large CO2 emissions when clearing CO2-saving forest, the conversion is associated with a loss of biodiversity, water and air pollution but can also provoke conflicts over land rights (Khatun et al., 2017).

In Indonesia, around 40 % of the palm oil production is done by smallholders, operating on smaller plantation sizes (Jelsma et al., 2017). Particularly for them, palm oil production can be an economic blessing, like it is for the national economy, but they are also relatively vulnerable compared to the large companies that operate industrial production. Unfortunately, this dependence sometimes leads to the threat of livelihoods, exploitative working conditions, or strong dependencies (Geibler, 2010; Li, 2015).

The potential of the oil palm is high, so are the risks. Particularly deforestation triggers many of the problems mentioned. To pursuing a sustainable future, transformation in the palm oil sector is needed. The ubiquitous appearance of palm oil in our everyday used products like soap, margarine or even biofuel is showing that the problems of the palm oil production and the deforestation risk are not just an issue of the producing areas but a global issue that affects everyone.

Initiatives are emerging, where companies try to remove deforestation from their supply chains. The number of producers, processors, traders, manufacturers and retailers who implemented such a supply-chain initiative increased in the last years, not at least because of the pressure from the civil society (Lambin et al., 2018). Along with these commitments, several initiatives exist to transform supply chains towards sustainability and support companies on their way towards zero deforestation. *Supply Change* for example identifies and tracks down corporate commitments analyses achievements (Donofrio et al., 2020). *Earthworm Foundation* works similarly with companies and the civil society to support them enforcing their commitments. Besides, they strive to find innovative solutions for a transformation towards sustainability, from the individual link to the whole supply chain (Earthworm, 2020).

The *Earthworm Foundation* brought up the need for spatially explicit knowledge about palm oil mills, the first processing stage in the palm oil supply chain. Even though knowledge on the individual members of the palm oil supply chain and their linkages is increasing, knowledge on the mill's supply catchment is scarce. However, it would be crucial for characterizing a mill's impact on the surrounding landscape and thus predicting linked deforestation areas due to the development of palm plantations. In Indonesia, the investment in installed mill processing capacity is twice as high as the actual production, which poses a high request for new palm plantations, and thus putting forests at risk (Pirard et al., 2020). The aim of this thesis is to couple predictions on future deforestation with the palm oil mills as a key actor of the palm oil supply chain to directly characterize and prioritize actors for transformations towards sustainability. It is an approach that could not be found in previous research but it promises great potential for target-oriented changes.

Research on palm oil and its transformation towards sustainability has vastly grown during the last years. This research is mostly focusing on technical issues to make palm oil production more efficient (Hansen et al., 2015). The research community for measuring deforestation due to oil palm plantations has experienced an upswing thanks to the improved data and especially the tree cover loss data from Hansen et al. (2013) (see Infobox 2, p.17 for definitions of tree cover loss and deforestation). Current research on *predicting* forest loss risk draws on trend analysis or logistic regression and machine learning (Cushman et al., 2017; WWF-US, 2017). To account forest loss risk due to oil palm, the analysis is often supplemented with data on palm oil concessions, land that is in some way allocated to palm, or biophysical suitability for new plantations (Austin et al., 2017; WWF-US, 2017).

The thesis at hand is structured as follows: After an introduction to the palm oil supply chain, the role of the palm oil mills and why they have been defined as key players in the supply chain is explained. Afterwards, current approaches to shaping a sustainable palm oil production are presented. From this, the detailed objectives and research questions for this work are derived and the research area is presented. After the presentation of the data used, the developed method is explained. Finally, the results of the palm oil and deforestation situation are described and analysed and recommendations for sustainable palm oil production are discussed.

1.2 STATE OF THE ART

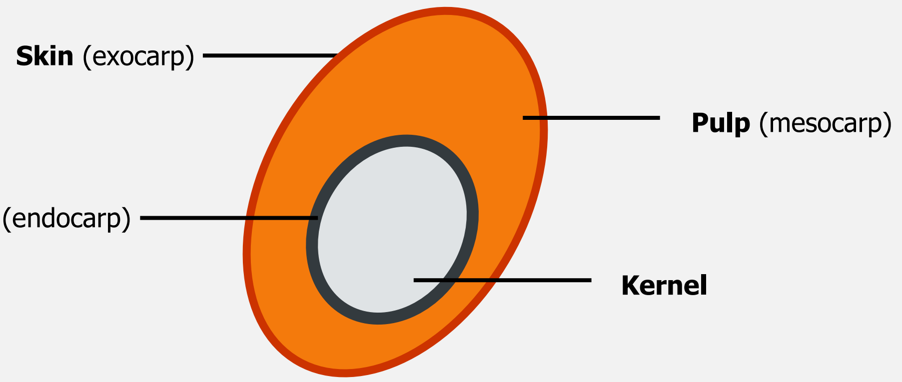
1.2.1 THE PALM OIL SUPPLY CHAIN AND THE ROLE OF MILLS

The oil palm originates from Western Africa and is characterized by a rapid expansion history. The plant prospers on the soil when forest was cleared, and it can act as a pioneer species. With the invention of margarine, glycerine, and the overall industrialization, the European demand for palm oil increased vastly. The industry expanded and in the 1940s palm oil was fully established in Indonesia and Malaysia who are now's world-leading production countries (Corley and Tinker, 2015).

The oil palm owes its triumph to its characteristic as a flex crop. This means that the composition of the oil palm fruit provides material for multiple uses in different sectors like food, cosmetics, and the transport industry (see Infobox 1). Due to more possibilities reacting to changing market prices, there is lower uncertainty for a producer. Thanks to the attractiveness of this crop, palm oil investments are increasing (Alonso-Fradejas et al., 2015).

Infobox 1
Oil Palm Products

The palm carries a fruit bunch with 1500-2000 individual fruits, the so-called fresh fruit bunch (FFB) (Woittiez et al. 2017). Each of these is made up of four layers (see figure). The palm oil itself is extracted from the pulp. Further processing makes it suitable for cooking and frying oil, margarine, cosmetics, and biodiesel. The nutshell can be used as fuel material in the mill. The kernel resembles coconut fat and is crushed to produce palm kernel oil, which can be used for food and soap. It is also processed to a cake for animal feed. Further side-products result from the processing (Alonso-Fradejas et al. 2015; Corley and Tinker 2015).



Infobox 1: The palm oil fruit and possible products that can be processed (own figure).

In general, there are two management types of oil palm plantations: the industrial oil palm plantations (IOPP) and the smallholder plantations (SHP). The Indonesian government distinguishes these two types alone by the size of the plantation area and sets the threshold at 25 hectares. The certification scheme of the roundtable for sustainable palm oil (RSPO) separates smallholders from IOPP's as family-run, mixed plantations, with an oil palm area of fewer than 50 hectares (Jelsma et al., 2017; RSPO, 2020a). Additionally, smallholders are discerned into independent and plasma smallholders. The independent smallholder plantations are mostly used for subsistence production, however, with the developing palm oil industry, some of them are participating and benefitting from the commercial use of palm oil and its global value chain. The plasma smallholders are smallholder plantations that are integrated into a larger plantation company. What began as a state initiative to support the economy of marginal regions, is today connected to the private sector. These arrangements can provide the smallholders with knowledge, technical backing, and sometimes also monetary support. Most important is that they are contractually connected to a mill (Jelsma et al., 2017).

In these mills, the fruits are controlled, sterilized, separated from the bunch, and processed, before the crude palm oil (CPO) and palm kernel oil are extracted. This crude oil is a mixture of the oil itself, water, some fibre, and dirt and gets clarified in the last step. After this, the crude palm oil is transported to the refineries, which are mostly situated in the producing countries, although there is still a small number of refineries in consuming countries. These refineries are processing the CPO to enhance the quality of the oil (Corley and Tinker, 2015). The refined palm oil is transported to nutrition, cosmetics, and other companies for further processing. This supply chain can be integrated into a company-owned supply chain but can also be driven by individual stakeholders (see Figure 2 for an overview). In reality, the palm oil supply chain is often much more complex including several intermediaries, retailers, and carriers, with governmental influences (Purnomo et al., 2018).

The rise of the palm oil industry led to more power among the stakeholders and distributed the balance of it along the supply chain - sometimes unequally. After the central government, the stakeholder with the highest power to alter other actors within the supply chain in any direction

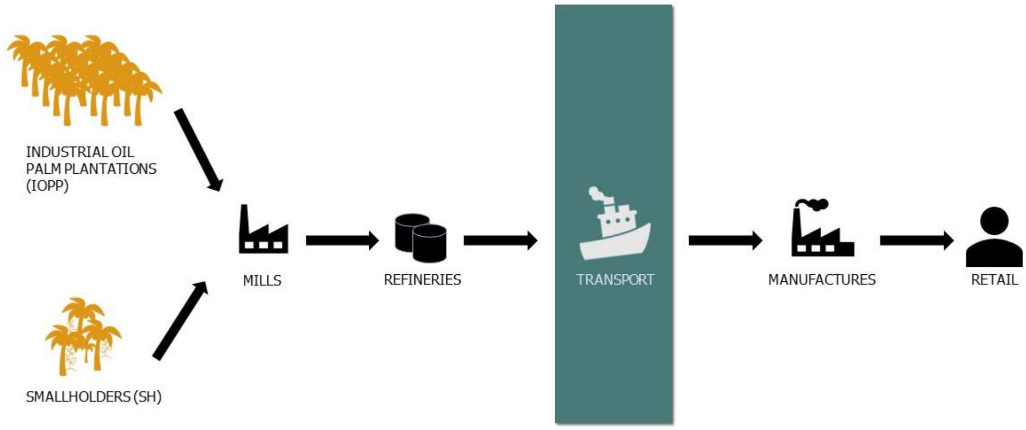


Figure 2: Strongly simplified Palm Oil Supply Chain (own figure).

is the palm oil mill. It also only gets impacted by the government and the refinery (see Figure 3). This power is based on the added value to the palm product at a mill, which is second highest after the refinery. With this, economic power and specifically the mill owners are among the most powerful actors within the supply chain who can shape the whole palm oil supply chain regarding standards and practices applied (Purnomo et al., 2018). In addition to this hierarchical-induced power, the palm oil mills are an important node within the palm oil supply chain, since they are decisive when it comes to the profit per tonnes of FFB, the quality of the oil, and the decision on the final product (Corley and Tinker, 2015).

The finding that the installed mill capacity is higher than the actual production volume means that some mills must be operating below their installed capacity (Pirard et al., 2020). One study supports this assumption by stating that especially non-integrated mills, mills that are not integrated into a company-owned supply chain, but from time to time also integrated mills need to buy FFB from other estates to utilize their capacity (Azman, 2014). In Colombia, it is known

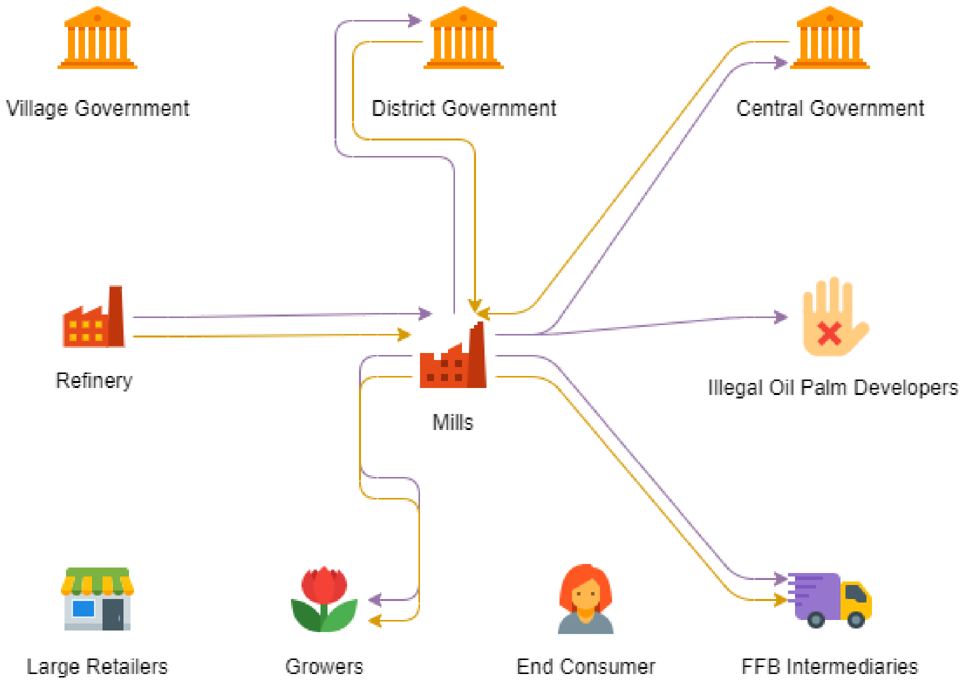


Figure 3: The palm oil mill and its power relations. There are no power relations found between mills and large retailers and village governments. Types of power are: orange: coercion, violet: (dis-) incentive, green: dominant information (Source. own figure, based on Purnomo et al. 2018).

that mills engage in alliances to utilize their full capacity. In a certain area, this led to an increase in utilization from 57% to 85%. However, there is still a mill overcapacity (see Infobox 2 for a definition of mill overcapacity). Sometimes even the refineries are operating below capacity (Potter, 2015). A recently published study expects, based on mill capacity data and aggregated palm oil production volumes, that the installed capacity of palm oil mills in Indonesia is nearly 50% higher than the produced amount of palm oil (Pirard et al., 2020). The consequences are apparent and were already analysed in Nigeria: to reach the full productivity and achieve high economic efficiency, more land for oil palm plantations is needed and allocated (Potter, 2015). Because of this need for land consumption, these mills are called "hungry palm oil mills" in the thesis at hand (see Infobox 2 for a definition of a hungry mill).

Current research on the sustainability of palm oil mills often focuses on technical improvements to increase the efficiency of mill operations (Foong et al., 2019). A lot of studies are also focusing on different emissions of mills or the treatment of the wastewater from the FFB-processing since this is critical for the environment (e.g. Jamaludin et al., 2018). However, there is little research on the mills, their role in the supply chain and in causing deforestation.

Infobox 2
Key Terms used in this thesis

Deforestation: The FAO (2012) defines deforestation as "the conversion of forest to another land use or the long-term reduction of the tree canopy cover below the minimum 10 percent threshold." Whereas forest can be primary forest, a forest that has never cut, or secondary forest, a regenerated forest after human or naturally caused disturbance.
Tree Cover Loss: The widely used global tree cover loss dataset by Hansen et al. (2013) defines tree cover loss as the cutting of primary, secondary but also every other tree loss. This means that also the cutting down of a plantation can be accounted as tree cover loss. Vice versa, the establishment of a new plantation can be assigned with tree cover gain, depending on the crop.
Mill Overcapacity: The amount of capacity that is installed but not used (based on Heilmayr et al., 2020): *Installed Capacity – Production Volume = Mill Overcapacity*
Hungry Mill: A mill that is running below the installed capacity and is consequently in need for more palm fruits or a more efficient use of these (own definition).

Infobox 2: Key Terms used in this thesis.

1.2.2 OF ROUNDTABLES AND COMMITMENTS FOR SUSTAINABLE PALM OIL

The rapid expansion of palm oil plantations and its associated negative impact has led several organisations and governments to take action (Lyons-White and Knight, 2018). A vision of a future with sustainable palm oil production was created and agreed yet with a wide understanding of what exactly sustainable palm oil production could look like and how measurements and monitoring are implemented. From this thought, many initiatives were taken to turn this vision into reality.

1.2.2.1 ROUNDTABLE FOR SUSTAINABLE PALM OIL (RSPO)

The most popular initiative for sustainability is the Roundtable for Sustainable Palm Oil (RSPO), a supply chain initiative, which was founded in 2004 (Carlson et al., 2018). To date, 19 % of the global palm oil production is RSPO-certified. In the beginning, their focus was on primary forests and areas with a high conservation value (HCV) (Lyons-White and Knight, 2018). After the review of their principles and criteria (P&C) in 2018, they added further regulations like no deforestation, no peatland regardless of depth, fire prevention and the High Carbon Stock Approach (HCS) to the program (RSPO, 2018). The certification is audited by third parties along with a standardized scheme. Especially this aspect is frequently criticized since the credibility of the auditors is questioned (Carlson et al., 2018).

RSPO has four different supply chain models that can be certified: *Identity Preserved* and *Segregated* supply chains separate certified palm oil from not certified ones through the whole processing and manufacturing. The oil origins from either one or several certified sources. Supply chains that are certified by *Mass Balance* can mix certified and non-certified palm oil and need to keep the proportions transparent. The last one is the *RSPO credits* system, where manufacturers and retailers can buy credits from RSPO-certified producers, whether they use RSPO-certified oil or not (RSPO, 2020b).

1.2.2.2 CORPORATE SUPPLY CHAIN INITIATIVES

Companies can make up their own no-deforestation commitments. They differ from RSPO in such a way that these company commitments do not get an official certification and are mainly implemented to exclude deforestation from a company's supply chain. 96 % of the global palm oil production has some sort of company commitment (Lyons-White and Knight, 2018). Since these commitments are not standardized, a comparison between companies is difficult (Carlson et al., 2018).

1.2.2.3 EFFECT OF SUSTAINABILITY INITIATIVES

A case study by Carlson et al. (2018) found that RSPO certification reduced palm oil-driven deforestation by 33%. They conclude, that with such an impact, stricter certification criteria would have even a greater potential to combat deforestation. Since the analysis was done before RSPO's P&C were revised and the no-deforestation article was added, this is a remarkable result and future long-term studies will show whether this will prove to be true. In a follow-up study, the effects of RSPO certification was analysed in a more detailed way. It was found that so-called spill-over effects emerged in reducing deforestation in forest estates on the one hand. On the other hand, forest clearing was induced in land zones already allocated for palm (Heilmayr et al., 2020). A recently published study found, that RSPO-certified palm oil is not completely deforestation-free. In some concessions, deforestation happened before the initiation of the certification, which is a remarkable loophole in the certification system as land use is often not traced back very far (Cazzolla Gatti et al., 2019).

The government plays an important role in the effectiveness of no-deforestation commitments of companies. They are an important lever in fostering or inhibiting sustainability efforts when implementing related regulations (Lambin et al., 2018).

1.2.2.4 LEGAL ASPECTS IN PALM OIL PRODUCTION IN INDONESIA

Besides all the private efforts on shaping sustainable palm oil supply chains, in Indonesia, the palm oil industry is controlled and influenced by several instances. It is a complex, interweaved system, and mixed with governmental and non-governmental actors. Palm oil plays an important role in the country's development strategy. The legal framework consists of multiple laws and regulations like a spatial planning law, land-related laws, a forestry law, a plantation law, and environmental management laws. Above all these regulations, the state owes the control over land and natural resources by a constitutional provision. All these regulations influence the licensing of oil palm plantations, whether a concession is granted. While the central government is mainly responsible for the enactment of such regulations, the local government, which is on the district (Kabupaten) level, focuses on the enforcement. Figure 4 shows an overview of this legal framework. It quickly becomes apparent that the local government has little to say in shaping the legal framework, while the implementation and enforcement strongly rely on them. In further steps, it is the role of companies and local communities to negotiate the final establishment (Paoli et al., 2013).

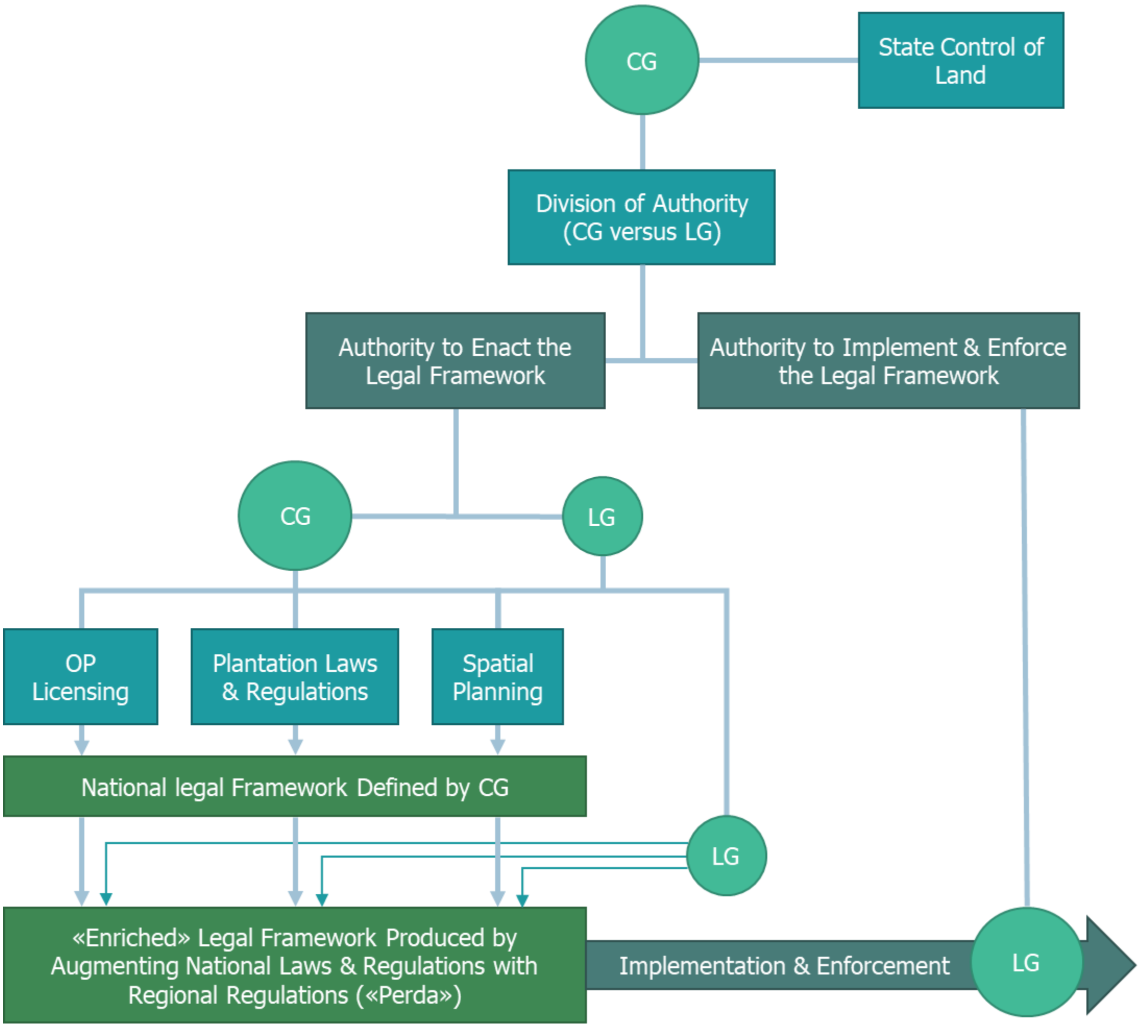


Figure 4: The legal framework governing palm oil plantations in Indonesia (OP: Oil Palm). The central (CG) and the local government (LG) are the most important actors in the beginning. The size of the circle indicates the relative importance of the actors at the corresponding step (adapted from Paoli et al. 2013).

Regarding sustainability, Indonesia has the mandatory standard of Indonesian Sustainable Palm Oil (ISPO), which requires the companies to avoid environmentally sensitive areas in the establishment of new plantations. The local government is then responsible to enforce these environmental management, monitoring and reporting issues. But in practice, it looks different. The local government often moderates its regulatory position since the competition for palm oil investments between districts is quite high (Paoli et al., 2013).

Eventually, although the ISPO requires environmental efforts by the companies; it is their own choice on how they manage their plantations. If they decide to set aside land for conservation in their concession, they still must pay taxes on agricultural land. This is neither supported nor popular with the local government due to land zoning policies and the competition just mentioned (Paoli et al., 2013).

1.2.2.5 WHAT EXACTLY IS SUSTAINABLE PALM OIL?

Throughout all these sustainability initiatives it can be seen that the idea for sustainable palm oil is not only about deforestation. The establishment of new plantations on peatland and the resulting carbon release is also a big issue. Additionally, there is a huge bundle of community, labourer, and land rights that wants to be in fair conditions. However, the approach of only using some kind of *degraded land* for palm plantations can be found in almost every meaning for sustainable palm oil (Gingold et al., 2012). The definition of *degraded land* is again very diversely done. Two commonly used approaches are the *High Conservation Value* (HCV) and the *High Carbon Stock Approach* (HCS). With the HCV-approach environmental and social values shall be preserved and protected. Six components need to be assessed to qualify an area to have a high conservation value: *species diversity*, *landscape-level ecosystems and mosaics*, *ecosystems and habitats*, *critical ecosystem services, community needs*, and *cultural values*. The last one includes areas and resources of high cultural, religious, or historical significance for either the local or the global community. At least one of these components must be present to classify an area with HCV. Although the approach serves as a tool to protect such values, the assessment is sometimes vague and not clearly to handle, even though national interpretations do exist to include the local context (Senior et al., 2015). In contrast, the HCS approach works with clearer indicators, but focuses on environmental values and intends for no-deforestation. By using remote sensing and field evaluations the carbon value of a particular area is measured. Areas with a value above a specific threshold are proposed to be set under conservation. Land with a value below the threshold is classified as *degraded land*. Throughout the whole assessment, HCV evaluations and analyses on whether the land is subject to *Free, Prior and Informed Consent* (FPIC) are included to add social values (Rosoman et al., 2017).

The assessment on *suitable land for sustainable palm oil* by Gingold et al. (2012) includes these two approaches and is developed for the specific context of palm oil in Indonesia. The indicator bundle includes appropriate Indonesian regulations, is in line with the national REDD+ program and RSPO certification requirements. Even though their focus is on degraded land, which they define as land with low carbon and biodiversity levels, they have additional factors to assess an area. It consists of four fields with two topics each. Each theme is assigned 1-4 indicators to evaluate a site (see Figure 5). Altogether, it is similar to the HCS but adapted to the conditions in Indonesia and palm oil production.

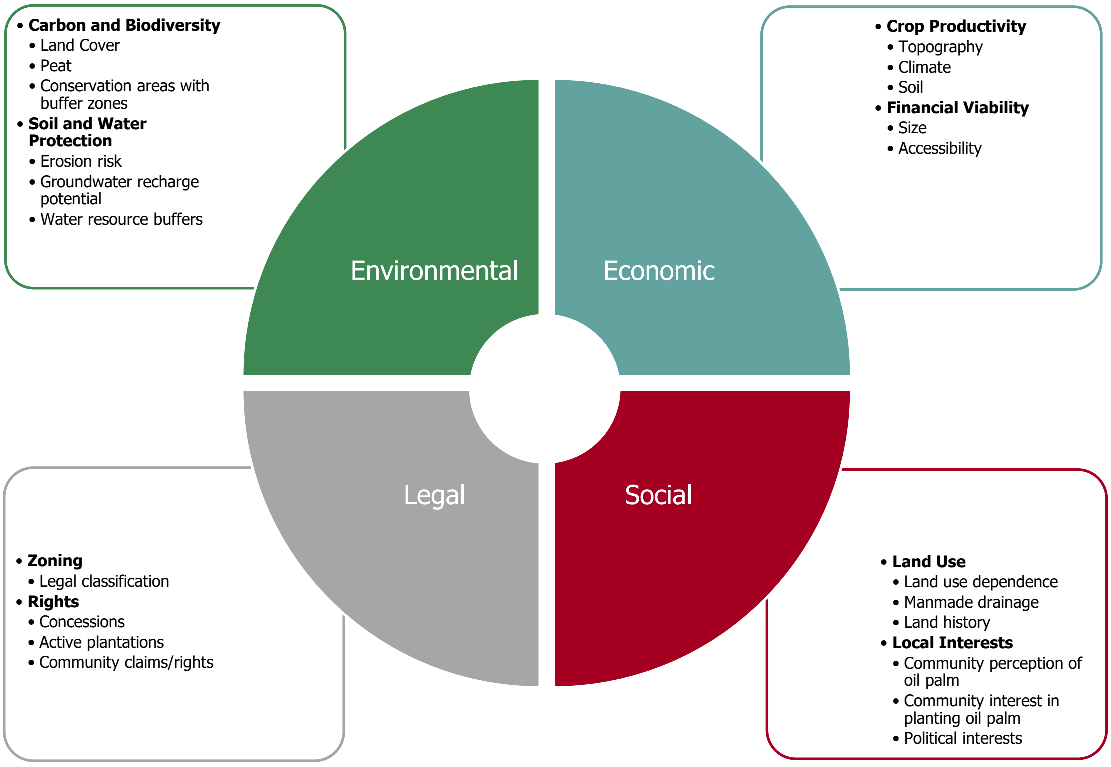


Figure 5: Factors and indicators to evaluate land for its suitability for sustainable palm oil production (according to Gingold et al. 2012).

Figure 6: Palm Oil Fresh Fruit Bunches (Photo by tk tan, Pixabay).

2 SCOPE AND DIRECTION

As has now been explained, mills are important levers in the palm oil supply chain. Therefore, hungry mills serve as an indicator for possible future changes in their surrounding palm oil landscape. These hungry mills and their associated stakeholders are crucial regarding transformation towards sustainability. A mills location, ownership and certification have a decisive impact on these changes. These characteristics are shaping and steering the palm oil development around the mill and vice versa. They all are characterized by specific actors. The *location* is crucial because it is important to keep the time frame to preserve the quality of the fruits. Since it is the local government enforcing the legal aspects of oil palm development and issues on management or land-use allocation rely on the district, the decision on the location is crucial. The *stakeholders* of a palm oil mill are crucial in shaping the direction of palm oil development in the surrounding landscape. The mill owners, specifically, the group, the mill companies belong to, are powerful, because it is the actor controlling the financial investments while adding value during the palm oil production and thus steering other actors down- and upstream the supply chain. They also are in control of where and how to develop new infrastructure for the palm oil industry. Additionally, it depends on the owners, whether the mill gets certified or is even linked to a no-deforestation-commitment. A *certification* determines the amount of certified and non-certified fruits which can be processed and therefore needs to be planted around the mill.

2.1 GOAL, OBJECTIVES, AND RESEARCH QUESTIONS

The thesis at hand intends to use the identification of hungry mills as a method to predict possible forest loss. As it is coupled with a key actor, it promises great potential for transformation towards sustainability. Therefore, the goal of this thesis is to explore palm oil mills positions altering the oil palm plantation landscape and thus to contribute to a transformation towards a sustainable palm oil supply chain. To reach this goal, the following research questions will guide the research. The questions are following the three key characteristics of a palm oil mill that shape its impact on the surrounding area: a mills location, the associated stakeholders, and its sustainability certification.

Location

How can a supply catchment of a palm oil mill be calculated?

Research Question 1 will be answered, to detect hungry palm oil mills according to their supply catchment and capacity and thus identify future deforestation areas.

Stakeholders

Who are associated stakeholders of hungry palm oil mills in terms of increasing productivity?

Based on the results of the first research question, further implications for the responsibilities in the private sector and the government shall be made, by answering the second question.

Certification

What are implications for a sustainable palm oil production regarding mills overcapacities?

The aim of Research Question 3 is to find implications for these hungry mills to move towards sustainability.

2.2 AREA OF INTEREST

In 2006, Indonesia became the world leader in palm oil production (Corley and Tinker, 2015). Only three years later, Kalimantan, the Indonesian part of Borneo, which is the focus of this thesis, became a hot spot of deforestation due to establishment of palm plantations. The palm oil production in this region is dominated by big industrial plantations (Pacheco et al., 2017). The proportion of oil palm-driven deforestation in Kalimantan has fallen from half in the years 1995-2000, to around one fifth in the years 2010-2015 due to other drivers of deforestation. However, the island region was responsible for almost 70% of national deforestation due to oil palm between 2010 and 2015 (Austin et al., 2017). The focus might have shifted to other regions, still, the risk of forest loss due to oil palm is estimated to be remarkably high for this region in the future. A high amount of the area of the province of Central Kalimantan was always in the upper quarter in forest risk for every analysed forest area (see Figure 7 for an overview of the province).

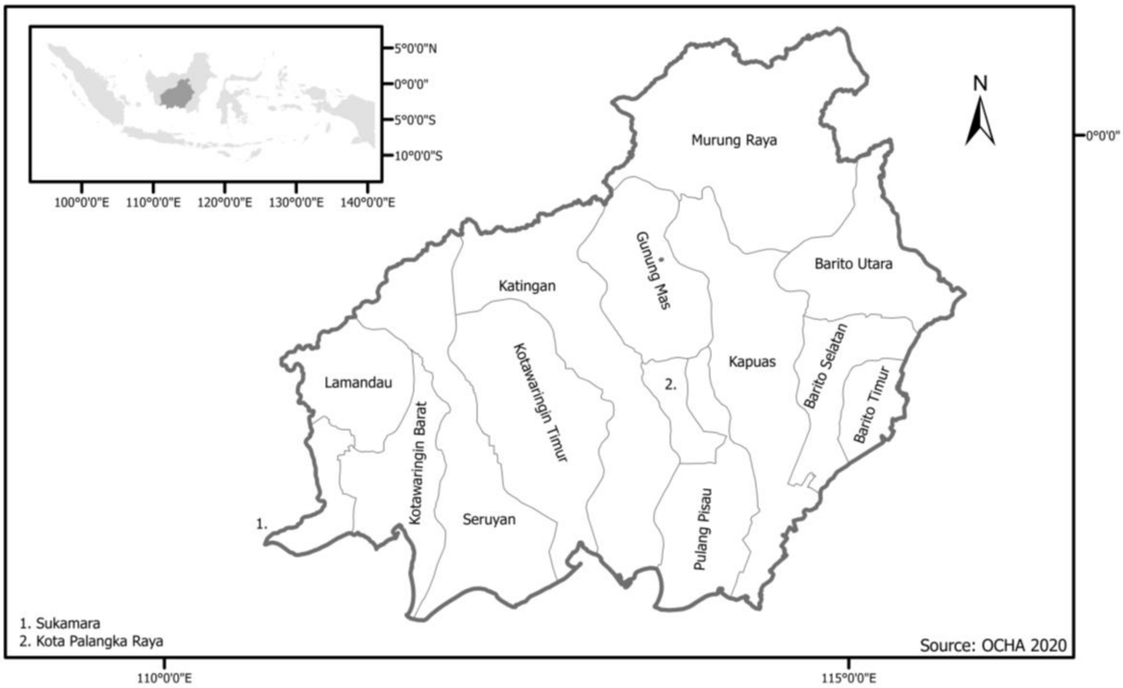


Figure 7: Overview of the province Central Kalimantan with the Kabupaten (districts) (own figure).

According to a forest risk assessment by WWF-US (2017) regions of Central Kalimantan are designated with high risk due to palm oil development. According to Global Forest Watch (2020) who bases its analyses on the Hansen et al. (2013) – tree cover loss data, Central Kalimantan lost 24 % of its tree cover between 2000 – 2019. As of 2010, 80 % of the province was covered with natural forest, 10 % with plantation, which shows the high amount of forest area of this region (see Figure 8 for an overview of the land-cover in Central Kalimantan in 2018).

Given the urgency of the destruction of high-value forests and the need to examine the key levers for sustainability transitions within the palm oil supply chain, the province of Central Kalimantan was chosen as the area of interest because it requires a lot of attention.

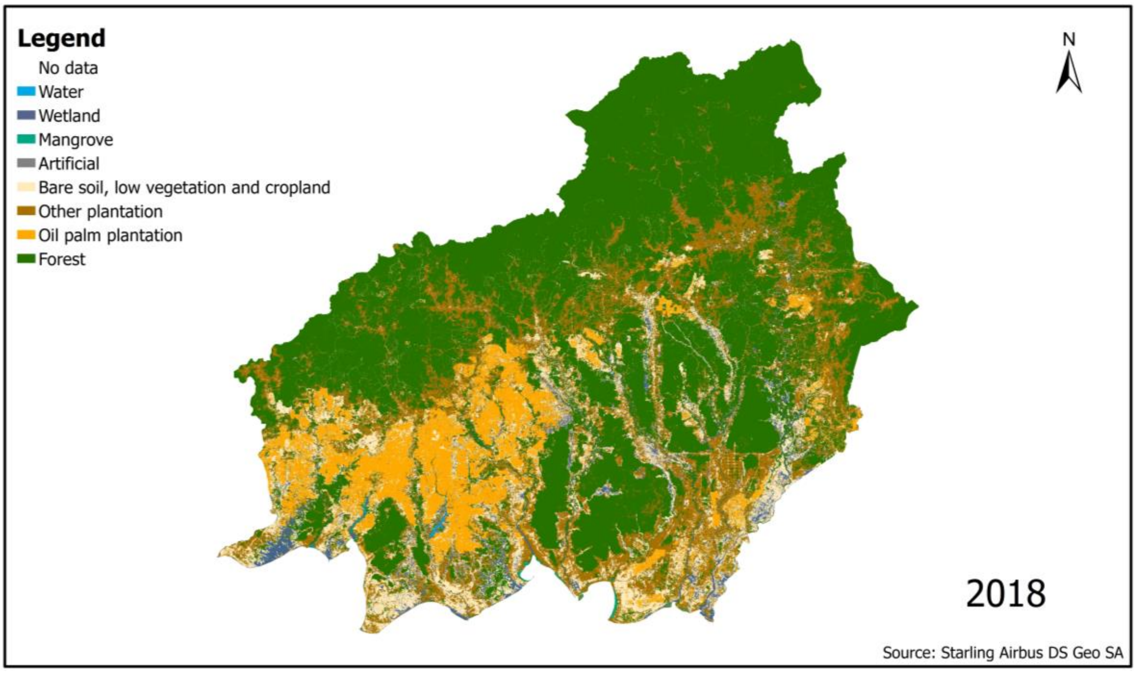


Figure 8: Land Cover in Central Kalimantan, Indonesia 2018. Classification based on Starling (own figure).

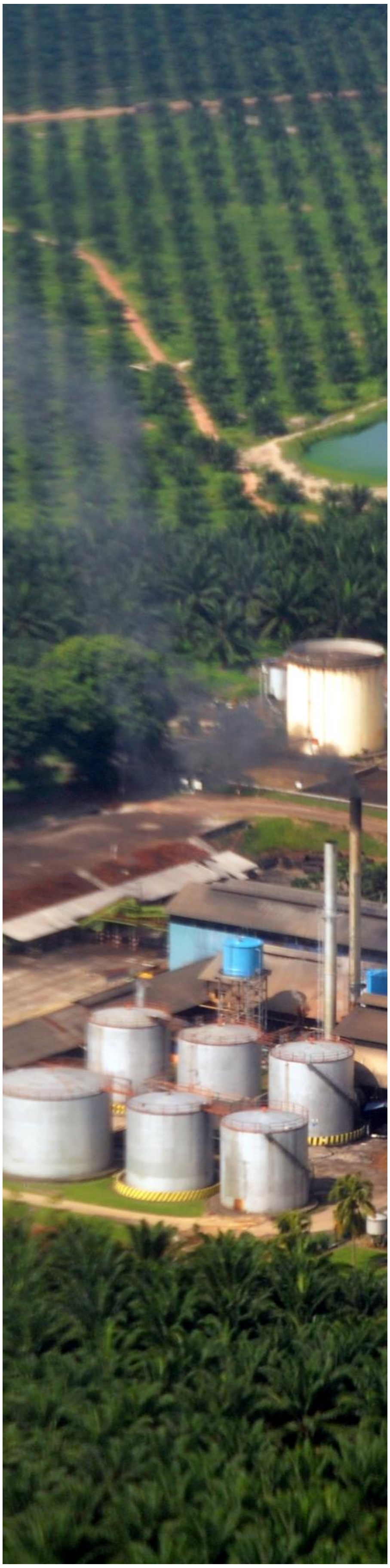


Figure 9: Palm Oil Mill in Sepang, Malaysia (Photo by Marufish).

3 DATA AND METHODS

The answers to the research questions are based on the calculation of a mills supply catchment, to characterize palm oil mills and estimate their impact on the surrounding. With this, production volumes can be estimated, land cover changes allocated, or, deforestation spill-overs from sustainability certification analysed (e.g. Heilmayr et al., 2020).

Because the yield needs to be processed within a specific time frame to preserve the quality, the studies conducted so far worked with km-distances to approximate the mill supply catchments based on this criterion. The distances applied are diverse. *Starling*, a tool to monitor agri-food supply chains, uses 5, 20, and 50 km zones and Heilmayr et al. (2020) even applied 84 km zones.

In this thesis, the supply catchments were calculated based on the travel time to narrow down the catchments in a way that is better adapted to the local conditions. Based on road infrastructure, topography, and impassable land cover, the temporal reach from a mill was calculated. With this, spatial data on the accessibility of a mill was available. Within this catchment, the estimated yield was summarized and then compared with the installed mill capacity to identify the mills that are running below it (see Figure 10 for an overview).

The methodological approach is based on a geographic information system (GIS) and the software ArcGIS was used to run the analyses. It was supplemented with programming scripts based on Python. A detailed workflow can be found in Appendix 8.1, Hungry-Mills-Toolbox.

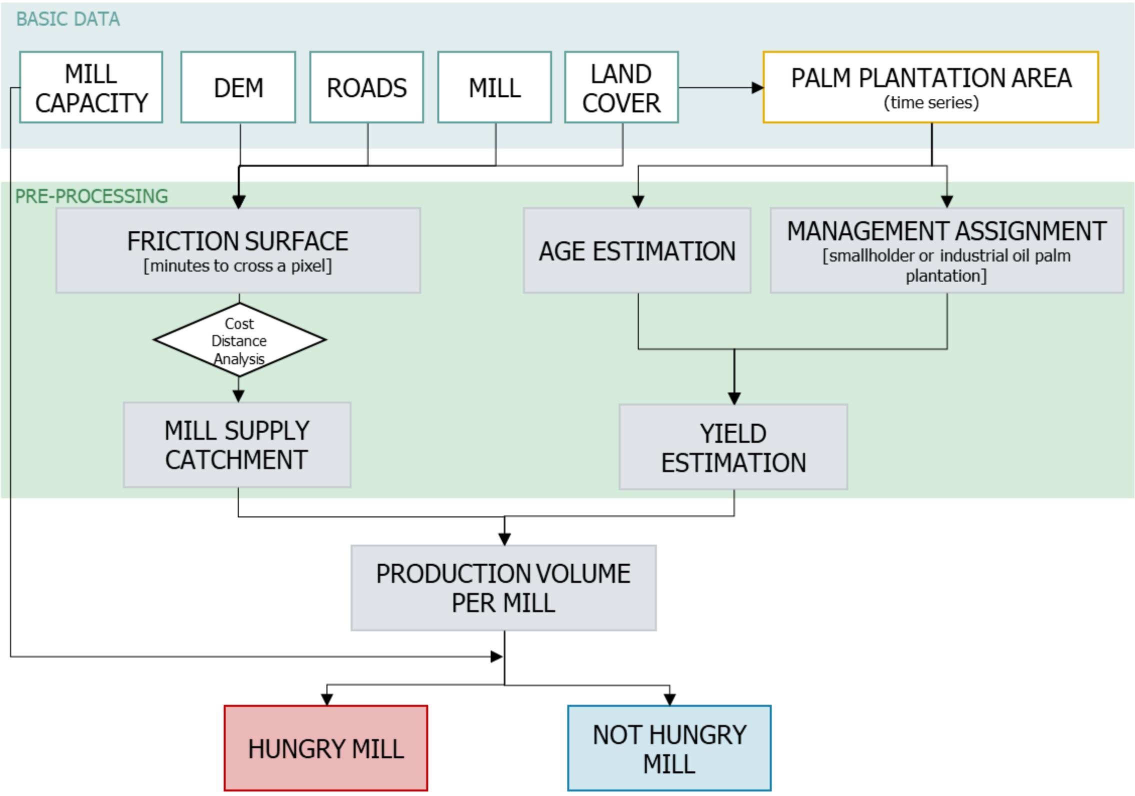


Figure 10: Methodological workflow to identify hungry mills based on the estimated yield in their catchment (own figure).

3.1 DATA

3.1.1 STARLING - LAND COVER DATA

The analyses based on palm plantations were done with data of *Starling*, from Airbus and the Earthworm Foundation. *Starling* was initiated to help agri-food companies monitor their supply chains and whether they are linked to deforestation and verify their achievement of forestry conservation commitments. It provides an accurate land cover dataset and deforestation alerts four times a year. The dataset is based on Airbus' SPOT constellation, a combination of optical and radar satellites. (Airbus DS, 2020). They explore and define deforestation as the clearing of forest and differentiate between tree crops and natural forest. This is the main difference to the well-known Hansen et al. (2013) tree cover loss data that includes the cutting down of plantations. This often leads to problems, when the Hansen - tree cover loss is interpreted as deforestation, which is not directly the case. However, this dataset could be used for visual verifications of plantation clearings. The land cover time series (2001-2020, without 2016) was available with a resolution of around 20 meters. The land cover dataset and its spatial resolution were used as a reference for all the other datasets used and calculated. In this way, every calculation including palm plantation area was as accurate as possible.

3.1.2 UNIVERSAL MILL LIST (UML)

Information and data on palm oil mills were available at the World Resources Institute (WRI) as a verified list of mills, based on publicly available information with accurate location information. It can be downloaded from WRI's Global Forest Watch Open Data Platform (Global Forest Watch, 2019b). This Universal Mill List (UML) is used to support companies and NGO's tracing palm oil to the source. Mills are a good reference for this purpose, due to their role at the intersection between farms and processing industry. The data collection is based on a standardized methodology and made through the companies themselves, NGO's, or research organisations. In the UML, every mill is indexed with a specific ID, to improve their identification. Besides the mill name and location, the list also includes the name of the company, the group name the company belongs to, RSPO status and type, and further information (WRI, 2020).

3.1.3 MILL CAPACITY

The capacity data is based on the UML and was collected by Heilmayr et al. (2020) from Annual Plantation Statistics Reports from Provincial Dinas Perkebunan (Plantation Service) Publications. The dataset was collected to analyse the impact of certification by the amount of certified capacity instead of only taking the number of certified mills. Whenever the capacity was not stated, nearest neighbour interpolations were done to fill the gaps (ibid.). To make the shift from an hourly [t FFB/h] to an annual [t FFB/y] unit, an average running time of the mills was expected to be 20 hours per day during 330 days in the year (Schulz, N., personal communication 10. April 2020). The data has been updated since then, so the capacities were available for the year 2018. Therefore, every analysis in this thesis was made for this year.

3.1.4 OTHER DATA

The administrative boundaries on the national, provincial and district level were provided by the Indonesian statistics services and downloaded from the Humanitarian Data Exchange platform (OCHA, 2020).

To calculate the supply catchments, information on topography and travel infrastructure was needed. To get the topography, the ASTER Global Digital Elevation Model Version 003 (ASTER GDEM 003) was used. It is available with a spatial resolution of 30 meters and thus, lower than the *Starling* land cover data (NASA/METI/AIST/Japan Spacesystems, 2019). Therefore, it was resampled with a nearest-neighbour-method to the resolution of the land cover data.

The travel infrastructure, namely the roads, was an open street map (OSM) dataset derived from WFPGeoNode (2018). OSM comes with the advantage that it is available with an *Open Data Commons Open Database License* and therefore can be used without any limitations. As this is an open source project to which anyone can contribute, the classification of roads is easily accessible. Since the information on the allowed road speed in Kalimantan was not available, further details on the individual classifications proved to be helpful (OpenStreetMap Wiki, 2020). However, since it is an open source project, the completeness of the dataset is not guaranteed.

The further analysis applied the land suitability index for palm oil which was developed by Gingold et al. (2012) to identify land for sustainable production of palm oil. The dataset was lastly updated in 2019 and derived from the beta version of the Global Forest Watch open data platform (Global Forest Watch, 2019a). The index follows several indicators to select a suitable site, explained in Chapter 1.2.2.4 (Gingold et al., 2012). A map of the suitable land for sustainable palm oil in Central Kalimantan can be found in Appendix 8.2, Figure 36.

All the datasets were projected to a WGS 1984 UTM Zone 50S coordinate system.

3.2 METHODOLOGICAL APPROACH

3.2.1 SUPPLY CATCHMENT OF A PALM OIL MILL

To detect hungry mills, the concept of supply catchments was applied. For every mill, an individual catchment was calculated. The estimated yield within this supply catchment then rendered an approximation of the possible production volume for a mill at hand. The difference between this estimation and the stated mill capacity indicated at what level of capacity the mill is running. This was made through several GIS-Analyses.

In environmental studies, there is practically no literature on mapping a supply catchment, besides the well-known water catchments. Some studies are on wood supply, but these are mostly focusing on how much wood is available, with no specific source point (Alberdi et al., 2020). However, in economic studies, modelling catchment areas, especially for retail stores, is a widely applied approach. It is used to find locations of planned shopping centres and select the most suitable ones (e.g. Cheng et al., 2007; Dennis et al., 2002; Dolega et al., 2016). The three main variables used are *distance*, *attractiveness*, like square footage, and *competition* to other stores. The attractiveness can be measured in size or number of service units (Dolega et al., 2016). Based on this knowledge, variables to map a supply catchment of a palm oil mill were defined (see Figure 11 for an overview).

Figure 11: Variables that shape a mill supply catchment (own figure).

Distance is a crucial factor when it comes to preserving the quality of palm fruits. According to FAO (2002), the FFB needs to be processed within 48 hours. Other sources indicate a time frame of 24 hours (Syahza et al., 2013; Verheye, 2010) and palm oil companies like Goldenagri (2017) or Wilmar (2020) are using this time frame to promote the quality of their oil palm products. Syahza et al. (2013) even indicate a time frame of only 8 hours to guarantee the quality. This restriction is basic to define the distance variable.

To measure the *attractiveness* of palm plantations to palm oil mills, several factors are possible. These are immediately influencing whether there is a *competition* between mills or not. On the one hand, there are integrated mills, directly sourcing from specific plantations belonging to the same group or company. Since such relations are very stable; the attractiveness is high, and competition is low. But as already stated, there is evidence, that sometimes even integrated mills need to buy FFB from other estates (Azman, 2014). Another factor influencing attractiveness is the commitment. An RSPO-certified mill needs to report the ratio of certified and non-certified sources (RSPO, 2018). However, yields differ frequently; so, the mills need to change plantations their sourcing from. Changing yields are also affecting non-certified mills, which is directly reflected in a higher competition (Azman, 2014). These and further factors are making mill supply catchments to highly dynamic areas. Unfortunately, there is no research in understanding these dynamics and to investigate all these factors shaping attractiveness and competition, would go far beyond the scope of this thesis.

Considering all the variables, which shape a palm oil mill supply catchment, the distance is the only hard variable. It is a variable that stays relatively the same over time unless roads or their speed limits are changing decisively. Besides, the factors ownership, and whether it is an integrated mill, would be relatively stable as well. However, data availability, especially for plantations, is limited.

Another important factor defining a mill supply catchment is the site variable for oil palm production, including climate, topography, soil and other. These are directly included with the palm plantation dataset and in a later step with the data on land suitability for palm oil.

Due to these reasons, this analysis only focused on the distance variable by making an accessibility analysis for each mill to narrow down a catchment-based on the travel time to a mill.

3.2.1.1 ACCESSIBILITY ANALYSIS

3.2.1.1.1 PRE-PROCESSING

Roads

Since roads are the main and easiest infrastructure to transport goods, they were considered as the most important variable in the accessibility analysis. The OSM road layer was classified into five main categories according to the OSM wiki. The wiki provides a description of every single classification in a road network (OpenStreetMap Wiki, 2020). The resulting five categories represent roads with similar quality that allow similar mean speed. Table 1 shows these categories and their assigned mean speed values.

Category	Road Type	Mean Speed [km/h]	Source
1	Highway and major transit roads	80	(Angloinfo Indonesia, 2020)
2	Primary Roads	60	(Angloinfo Indonesia, 2020)
3	Secondary Roads	50	(Angloinfo Indonesia, 2020)
4	Minor Roads	30	Interpolation
5	Path and footways	5	(Weiss et al., 2018)

Table 1: Road categories and assigned mean speed limits.

Different references were used to assign a mean speed for the respective category. Since this analysis was done for cargo transport with mostly heavy vehicles, the taken values were slightly lower than the indicated ones. The lowest category and off-road areas were assigned with a value of a maximum of 5 km/h. In categories 3-5, the mean speed values can differ seasonally, especially in the case of unpaved roads. During the rainy season, transit is impeded and diminishes the mean speed. However, this variable was not included in this analysis.

Sometimes, waterways are used to transport FFB to the mills. Since this is not the case for Central Kalimantan, waterways were not included in the analysis (Y. Hardini, personal communication from 4. August 2020). Future analyses on other areas would need to consider and include these waterways.

Topography

To correct the DEM a Terrain Ruggedness Index was calculated for the DEM at hand (Riley et al., 1999). Pixels with a value over a specific threshold were masked and assigned with a new value that was derived from a neighbourhood analysis.

Both road and off-road speed values were adjusted by slope, according to Tobler's walking speed and its slope adjustment factor as shown in equations (1) and (2) (Weiss et al., 2018).

$$Tobler's\ walking\ speed = 6e^{-3.5|\tan(0.01745 \times slope\ angle)+0.05|} \quad (1)$$

$$Slope\ adjustment\ factor = Tobler's\ walking\ speed/5.0 \quad (2)$$

Since slope was classified as well for the further analysis, the medians of these factors for the different ranges were calculated and rounded. For off-road areas, equation (1) was used, since slopes steeper than 15% are seen as not passable for heavy vehicles and adjusted in such a way, that the possible speed turned to be 0.005 km/h. The road speed values were adjusted with equation (2) (Austroads, 2003).

Land Cover

Off-road areas were additionally adjusted by land cover, whereas *water*, *wetland*, *mangrove*, and *forest* were set to almost impassable with a possible speed value of 0.005 km/h. Everything else was set to *no data*.

In the end, all the speed values were modified by the size of the pixel to get a value stating the transit time that is needed for this specific pixel.

3.2.1.1.2 ANALYSIS

After the pre-processing, the three rasters (roads, land cover, topography) were merged by priority. The first to consider was the road layer. It prevailed whenever contained a value. Land cover was on priority position two, to mark the off-road areas that are impassable. The pixels that were left were assigned with the values from the off-road layer. The resulting raster was a so-called friction surface. The value of every pixel in this surface states how many seconds it takes to cross the pixel.

The friction surface was used as an input for the cost-distance analysis. This analysis calculates the distance with the least cost (smallest value) to reach a given source point based on the provided friction values. These source points were the mills, separated into single shapefiles. The maximum distance was set to 48 hours (172,800 seconds) since this is the maximum time frame. Due to this cost distance analysis, it was important not to assign the impassable pixels with *no data* in the pre-processing. If this had been done, the *no-data* pixels would have been simply ignored and skipped.

3.2.2 YIELD ESTIMATION

The calculated catchments were used as zones to summarize the estimated yield in it and to finally get an approximation of the FFB-production volume. The total yield of a palm oil plantation is mainly dependent on the three factors seen in Figure 12. Most important *climate* variables are humidity and precipitation. Another important factor is the *age* of the plants. An oil palm has its production peak at an age of 9-14 years and declines afterwards until it is around 25 years old. The plants are replaced at this age at the latest (Fitrianto et al., 2017).

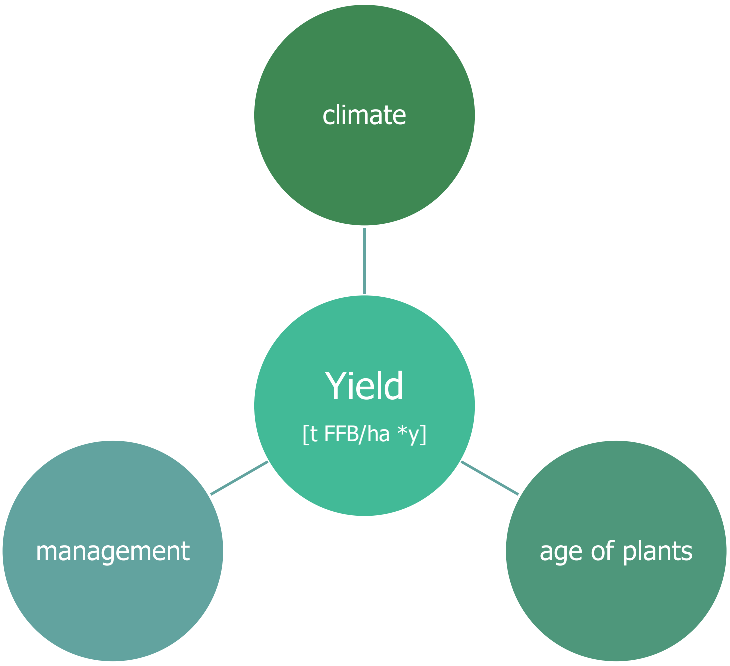


Figure 12: Important factors that influence the palm oil yield (own figure).

Furthermore, the *management* practice, especially whether it is a smallholder or an industrial oil palm plantation, makes a huge difference in yield volume. While plasma smallholders achieve similar yields like an IOPP due to better technical input, an independent smallholder makes up to one quarter less of yield (Morel et al., 2016).

In contrast to age and management, the inputs for the climate variable change very frequently over the year. Therefore, it was excluded for this analysis and the focus was set on the age and the management.

3.2.2.1 ESTIMATING THE YIELD BASED ON THE AGE OF OIL PALMS

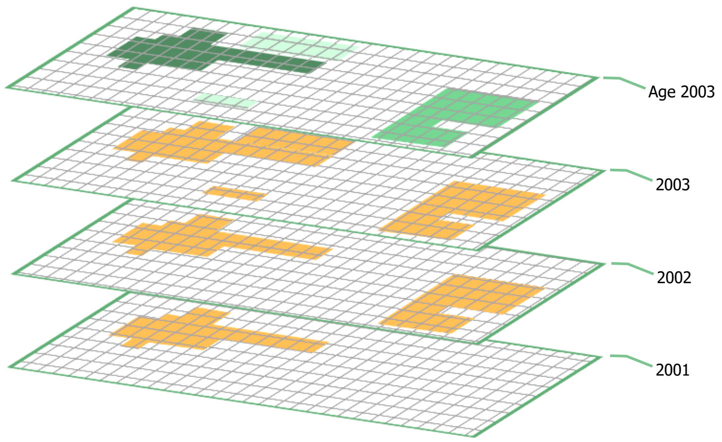


Figure 13: Stack of land cover data time series, masked by palm plantations, to derive the age of the plantations. Dark green: three years old, light green one year old (own figure).

There are several known approaches to get the age of oil palms with remote sensing technology. Most of these approaches are using the forest canopy density and its correlation to the age. Fitrianto et al. (2017) for example are using vegetation, soil, shadow, and thermal indices to calculate the canopy density. These calculations are complex, and it was difficult to get suitable imagery data for the area of interest. Instead, the *Starling* land cover dataset was used to derive the plantation age, since it is available as a time series from 2001-2020. Based on this time series, a summary grid was calculated. Every layer in this series was turned into a binary dataset: the pixels with palm plantation were assigned with a value of '1', the others were set to *no data*. Finally, all the layers up to the year of interest were summarized (see Figure 13). After this, the resulting stack was masked by the current plantation areas to delete plantations that disappeared by 2018. This means that at least some of the plantations established and planted before 2001 could be excluded. However, uncertainty remains for example for plantations that were re-planted in this period and would be younger than indicated through this summary grid. Verification would be needed for such cases. Nevertheless, a visual comparison with the Hansen et al. (2013) tree cover loss data (which includes the cutting of tree crops) did not show a significant change within the plantation areas.

Since Fitrianto et al. (2017) based their correlation of palm age and yield on Indonesian data, these mean palm yield rates per tree were taken over for Central Kalimantan due to the similar climate conditions. By using a triangle planting pattern with 9 meters distance between the individual trees and 7.8 meters between the rows, a hectare-per-yield value was calculated. This means that in one hectare, around 143 trees are planted (ibid.). This value was again downscaled to one pixel and assigned to the palm plantation raster (see Table 2).

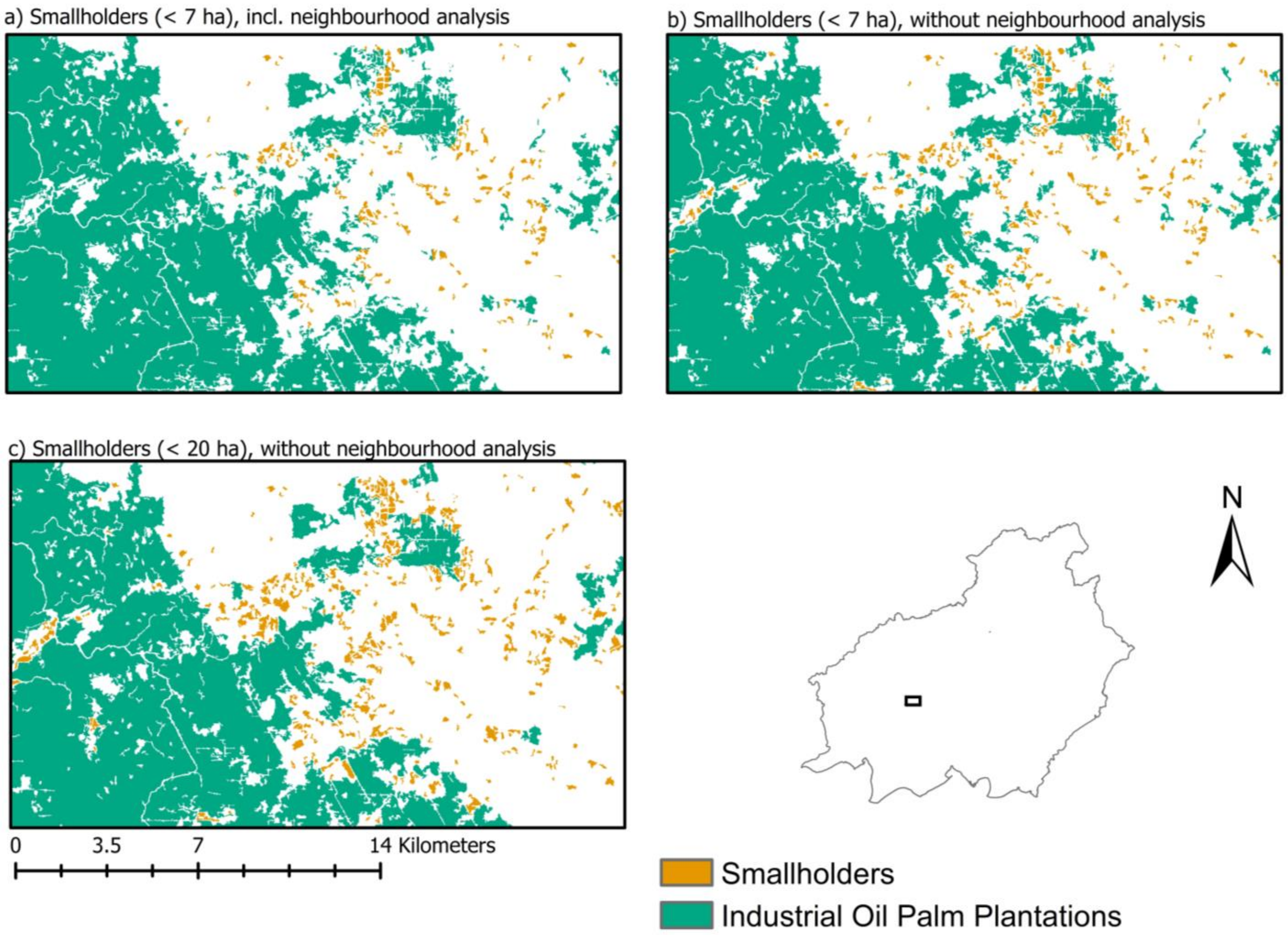
Class	Age	Average yield/tree [kg/ 0.5 yr]	Average yield [t/ha*yr]
Seed	0 – 3	0	0
Young	4 – 8	68.77	19.7
Teen	9 – 14	109.08	31.19
Mature	15 - 25	73.91	21.14

Table 2: Correlation between palm age and yield (adapted from Fitrianto et al., 2017).

3.2.2.2 ASSIGNING A MANAGEMENT TYPE

According to literature, smallholders and industrial oil palm plantations can be distinguished by the size of the cultivated area. Opinions, on where to set the threshold are manifold. However, experience shows that smallholders are not operating on more than 2-5 hectares land in Indonesia (McWilliam, R. personal communication 13. July 2020). Based on this information, the area of connected palm pixels was calculated. This was done by converting the palm plantations raster into a polygon, calculating the area of each polygon, and then assigning this value again to the palm plantation raster. After some attempts, the threshold to distinguish between SHP and IOPP was finally set to seven hectares. With this threshold, most of the small patches in the marginal regions were included. It also excluded most of the areas that seem to belong to an IOPP but are too small to be categorized as one. To reduce these false categorizations, a neighbourhood analysis was additionally applied. The majority value of the pixels found in a neighbourhood of 50 pixels was assigned to the pixel. Again, the 50–px–neighbourhood was approximated through several attempts. With this approach, the possibility was also higher, to set plasma smallholders to an IOPP since their yield is similar. Figure 14 shows the final classification and results of three different attempts in detail.

Because a smallholder plantation makes around 75 % less yield than an IOPP, again a binary dataset was created, stating for SHP pixels a value of '0.8' and for IOPP pixels '1'. A value of '0.8' instead of '0.75' was chosen because of the uncertainty, whether it is an SH-plantation or not. Afterwards, the yield estimation by age was multiplied by this management factor raster.



Source: Starling Airbus DS Geo SA; OCHA 2020

Figure 14: Palm plantation management (Smallholder (SHP), or Industrial Oil Palm Plantation (IOPP)), based on the size of connected pixel-area and three different attempts to approximate the differentiation (own figure).

3.2.3 HOW TO IDENTIFY HUNGRY PALM OIL MILLS

Zonal statistics were applied, to finally identify palm oil mills that might have an overcapacity. The catchment layers were used as zones, and the values of the yield estimations were summarized within these zones. Because the catchment was classified into an 8-, 24-, and 48-hour accessibility, also the yield could be separated into these three classes and then summarized for each catchment size. The estimated production volume was compared to the capacity data of 2018. A percentage-value on how much the mill capacity is reached was finally derived.

For the estimation of needed palm plantation area per capacity, equation (3) was applied. With an annual running time of 6600 hours and the highest possible production at a yield of around 30 tons FFB/ hectare (see Fitrianto et al., 2017), the average need for plantation area per mill capacity unit would be around 220 hectares. For example, a mill with an installed capacity of 60 tons FFB/hour would need to source from 13,200 hectares of palm plantation. This value was later adapted with the estimated mean yield for the province.

$$Mill\ capacity\ \left[\frac{t}{ha}\right] \times \frac{annual\ running\ time\ [h]}{mean\ yield\ [\frac{t}{ha*y}]} = needed\ plantation\ area\ [ha] \qquad (3)$$

3.2.4 FUTURE SCENARIOS FOR DEFORESTATION

Based on the Gingold et al. (2012) - dataset on suitable land for sustainable palm oil production, a scenario for possible future deforestation areas was calculated. For this, it was assumed, that the whole suitable land was planted with palm. The current plantation area situation was estimated to stay the same, while plants older than 25 years, would be replanted with new ones. The analysis was done for 2028 since the palms planted on suitable land in 2018 would reach the highest production when ten years old. The catchments stayed the same, as it was also assumed that no additional travel infrastructure would be needed and that the current land cover would stay the same. This also coincides with the economic factors for suitable land that the costs for infrastructure must be kept low (ibid.).

3.2.5 HANDLING OVERLAPS

Since the mill catchments were all calculated individually, overlaps between these catchments resulted. Thus, parts of the estimated yield volume were allocated to several mills. To visualize the possible current situation, two options were tested.

1. *Overlap Factor*

   To get an overlap factor, the median of overlapping catchments was calculated per catchment. The reached mill capacity was then divided by this factor, to approximate a reduction of the multiple counted yield volume.

2. *Cost Allocation Analysis*

   Additionally, a cost allocation analysis, which is based on the friction surface, was done. It allocates the nearest mill to every pixel. With this method, no overlaps were present. But it also resulted in the exclusion of these mills that are hardly accessible according to the friction surface.

With these approaches, every palm pixel was assigned to one individual mill. But both suggestions did not respect plantation affiliation to mills, or any economic factors. Therefore, outcomes must be handled with care. They only give an approximation to the hungry mill's situation.

Figure 15: Aerial view of oil palm plantation (Photo by Nazarizal Mohammad, Unsplash).

4 RESULTS AND DISCUSSION

In this chapter, the results will be presented and discussed. First, an overview of the palm oil production pattern in Central Kalimantan is presented, which is basic for the understanding and analysis of further results. These results were produced during the pre-processing of the data. This section is followed by analyses and discussions of the different catchments, hungry mills, related stakeholders, future deforestation areas and concluded with an overall discussion on the resulting ideas for a sustainable palm oil production. While the sections on the catchments and the hungry mills itself are focusing alone on the location, one of the predefined key characteristics of a palm oil mill, the other individual parts are outlined along all of the characteristics *location*, *stakeholder*, *certification*, and the *palm oil mill production* as resulting characteristic from these three.

4.1 PATTERNS OF PALM OIL PRODUCTION IN CENTRAL KALIMANTAN

<u>Location</u>

In terms of palm oil production, Central Kalimantan can be separated into a western and an eastern part, which are showing remarkable differences in palm oil infrastructure and production. While the west includes most of the palm area and mills, the east is dominated by forest and a diverse plantation landscape. 110 mills are established in the province. Most of these can be found in the western half. This is reflected in the distribution of the installed mill capacities (see Figure 16).

The installed mill capacities range from 20 to 120 tons FFB/hour. Around 30 mills each are working with 45, respectively 60 tons FFB/hour, and almost 20 have an installed capacity of 90 tons FFB/hour. The capacities of the other mills are distributed between these values. With an estimated mill running time of 20 hours for 330 days, a mill with a 60 tons FFB/hour capacity can process up to 396,000 tons FFB/year. A summarized mill capacity of 6770 tons FFB/hour is installed in the province. The district with the highest installed mill capacity is Kotawaringin Timur, which is also the district with the most mills; specifically, 36 mills. In contrast, Sukamara, a district in the west with only four mills, has the highest mean capacity per mill, which is 78 tons FFB/hour.

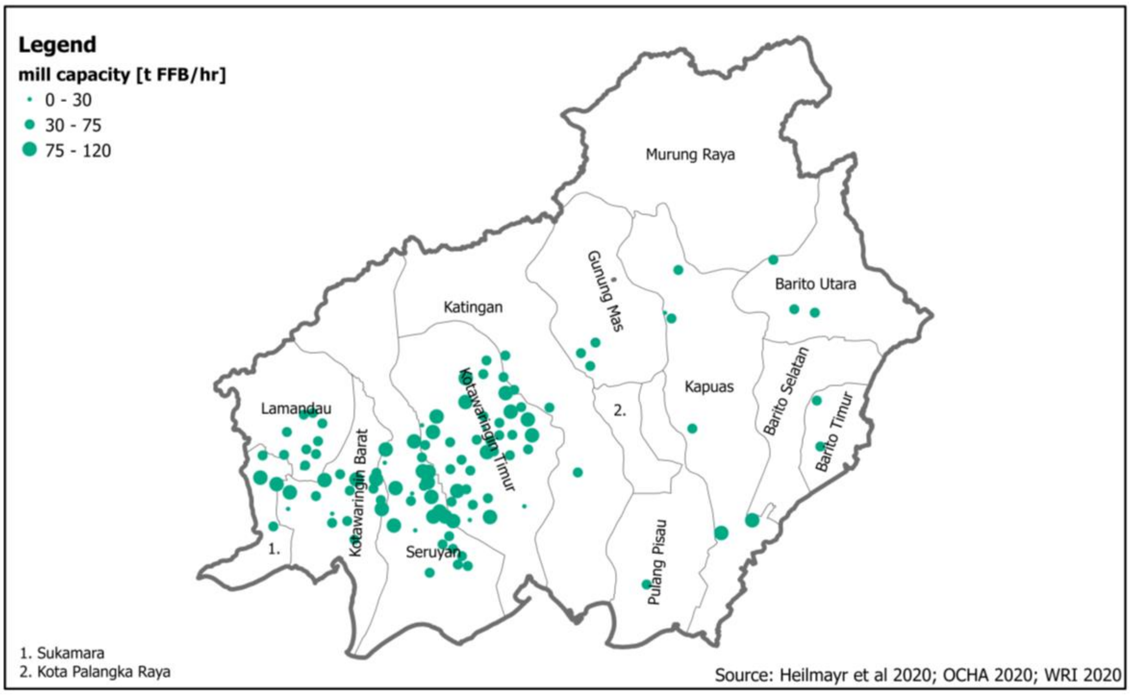


Figure 16: Installed palm oil mill capacities in Central Kalimantan in 2018 distributed over the districts (own figure).

<u>Stakeholders</u>

In terms of ownership, 41 groups are sharing the palm oil milling market in Central Kalimantan. These are the groups, the individual mill companies belong to. Out of that, 8 groups own half of all the mills. Referring capacity, it is only seven of these groups responsible for a little bit more than 50 % of the total installed capacity (see Table 3). Four of them stand out from the others

Group Name	Top Export Destination	Company Commitment	Mills	Installed Capacity [t FFB/hr]
Wilmar	India	NDPE	10	530
Bumitama Gunajaya Agro	NA	NA	8	540
Sinar Mas	India, China	NO-DF	8	620
Best Industry	Benin	None	7	690
Citra Borneo Indah	India	NA	6	390
Astra Agro Lestari	China	NO-DF	5	325
Goodhope	NA	NA	5	360
Musim Mas	India	NO-DF	5	315

Table 3: Overview of the eight most important groups in Central Kalimantan. The grey group is not needed to reach half of the installed capacity. Company Commitments: NO-DF: any no-deforestation commitment; NDPE: no-deforestation-peat-exploitation-commitment; NA: data not available (Source: Heilmayr et al., 2020; Trase, 2015; WRI, 2020).

with a total installed capacity between 500 and almost 700 tons FFB/hour. Even though the top export destinations of these groups are India and China, half of the palm oil production in Central Kalimantan is intended for the domestic market (Trase, 2015). Figure 17 shows how these groups are distributed over the province. For further analyses on hungry mills and their connection to specific groups, the group names will be anonymized.

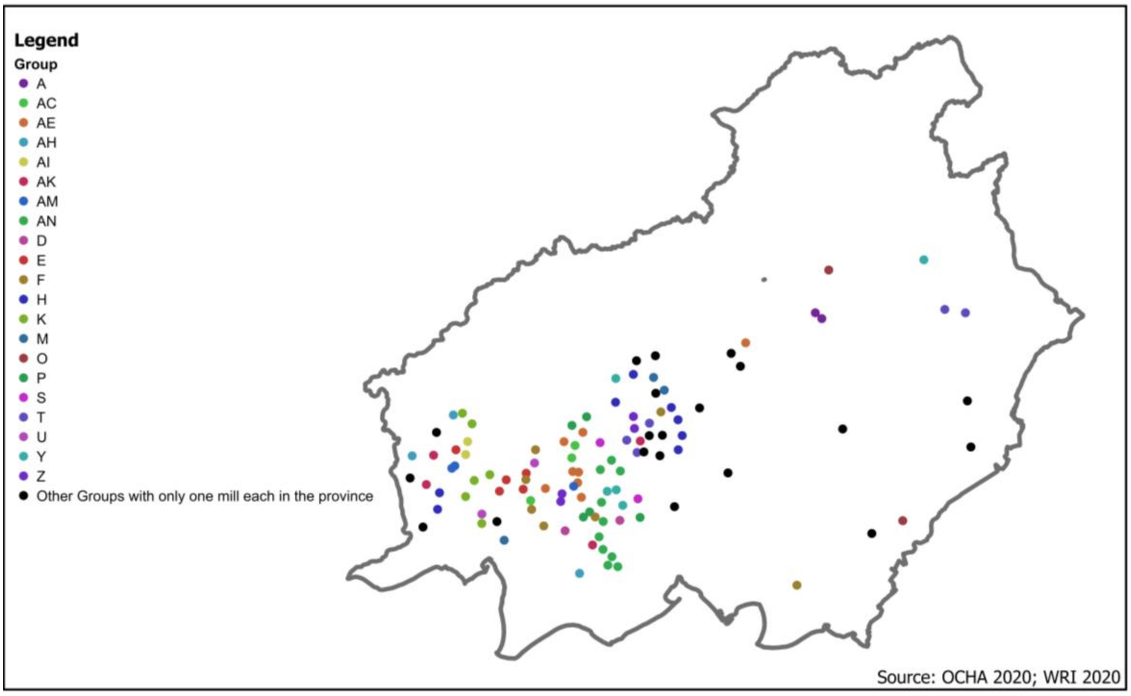


Figure 17: Distribution of the groups, the mill companies belong to (own figure).

Based on the size of plantations, Central Kalimantan has a smallholder ratio of 4 – 6 % with a threshold of 7 hectares (applying the neighbourhood analysis or not). Applying the governmental used threshold of 25 hectares, the ratio would rise to 10.7 % respectively 9 %. With this value, the plasma smallholders are probably included. These calculated ratios are remarkably lower than the national mean of 40 % found in the literature (Jelsma et al., 2017). Even it is known that the ratio for Central Kalimantan is lower (around 15 % in 2015, PILAR and CPI, 2015), the calculated value must be handled carefully, because of further factors deciding whether it is a smallholder plantation or not.

<u>Certification</u>

When it comes to certification, one-third, specifically, 34 mills are RSPO-certified. Except for one mill, all RSPO-certified mills are in western-Central Kalimantan (see Figure 18). At the same time, it is one-third of the total installed capacity that is certified, whereas the mean installed capacity per RSPO-certified mill is slightly higher than for the ones without certification.

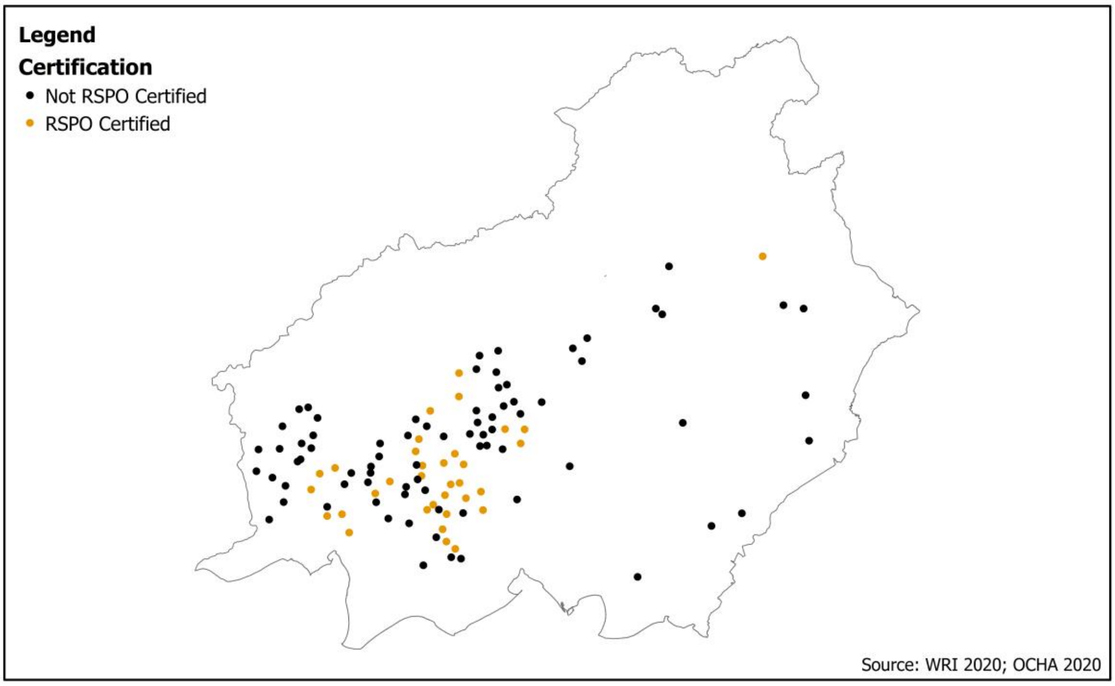


Figure 18: RSPO-certified mills in Central Kalimantan and their distribution in the province (own figure).

Palm Oil Production

The mills in Central Kalimantan are sourcing from a total palm plantation area of 1,505,014 hectares, which are remarkably diverse when it comes to their age. For the whole province, a mean age of 8.6 years (median age 7 years) was found with the land cover time series summary grid. For the year 2018, 26.3 % of the total plantation area is in the highest production age of 9-14 years old. 40.1 % is between 4-8 years old and accounts for the largest share. It will reach the main producing age of 9-14 years within 1-5 years. The proportion of seedlings and mature plants is almost equal, with around 16%. 6.7% is assigned with an age of 19 years, which indicates the minimum possible age, due to missing older data. Figure 19 shows the distribution of the age of palm oil stands. While the west is diverse in the plantation age distribution, young palm stands are dominating the bigger plantations in the eastern part, with one exception. There is also a lot of small (≤ 7 ha) plantations that are partly already a little older.

The mean age for the smallholder-classified plantation areas is 8 years and for the industrial plantations 8.6 which does not support the argument that especially independent smallholder plantations in Indonesia have declining yields due to old trees (Kusumaningtyas et al., 2019). Beyond that, the median for smallholders is even only 4 years and for industrial plantations 7 years, which would be the opposite of this estimation but still corresponding to low yields. However, the reason is not old plants but very young plants.

Including age and management, the estimated FFB yield in Central Kalimantan is 29,684,384 tons of FFB per year. This makes an average yield per hectare of 19.72 tons FFB which compiles with

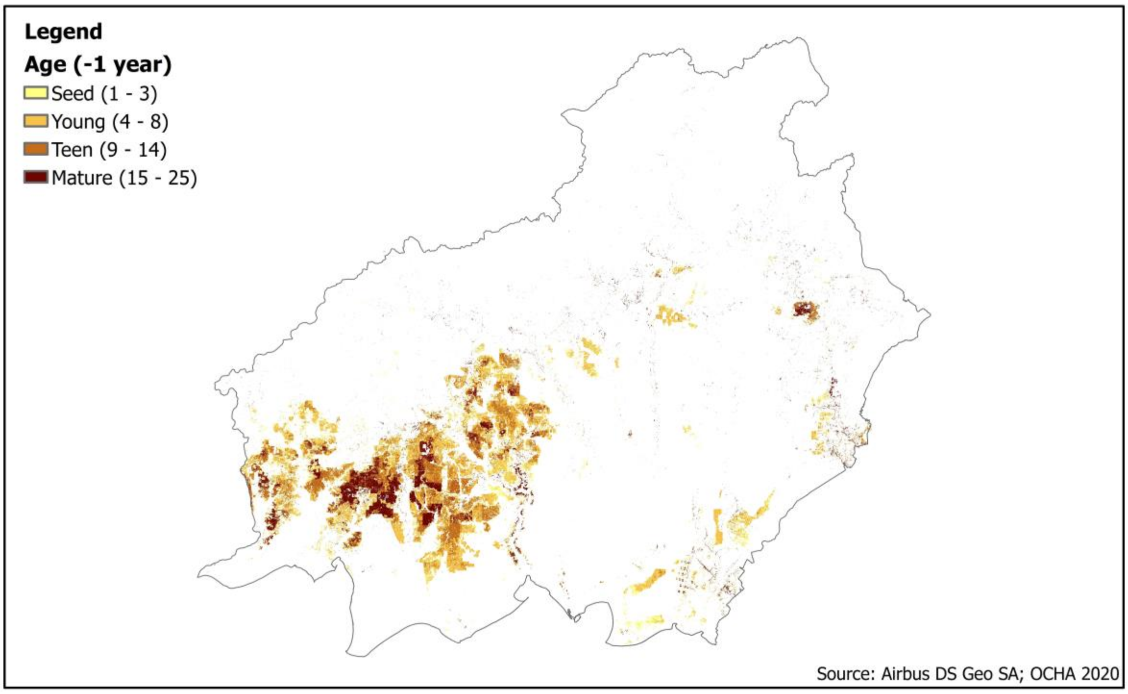


Figure 19: The age of the oil palm stands in Central Kalimantan in 2018. The age was calculated by summarizing the land cover time series. Because one year is missing in the time series, there is an insignificance of at least 1 year (own figure).

Paoli et al. (2013) assuming a yield of circa 19 tons FFB/ hectare for Indonesia. Based on this value, the average needed plantation area for one mill capacity unit can be calculated and is expected to be 330 hectares. This reference value will be used to calculate the needed plantation area for mills with an overcapacity (see for final yield estimation Figure 20).

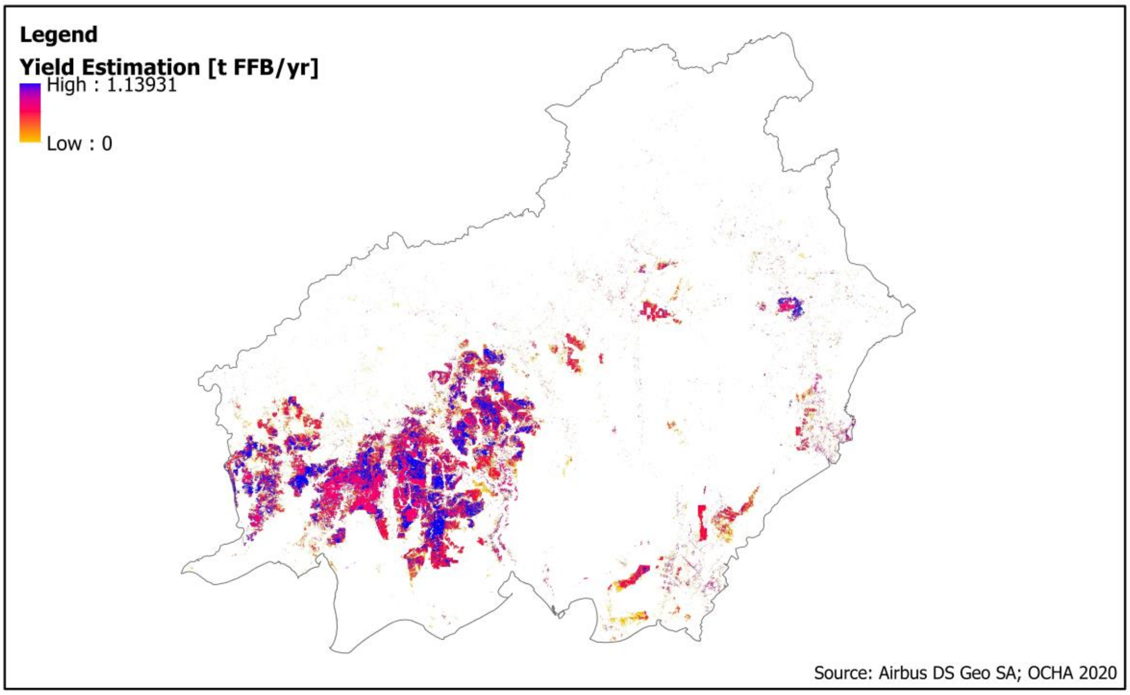


Figure 20: The estimation of the expected yield in Central Kalimantan, Indonesia in 2018, based on palm stands age and management (SHP or IOPP). The indicated value is per pixel area (own figure).

The findings on the palm oil production location of Central Kalimantan showed that it is remarkably diverse in age and type of infrastructure. Regarding ownership and districts, it is concentrated, though. This could result in a high competition intensity in these regions but has also potential in taking advantage of the existing transport and processing infrastructure and knowledge. In this way, companies can reduce costs and efforts in the palm oil development that makes some districts profitable and attractive for new investments. The laws and regulations which are sometimes generously enforced on the district level, are making the location particularly accessible for investment-strong companies, as these are desirable for the districts in terms of taxation.

4.2 A MILL'S SUPPLY CATCHMENT

The calculated catchments exemplify the reach of a palm oil mill and its possible impact on the surrounding landscape. Based on the available roads, the land cover, and the topography, the shortest travel time from a mill to its surrounding landscape was calculated, applying a threshold of 48 hours. With a few exceptions, appropriate catchment areas could be calculated for all mills which respect the transport time of FFB to keep the best quality.

Figure 21 shows some examples of the calculated supply catchments. The variety in size of the whole catchment but even of the individual classes is evident. It depicts the different infrastructural situations that are available over the province. The comparison of the catchments with the km-zones gives an idea of how the calculated catchments correspond better to reality than the ones based on spatial distance. While example b) matches most likely with the distance buffers, examples a) and c) are differing extremely from this approach. In the example a) 8-hour and 24-hour accessibility classes are not even visible, and the 48-hour-class does not exceed the 50-km-buffer much. In contrast, the accessibility in example c) goes far beyond the 50 km-buffer.

Figure 22 shows two catchments where either one class or the whole catchment is reduced to a minimum. This happened to catchments when high values were present in the friction surface. In the example A), the area around the mill was indexed as wetland in the land cover data, which was reclassified in the calculation of the friction surface as not passable and thus assigned with the highest possible time to cross the pixel. Missing roads in the OSM data are reflected in example B) when off-road speed values were used and reduced the 8- and the 24-hours classes. 24 catchments are estimated to be affected by missing or false data. In 14 cases, the main effect is on the 8-hours-class while the rest of the catchment seems not to be highly affected. Ten cases are showing a strongly reduced catchment. Out of this, seven are probably mainly reduced due to the land cover classification as wetland or water in the mill area. A possible reason

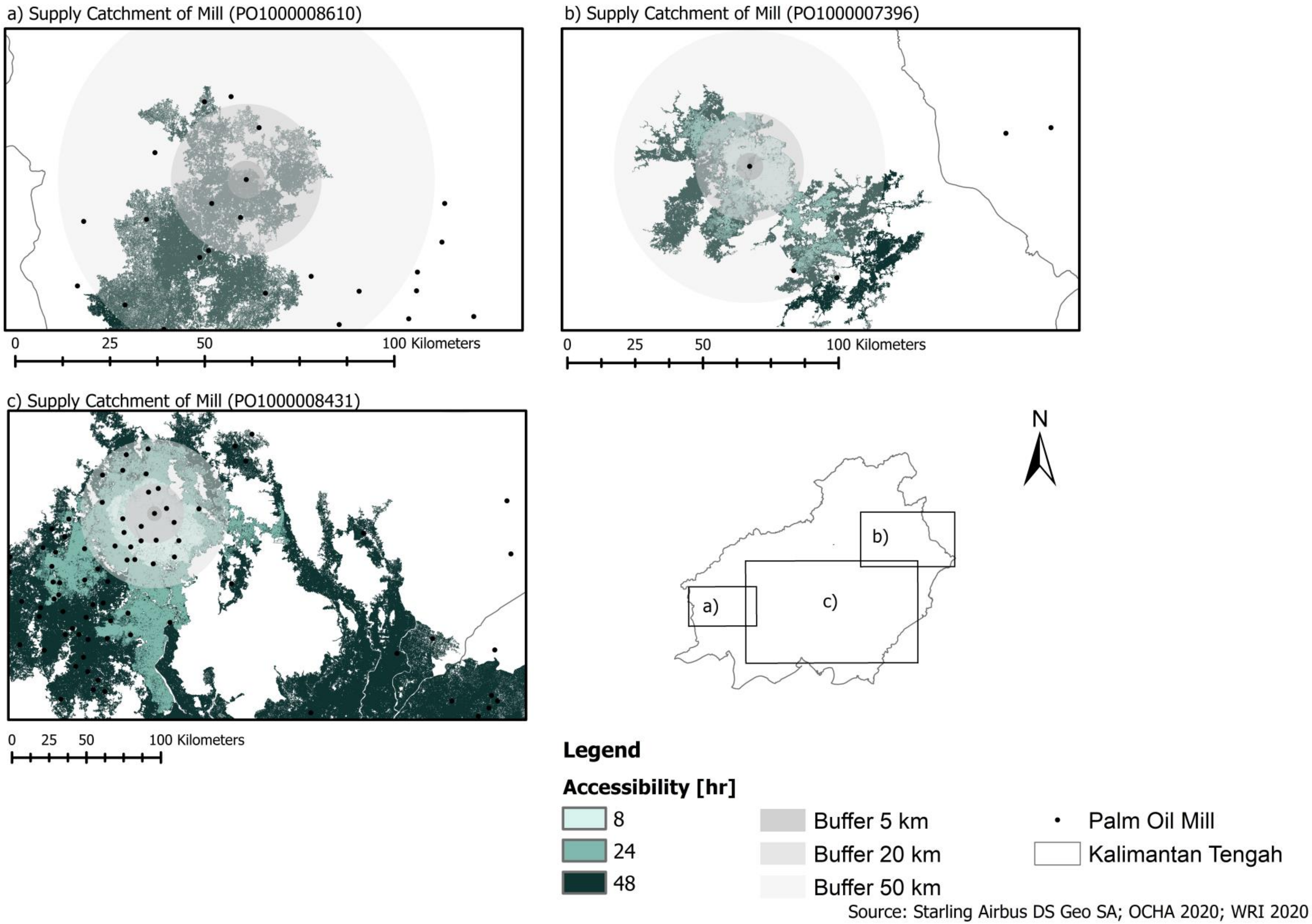


Figure 21: Comparison of calculated catchments with km-zones (own figure).

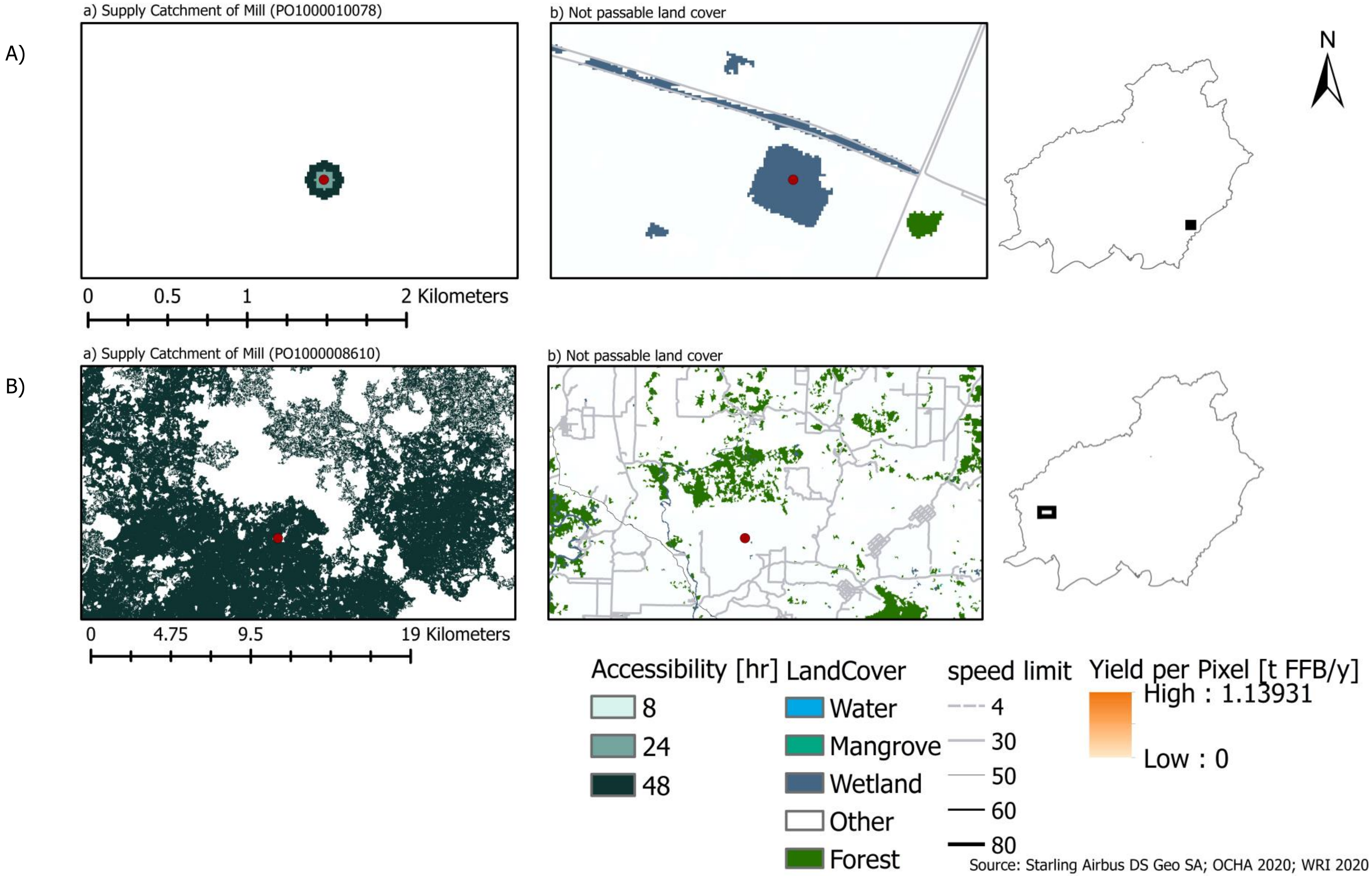


Figure 22: Examples of non-conforming supply catchments, compared to the land cover and the available roads (own figure).

for this classification could be the palm-oil-mill-effluent-tanks around a mill. Missing road data was the main reason for the reduction of two, and steep slopes for one catchment. However, mostly it was a combination of at least two variables that caused such non-conforming catchments.

In summary, there are two main limitations of the calculated catchments. The first limitation refers to the errors in catchments due to false land cover data or missing road infrastructure data. The second applies to the missing economic and structural factors, and therefore overlapping catchments. In some areas, the number such overlaps is remarkably high (see Figure 23). Since research is very scarce on this topic, and it could not be found that this approach has already been applied, the potential for improvement is high. But it requires further basic research on the plantation – mill – connections and on the dynamics within this system. However, a first methodological approach to calculate such catchments was developed to answer the first research question of the thesis at hand. The method can serve as a basis for future studies to adapt and build on.

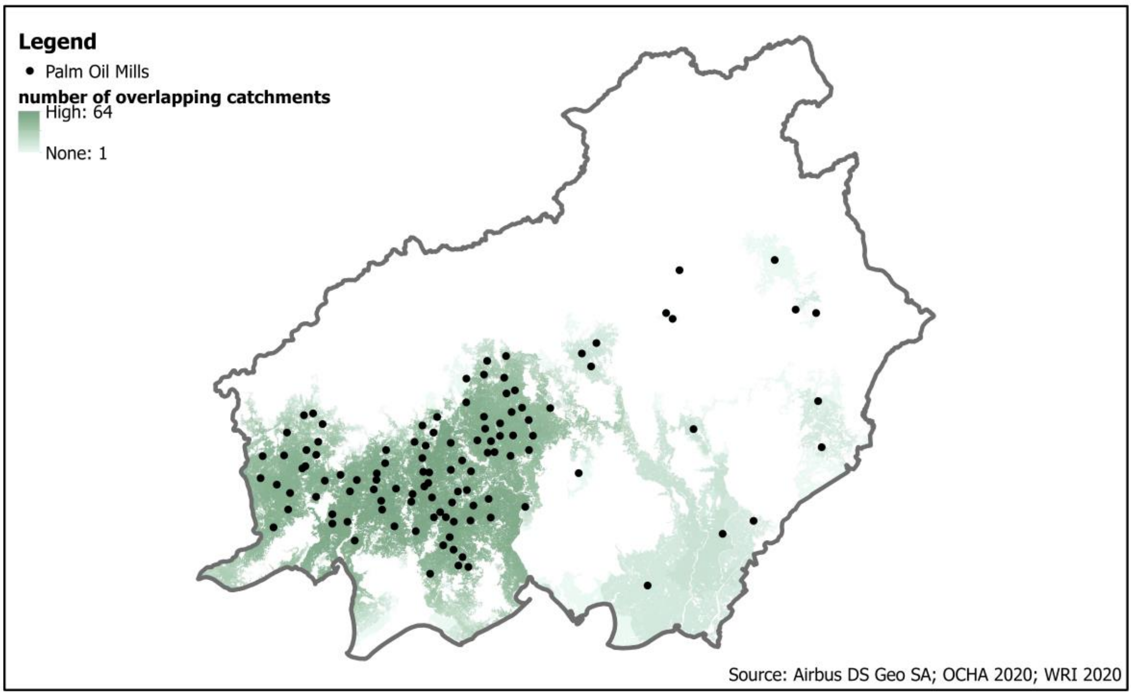


Figure 23: Number of individual 24-hours-catchments of palm oil mills that are overlapping (own figure).

4.3 HUNGRY PALM OIL MILLS SITUATION IN CENTRAL KALIMANTAN

Identifying Hungry Palm Oil Mills

The difference between the estimated production volume and the installed mill capacity identified the mills with an overcapacity: the hungry mills. For three different classes in travel time that were applied, different numbers of hungry mills have been found. The shorter the time to

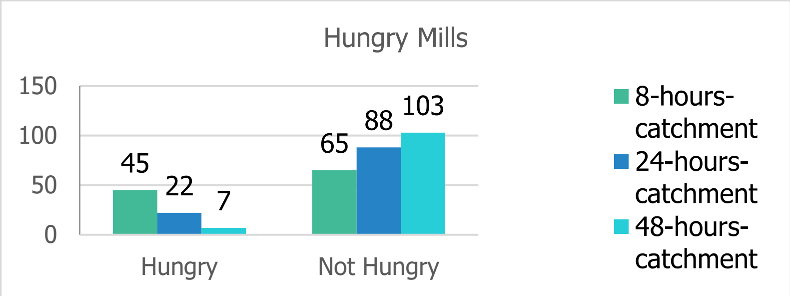


Figure 24: Number of identified hungry mills in the different catchments (own figure).

transport the FFB, the less production volume available in the catchment and thus, more hungry mills were identified. In turn, there are less hungry mills when a larger catchment is applied (see Figure 24). With the 8-hours-catchment, 41 % of the mills are found to be hungry. Extending the catchment to 24 hours, 20 %, and with 48 hours, still, 6 % of the mills are shown to operate below the installed capacity. These numbers include the mills that have no plantation area in the catchment, mostly because it is too small. This happens especially with 8-hours-catchments. It also includes the three mills which did not have capacity information.

Locating Hungry Palm Oil Mills

The spatial distribution of hungry mills can be seen in Figures 25 - 27. Orange dots indicate the above-mentioned special cases with non-conforming catchments. While there are a lot of such orange mills with the 8-hours-catchment-analysis (29 mills), the number is strongly reduced when applying the 24-hours-catchment-analysis (4 mills). The remaining orange mills are the three without capacity information and one with an extremely reduced catchment. Most of the hungry mills (red dots) can be found in the north and north-east of Central Kalimantan. This is a marginal area, where oil palm production is not as dense as in the middle of the province. In this region, where mill density is extremely high, almost no hungry mills are identified. It is the area, where a lot of catchments are overlapping and therefore, production volume could be assigned several times to different mills. Still, a closer look at this area shows a summarized discrepancy of around 5-10 % that is still needed to be filled with the 24-hours-catchment-analysis.

In the following, there will be a focus on the results of the 24-hours-catchment-analysis since this is the most widely used and applied time frame. The distribution of hungry mills with the 24-hours-catchment-analysis shows that even only around 20 mills are operating below 100%, an additional 10 mills are operating at 200 %. These mills could reach their capacity twice with the calculated catchment.

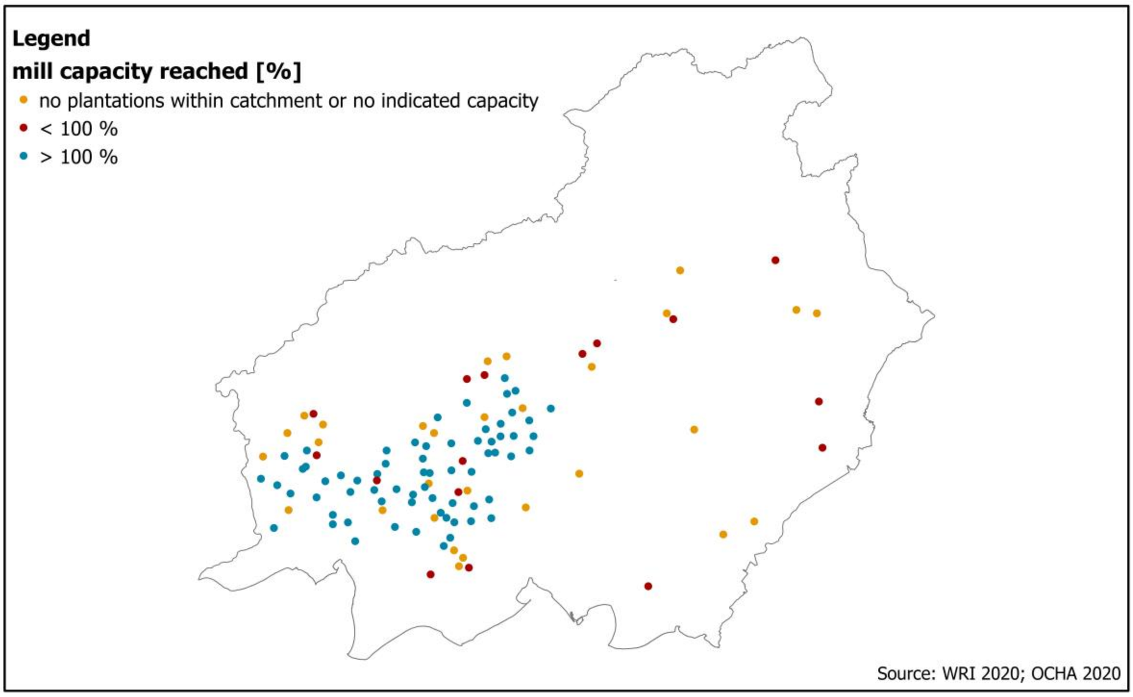


Figure 25: Hungry palm oil mills situation in Central Kalimantan in 2018, when applying an 8-hours-accessibility (own figure).

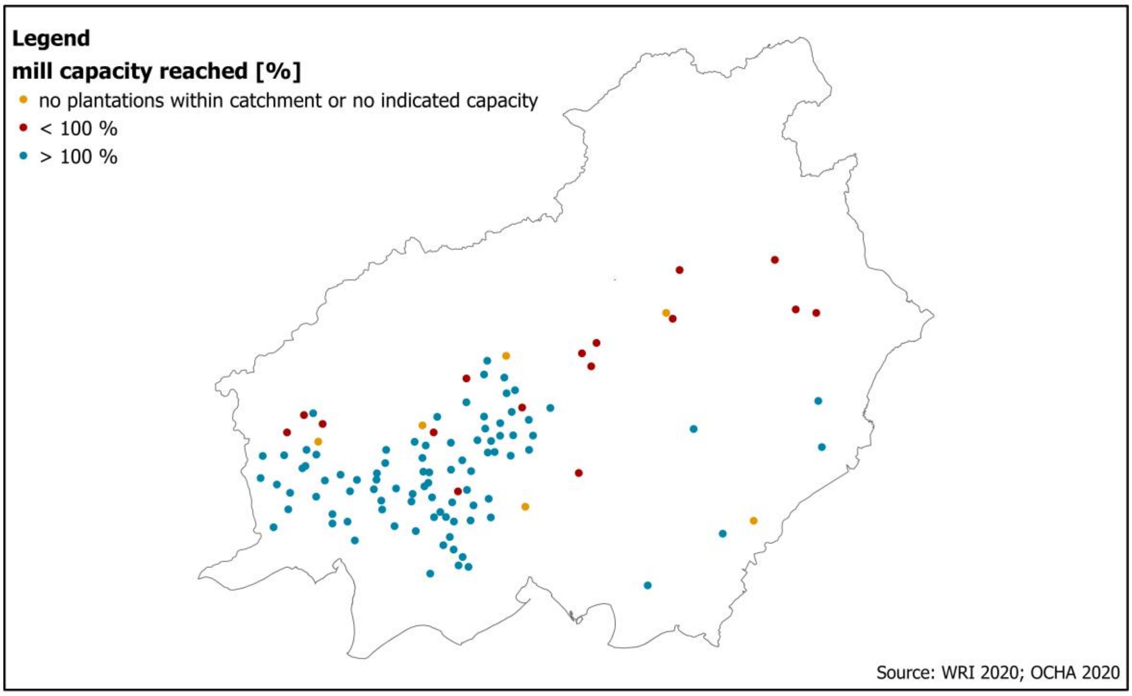


Figure 26: Hungry palm oil mills situation in Central Kalimantan in 2018, when applying a 24-hours-accessibility (own figure).

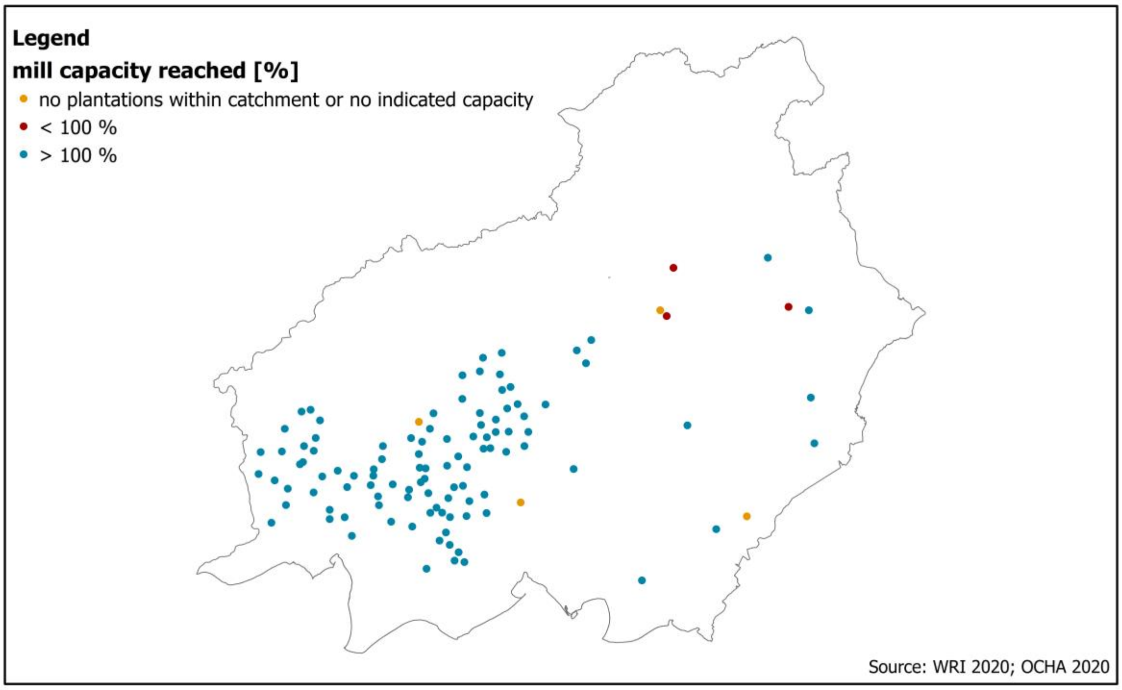


Figure 27: Hungry palm oil mills situation in Central Kalimantan in 2018, when applying a 48-hours-accessibility (own figure).

Characterizing Hungry Palm Oil Mills

The following two examples are showing reasons for a mill to be identified as hungry. The upper left image shows the catchment with its accessibility boundaries, the upper right image the not passable land cover and the travel infrastructure and the lower left shows the plantation area with the estimated yield. The first catchment is mainly limited by the forest around the mill (see Figure 28). Within this limited catchment, almost no palm is available. Even this mill has an installed capacity of rather low 45 tons FFB/hour, the mill is operating below it. Besides, the available plantation area shows a low yield. Further analyses on land cover data in *Starling* from the year 2020 showed that the plantation area around this specific mill has already increased. Therefore, this mill and the surrounding plantation is probably in the establishment process with currently young palm stands. This could be the case for some hungry mills since 40% of the palm is teen and will reach the highest producing age in a few years. The second example (see Figure 29) shows the catchment for the mill which is on the left. Both mills are shown as hungry, even some of the yield is counted twice because of the overlap. Since both are from the same parent group, they are probably sharing the respective amount of palm that can be seen. This catchment is limited by forest as well and besides, because of the river, the palm plantation area on the west side of the river is not accessible with the applied conditions. Since the yield is already quite high, it is not expected, that these mills are in the establishment process. A comparison with the 2020 land cover showed no significant increase in the plantation area.

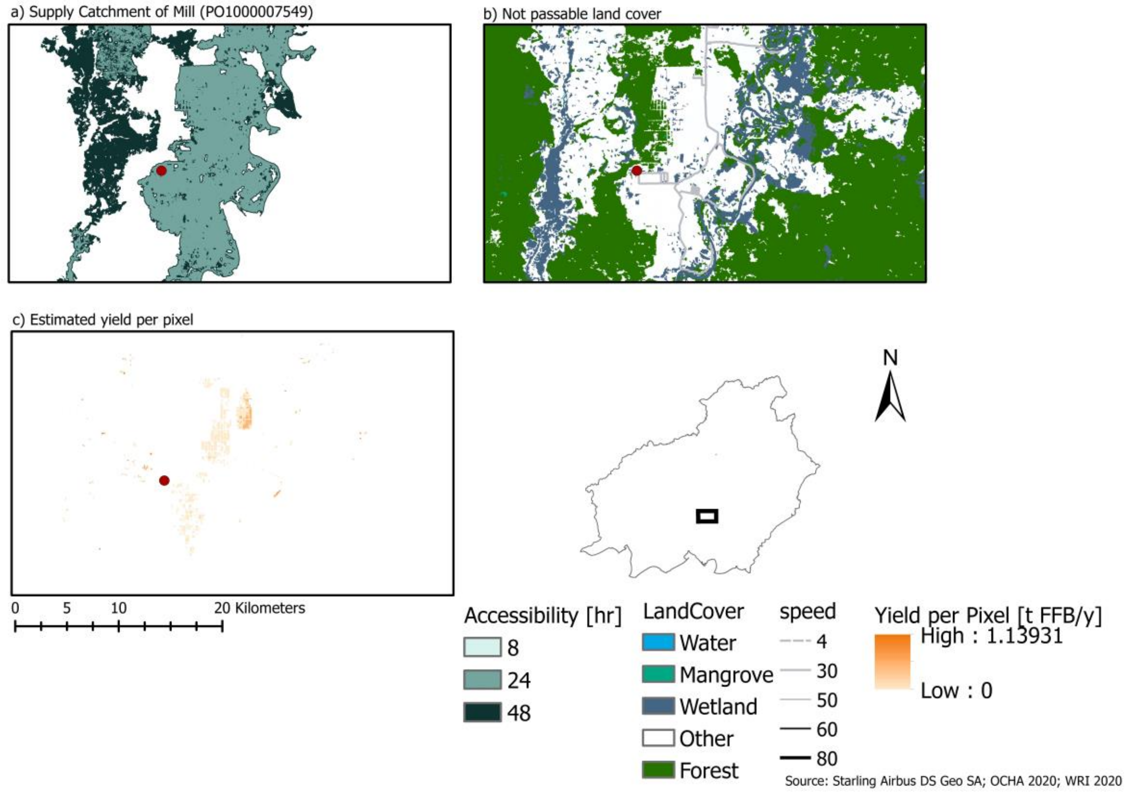


Figure 28: Overview of a hungry palm oil mill. Upper left: catchment based on accessibility analysis; upper right: the not passable land cover and roads with assigned speed limits; lower left: estimated FFB yield (own figure).

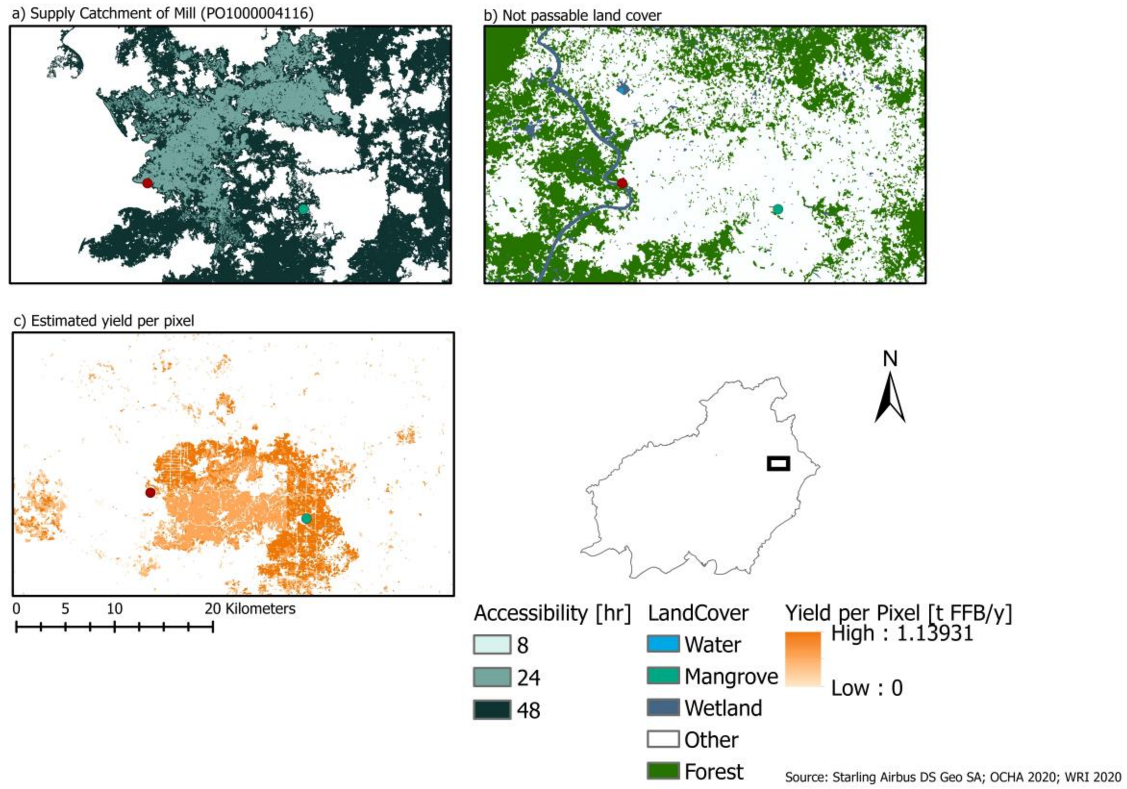


Figure 29: Overview of a hungry palm oil mill. Upper left: catchment based on accessibility analysis; upper right: the not passable land cover and roads with assigned speed limits; lower left: estimated FFB yield (own figure).

A further reason for a mill to be identified as hungry could be, that the installed capacity is already high. But the results are showing that the median capacity of all the hungry mills is 60 tons FFB/hour, only two mills have a rather high capacity with 90 tons FFB/hour. With a processing capacity of 60 tonnes FFB/hour, these hungry mills are in the upper half but are still on average in terms of the capacity situation in the province.

Handling Limitations

When applying the overlap factor, the probable hungry mill's situation is approximated (see Figure 30). With this approach, 82 mills are expected to operate below the installed capacity, only 22 mills can reach the needed amount of yield. When identifying hungry mills based on the catchments calculated with the cost allocation analysis, 28 mills are excluded because they are hardly accessible (orange dots). This applies particularly to mills with non-conforming catchment areas. Figure 31 shows the hungry mills situation with catchments based on the shortest travel time. 54 mills are identified as hungry, with a median reached mill capacity of 43 %. The average needed plantation area for these mills is around 7700 hectares per mill, in total 525,000 hectares, with 28 mills out of the competition.

By looking at the summarized hungry mill's situation on the provincial level, the results of these different approaches are tried to be sorted. For an installed capacity of 6770 tons FFB/hour, 2,234,100 hectares of palm plantation would be needed with an average yield of 19.72 tons FFB/year. Therefore, without considering the accessibility, Central Kalimantan requires 729,086 hectares. 58,090 hectares are added to this need when applying the accessibility with a 48-hours-threshold to the whole province (787,175 hectares in total). This means that only two-thirds of the needed palm plantation area is established in Central Kalimantan. Specifically, the installed capacity in the province is around 35% higher than the production volume. This is less than the proposed 50 %-difference by Pirard et al. (2020) on the national level. Reasons, that around 60,000 hectares are not accessible within 48 hours from any mill can be diverse. On the one hand, it could be methodological reasons, like blocking land cover or missing road data. On the other hand, it could be a management issue that particularly independent smallholder plantations are not in reach of a mill because they produce palm oil for subsistence use.

The methodology used and developed in this thesis to identify hungry mills showed to have a huge potential in investigating a mill's reach and impact in a more detailed way and can serve as a tool for further development. Nevertheless, the calculated catchments must be handled with care and must not be taken as static. They reflect theoretically possible supply catchments of mills. Based on these analyses and specifically based on the cost allocation and the mills excluded there, the calculations for the friction surface can be improved and refined. A further limitation is in the assumption that mills are operating 20 hours for 330 days. Mill capacity information adapted to the actual running time could improve the accuracy of the hungry mill's identification.

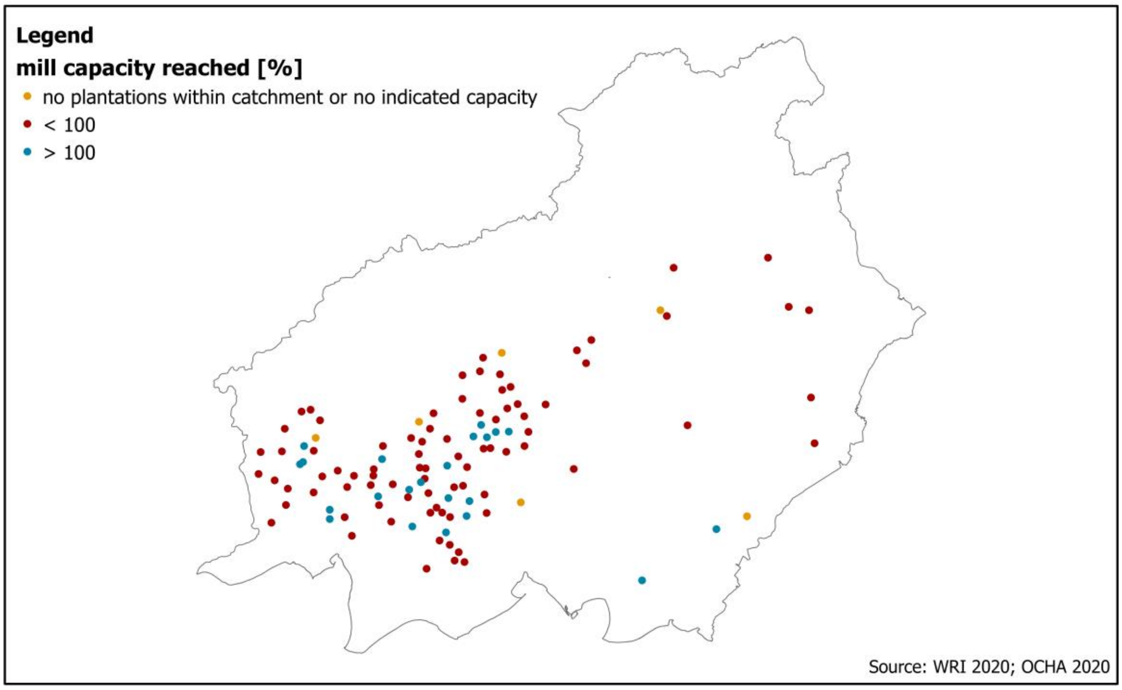


Figure 31: Hungry palm oil mills situation in Central Kalimantan in 2018 when applying an overlap factor, based on the number of overlaps within a mills catchment (own figure).

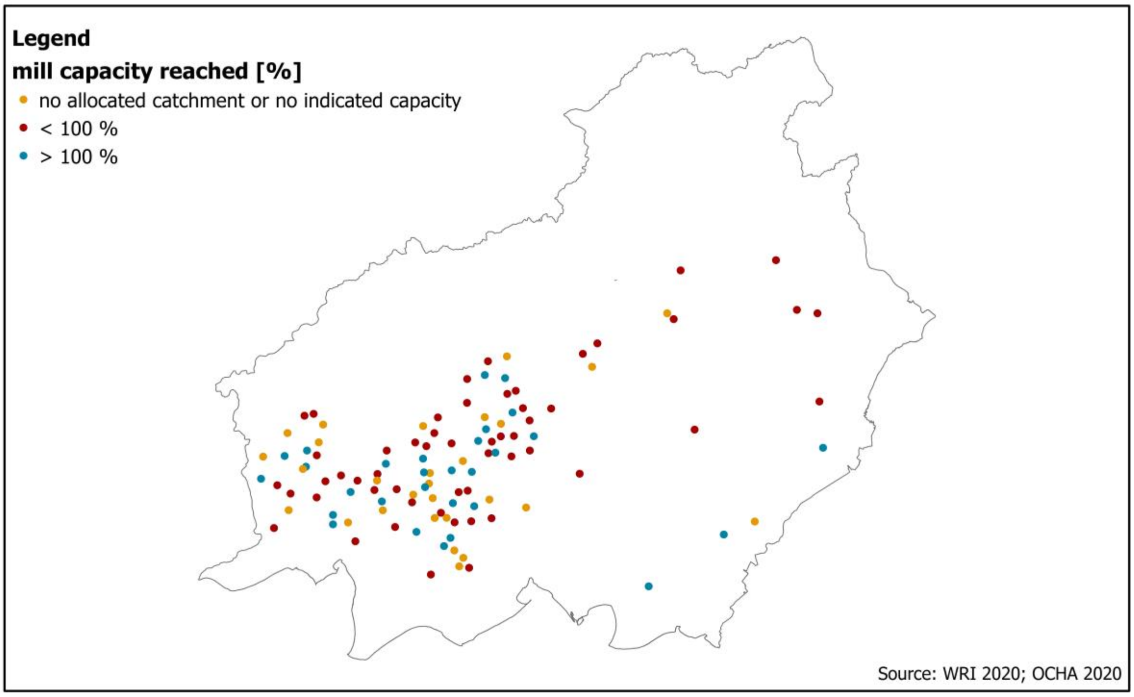


Figure 30: Hungry palm oil mills situation in Central Kalimantan in 2018, when applying a nearest-mill-accessibility (own figure).

4.4 RELATED KEY ACTORS OR WHO CAN FILL THE MILLS

In order to answer the second research question: *Who are associated stakeholders of hungry palm oil mills in terms of increasing productivity?*, the relevant actors need to be identified. This happens by analysing the main characteristics of the hungry mills that have been identified.

<u>Location</u>

In Indonesia, the local governments, namely the districts are mainly responsible for enforcing land and infrastructure licenses for palm oil and thus enabling palm oil development (Paoli et al., 2013). On this level, it is simply the districts with the most mills, where also most hungry mills can be found: Kotawaringin Timur. However, because there are so many mills, the district can compensate the overcapacity: The summarized estimated yield that is within 24 hours reach of the mills in this district, is 20 times higher than the installed capacity. This is probably due to the good infrastructure and high palm oil development in this district. Smaller districts or districts with fewer mills cannot compensate overcapacity in the statistics. For example, the districts Gunung Mas, Barito Utara, and Kapuas have 3-6 mills located in their area and a hungry mill ratio of two thirds up to 100%. These are also the district with the highest need of plantation area.

When summarizing yield and capacity for the districts, the situation looks different, especially because it does not include overlaps. Figure 32 shows the ratio of the estimated yield and installed mill capacity in a district. An index value close to '1' indicates a balance - so, the capacity to process FFB by the mills in the district is approximately equal to the available FFB in the district.

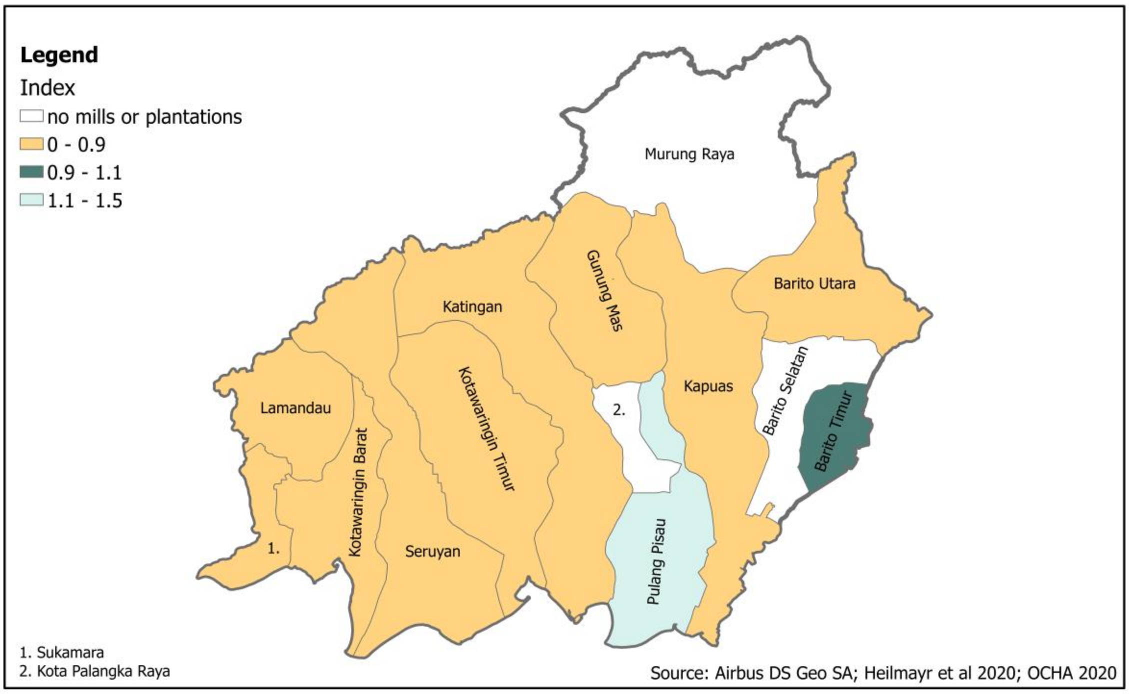


Figure 32: The proportion of estimated yield and installed mill capacity per district in Central Kalimantan, Indonesia in 2018 (own figure).

A low value implies high competition for FFB in a district since there is less yield than installed capacity. The figure depicts a lot of competition for FFB in almost every district.

Stakeholders

Regarding groups, there are six, which cannot even reach half of their mills' capacity on average with the yield in their 24-hour catchment areas. Concerning needed plantation area, one group can compensate for this deficit with other mills, the other groups are at the top of this ranking as well. Two additional groups can utilize their mill capacity more than halfway but would still need further plantation area (see Table 4). The group which is ranking at the top would theoretically need about 46,000 additional hectares. The next five groups require between 10,000-20,000 hectares of palm plantations. Regarding the median palm stands age of the groups (group mean of median per group and accessibility class), particularly one group stands out with remarkably young palm plants. This *Group O* also appears in the first place in needed plantation area and on the third place regarding mean overcapacity. A connection between the overcapacity and the young plants and thus resulting low yields can be assumed. The same corresponds to *Group N*. The group which is hungry with an overcapacity of 100%, *Group B*, does not appear in the age ranking. This leads to the assumption that there is simply not enough palm plantation area around the mills of this group. *Group AD* appears so many times in these rankings since it does not have capacity information.

Mean Overcapacity of Hungry Mills of Group		**Summarized needed Plantation Area**		**Median Palm Age (mean of accessibility classes)**	
Group	**[%]**	**Group**	**[ha]**	**Group**	**Years**
AD	100	**O**	46,705.1	**AD**	0
B	100	**B**	19,800	**O**	2
N	98.7	**L**	15,360.2	**X**	4.5
O	96.1	**N**	14,662.3	**N**	4.5
A	89.8	**A**	11,831.8	**AG**	5
L	77.6	**X**	9281.4	**C**	5
AI	50	**AF**	3837.2	**AF**	5
		AD	0		

Table 4: Different group rankings compared. 1. mean overcapacity per mill: > 50%; summarized needed plantation area: > 0 ha; median palm stands age, ≤ 5years. Coloured by group for a better comparison.

Despite the concentration of the palm oil industry in Central Kalimantan on a small group of owners, issues of overcapacity are not affecting these groups directly. The focus here is therefore more on the smaller owner groups. However, the same applies here as in the districts: groups with many mills are on average much better at compensating for overcapacity and therefore do not appear in the ranking. Nonetheless, most of these dominant groups have their mills in the area of dense palm oil production, which means that possible overcapacity was not captured due to overlapping catchments. Still, the dominating groups need to be monitored due to their high power on half of the palm oil production in Central Kalimantan.

Owners are responsible for financing their mills, but also managing the efficiency of the mill operations. When it is a mill integrated into a supply chain, the owners can also be responsible for plantation management. Even though the mills in the east have many more smallholder plantations in their catchment area than those in the west (see Figure 33), there is no significant connection that hungry mills are rather sourcing from smallholder plantations than not hungry mills. The median SHP ratio of hungry mills is 0.48 percent and the median of the mills not identified as hungry is 0.72 percent. This result is in contrast to a lot of literature referring to the independent smallholders that since they have too low yields and too old palms, they are playing an important role in making mills hungry and consequently driving future deforestation (Kusumaningtyas et al., 2019; Potter, 2015).

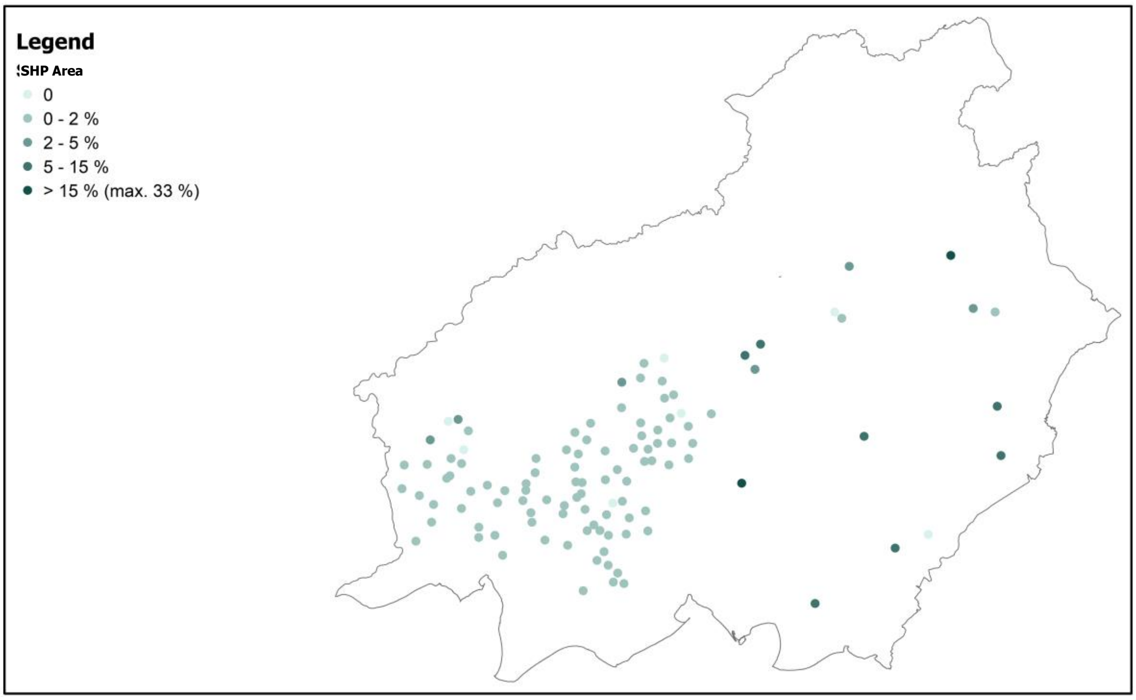


Figure 33: Proportion of identified smallholder plantation area within a mills 24-hours-catchment (own figure).

<u>Certification</u>

Analysis of RSPO-certified mills showed that 8.8% of these mills are hungry. At the same time, almost 25% of the non-certified mills are expected to be hungry, which is a considerable difference. However, the mean overcapacity of the hungry mills is two-thirds lower when not certified than when certified. So, even the certified mills have a lower ratio of hungry mills, their hungry mills are hungrier than the non-certified ones.

All in all, the findings that stand out the most, are the results on the smallholder yields and its contribution for a mill to be hungry that contract the results found in other studies. Field validation would be particularly important here, due to the different definitions of smallholder plantations, whereas not every factor can be analysed with a desktop analysis. Further research could also focus more on developing a competition factor to the catchment calculations since this variable would be decisive in yield allocation.

4.5 OUTLOOK ON FUTURE DEFORESTATION

The findings showed that regarding *location*, some districts and regions are standing out concerning the number of hungry mills or to have a high overcapacity. Besides, some regions are expected to have high competition for palm due to the availability of a dense palm oil infrastructure. The results on the *stakeholders* depict a focus on some of the smaller owner groups, especially since they cannot compensate an overcapacity. Regarding the management of plantations, smallholder plantations showed to have very young palm stands which result in low yields. However, their ratio in hungry mills is too low to make a significant change. Moreover, the plantations in the entire province are on average rather young. The *certification* did not prove a major impact on the hungry-mills-situation in Central Kalimantan. Even though less RSPO-certified mills are hungry, the certified hungry mills are hungrier than the not-certified mills.

Even though the yield increases with the age of the palms, there is still a lot of competition among the palm oil mills in Central Kalimantan. More land for palm plantations is needed and thus, deforestation risk automatically increases. The risk intensifies, considering that most of the hungry mills are not RSPO-certified.

Looking at the palm oil concessions, the land that is in some way allocated to palm oil development helps to find where future deforestation for palm is likely to happen. The concessions in the centre of the province, where most of the plantations are, are mainly covered with palm plantations, whereas the marginal ones are not and some still have a high amount of forest in it. However, this data must be handled with care, as the concession and land cover data come from different sources and are sometimes not spatially congruent.

The future scenario shows that the hungry mills could be reduced by 2028 with the current travel infrastructure and land cover. The only mills that are still identified to be hungry are the ones with catchment errors or no indicated capacity. On the provincial level, the total installed capacity would be reached by up to 160 percent. Regardless of accessibility, the estimated yield for the whole planted suitable land for sustainable palm oil production would require more than 25 times the currently established mill capacity. This means that Central Kalimantan could fill all its mills without deforestation, still with options of increasing the mill capacity.

4.6 POSSIBILITIES FOR A SUSTAINABLE PALM OIL PRODUCTION (OVERALL DISCUSSION)

Regarding the summarized overcapacity situation in Central Kalimantan with only roughly two-thirds of the needed plantation area installed, it seems inevitable to do something about it. The different analyses are confirming it: the whole province hungers and competes for more palm. But questions on what and whom to prioritize or what it is that should be changed, are a big challenge. Answering the last research question: *What are implications for a sustainable palm oil production regarding mills overcapacities?*, again draws on the already well-known pillars of location, stakeholders, and certification.

<u>Location</u>

A look at the results from the individual-catchments analysis can help to make a first prioritization of key areas (see Figure 34). A lot of hungry mills are in marginal areas, in the north and north-east of Central Kalimantan, where palm oil production infrastructure and roads are rare, and the land cover is dominated by forest. It is that specific part of the province, where less production happens and the large-scale IOPP’s are rare. Even though their catchments are overlapping, they are resulting in running below capacity. This makes it a high probability, that it is the situation

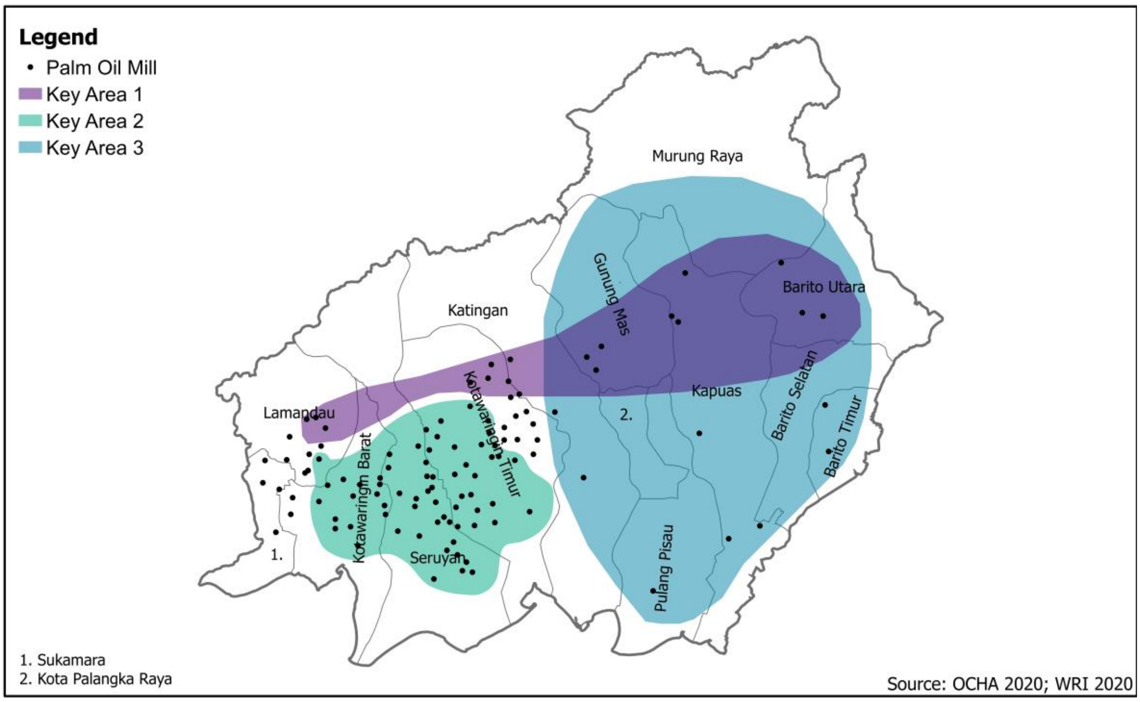


Figure 34: Defined key areas for transformation towards sustainability in Central Kalimantan, Indonesia. The definition is based on the findings of the thesis at hand (own figure).

unless there is an error in the data. Moreover, it is the area, where the concessions still have a high amount of forest in it (Key Area 1).

In a second step for prioritization, the area with the dense palm oil production can be focused. The nearest-mill-catchments showed for this area a lot of hungry mills, while a lot of mills were excluded from the analysis in the same area. The high density of mills, especially in the districts of Kotawaringin Timur and Seruyan already exemplifies a high competition for FFB, which was reflected in this follow-up analysis. Even though palm availability would be high, there are just too many mills in this area (Key Area 2).

As a third priority area, the eastern part where a lot of smallholders are producing palm oil could be prioritized. None of the results of this thesis could support any of the assumptions on smallholder's decreasing yields and for some parts, the outcomes were in some parts even contrary to them. Therefore, possible solutions for sustainable palm oil production by smallholders need to be focused and further research is needed (Key Area 3).

<u>Stakeholders</u>
Within these priority areas, key actors need to be defined. The stakeholders that stood out in the rankings in high numbers of hungry mills, needed plantation area, or overcapacity can be prioritized. The districts, as representative of the government, play an important role in shaping the future palm oil development. As seen in the analysis, some of them are dealing with major overcapacity issues. One suggestion is to focus on the district of Kotawaringin Timur since it is the district with most of the hungry mills. Further districts to prioritize are Gunung Mas, Barito Utara, and Kapuas since they have high overcapacity values and require a high amount of plantation area.

Besides, there are the owner groups, often representing financial power and responsibility for decisions regarding the future development of their mills and linked plantations. Some groups are outstanding in the rankings, where internal mill or plantation management issues could have led to their unlucky podium place. Namely, these are the groups O, N, and B, with high overcapacity values due to either young palm stands or limited plantation area. Further, the eight owner groups, responsible for half of the palm oil production in Central Kalimantan need to be focused on as important and powerful actors in the province.

Surprisingly, the RSPO-certification did only show an ambiguous impact in the overcapacity situation, even though these certifications intend to shape a sustainable palm oil development. However, since there are so many hungry mills without a certification, an uncertain situation remains regarding deforestation due to palm oil. A standardized certification can make palm oil supply chains linked to deforestation more transparent. Therefore, the roundtable for sustainable palm oil is a fundamental representative of sustainability and is regarded as a third key actor.

<u>Certification</u>

A look at the current palm oil concessions gives an idea on the direction for these prioritized areas and actors since most concessions in the eastern part still have a high amount of forest cover in it, the focus needs to be first on finding conservation strategies for these areas. An RSPO certification and its no-deforestation principle could be a possibility. However, this no-deforestation article only exists since 2018, the year this analysis was made for, and long-term effects could not yet be studied. Nevertheless, the study by Heilmayr et al. (2020) shows that RSPO-certification often leads to more deforestation within existing concessions. So, a certification could have the opposite effect and thus, requires a lot of attention on these spill-over effects. Most concessions in the region of dense palm oil production no longer show much forest cover. Therefore, it is important to protect the remaining part of the forest in these concessions.

In the second place, the focus should be on forest protection outside the concessions which is not yet allocated to any company or government and on making the cultivation and processing of palm oil more efficient. In this way, it is possible to prevent the spread of new palm plantations and the resulting deforestation, to focus on degraded land, and above all to make better and more sustainable use of existing infrastructure and plantations. There are already a lot of efforts and research in improving the efficiency of mill operations. To increase yields, the regulation of yield-enhancing best management practices would certainly be a possible solution (Paoli et al., 2013). Especially since a lot of palm stands are young, careful treatment is needed for a long-term, sustainable operation of a palm plantation. In the context of independent smallholders, several case studies show that an agroforestry system would be a suitable alternative. In addition to the increase in resilience through diversification, the studies show that yields are in some cases even higher (Law et al., 2015; Miccolis et al., 2019). Nevertheless, since these are experimental studies, they must be handled with caution.

A further important direction is focusing on allocating land for palm oil development based on the characteristics developed by Gingold et al. (2012). The findings showed that planting this area with palm would provide enough yield to feed all the mills without deforestation. Even the increasing demand could be given enough supplies. With this possibility of enough land available for sustainable palm development (it is not guaranteed that this land also will be accessible), stakeholders need to be encouraged to use this land. Due to this, Austin et al. (2017) recommend zero-deforestation commitments to reduce deforestation for palm oil so that they are forced to turn to the degraded land.

Transformation

According to Law et al. (2015) strategies to set land aside for conservation and limit the development of new plantations do have great potential to support biodiversity (land-sparing). Also, strategies like agroforestry, a part of regenerative agriculture, producing in a way that is favourable for biodiversity conservation, prove to be helpful (land-sharing). However, a better land-use allocation at the beginning outperforms these two strategies (ibid.). The approach to finding suitable land for sustainable production is following this suggestion.

Therefore, the directions for transforming palm oil production towards sustainability include the direct protection of existing forest area, improved and more responsible use of the plantations, and lastly, allocating degraded and suitable land for sustainable palm oil following current mill location and infrastructure. To summarize, Table 5 shows an overview of the directions and suggestions for the various key actors.

The recommendations for the local government are directly linked to the problem that they often limit their regulatory power for economic interests (see Paoli et al., 2013). Since they are key in increasing the effectiveness of sustainability initiatives, related regulations need to be implemented.

Actions recommended to the owners mainly concern the management, whether of the mill or the concessions and aim at better transparency and communication within their catchment areas. This is crucial for mills to prioritize plantations that are favourable for forest development. In particular, dialogue must be sought with plantation owners who have young palm stands to facilitate long-term and sustainable management.

Finally, RSPO needs to add specific credits not only to reduce deforestation but support forest and biodiversity development, to encourage growers and processers to adapt. Since it can sometimes be difficult to trace whether a plantation has been established on degraded land, certificates on supporting measures could eliminate this loophole. However, in principle, more actors must be motivated for certification, which is then also strictly controlled. Even though RSPO is named directly here, efforts in all kinds of initiatives are asked to reach a transformation towards sustainability in the palm oil supply chain.

Besides all the possibilities for deforestation-free palm oil in Central Kalimantan, there are still a lot of social, economic, and legal grievances which affect palm oil production in Indonesia. The palm oil sector is in its total structure strongly intertwined and complex and probably one of the reasons why so many mills are running below their installed capacity and yet new investments for installed mill capacity are still very high (Pirard et al., 2020). Good monitoring of the different aspects and stakeholders is necessary and basic, objective research about this complex system is strongly needed.

LOCATION	STAKEHOLDERS	CERTIFICATION		
		DIRECTIONS OF TRANSFORMATION		
KEY AREAS	**KEY ACTORS**	Improved land-use allocation	Land-Sparing	Land-Sharing
Hungry mills in the marginal areas	Local Government	Enforcing the *degraded land*-regulation more strictly.	Strictly protect and monitor forest area.	Enable land-zoning and taxing favourable for forest-friendly concession use.
Region with dense palm oil production	Owners	Prioritizing palm plantations that were established on *degraded land*.	Prioritizing palm plantations that have protected forest areas in their concessions.	Increase mill efficiency to reduce production intensity in the field.
Region with a lot of smallholder production	RSPO	Facilitating *degraded land* assessments and certification processes.	Concrete certification or commitment credits that *support* forest development.	Concrete certification or commitment credits that *support* regenerative agriculture.

Table 5: Overview of proposed key actors and directories for transformation towards sustainability for the chosen key areas with examples of concrete actions.

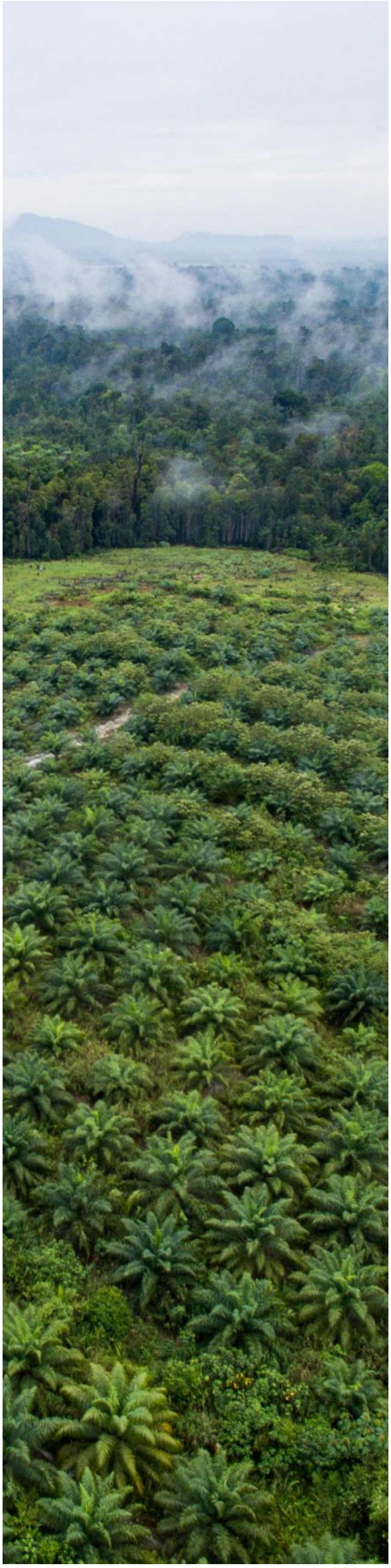


Figure 35: Palm Plantation in Sentabai Village, West Kalimantan, 2017 (Photo by Nanang Sujana, CIFOR).

5 CONCLUSION

The thesis at hand aimed to characterize mills as key actors for transformation towards sustainability in the palm oil supply chain. For this, palm oil mill supply catchments were calculated based on their accessibility. The estimated yield within these catchments was summarized and compared to the installed mill capacity to find mills that are operating below it – the hungry mills. Based on the findings, related stakeholders were identified and possible scenarios for future deforestation were drawn. The results for Central Kalimantan showed that only two-thirds of the needed plantation area is installed, and it is expected, that a high amount of the palm oil mills is operating below their installed capacity. Reasons for this can be either too young palm stands with low yield volumes, limited catchments due to surrounding forest, or high competition between mills for palm. The good news is that the needed plantation area can be covered by developing areas which are categorized as degraded land. Therefore, hunger for palm could be satisfied without deforestation at all. There is even enough supply to meet the increasing demand for palm oil.

Some districts and owner groups are standing out in the analysis on their need for more plantation area or the number of hungry mills. Besides, certification did not show to prevent mills to have an overcapacity. But there are also a lot of not-certified hungry mills that require more plantation area. Therefore, to shift the focus on sustainable production and make use of the degraded land for palm instead of cutting forest for new plantations, forward-looking steps are needed. Action recommendations were made for three key areas, that are concerned with either high numbers of hungry mills, high competition for palm, or areas with currently large forest area. Three groups of stakeholders linked to hungry mills are set to be key to transformation. The local government, the owners, and the roundtable for sustainable palm oil are called to stand up in three proposed directions. More strict law enforcements, legal facilitations for forest conservation, improved transparency between mill operations and plantation relations, and new certification credits for not only excluding deforestation from their supply chains but actively protect and support forest development – these are only some of the suggested actions to be taken.

Nevertheless, there are some limitations in this thesis, especially in the applied methodology. The data limitation and the complexity of the system proved to be the biggest hurdle for accurate results. Further research is inevitable for a successful transformation. Especially more studies on further supply catchment variables are needed to improve and refine the methodology for the mill catchments. The same applies to yield estimation and management allocation. Since this thesis relied on desktop-analysis, field validation of the results is necessary for new analyses based on the developed methodology and accurate prioritization of specific actors. Further research could also go deeper into the system and focus on mill investments and licensing despite the high competition. Accessible data on the dynamics of plantation-mill-relations would be interesting and supportive. To date, the existing and particularly accessible research relies strongly on reports from conservation NGO's or land programmes, which is often biased. Impartial and accessible basic research is necessary to promote sustainable approaches in palm oil development.

This study showed some ideas and methods on how to prioritize specific actors and proved palm oil mills to be actual key players. With a few targeted actions, they and their network can ensure that Central Kalimantan can once disappear from the top of the deforestation rankings and instead enable a forest of prospers at the side of palm oil supply chains.

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8 APPENDIX

8.1 HUNGRY-MILLS-TOOLBOX

The hungry-mills-toolbox was developed as a part of the thesis at hand. It is based on ArcPy-Scripts and can be used in ArcGIS Version 10.6 with a Spatial Analyst license. There are three individual tools for calculating the supply catchment, including the pre-processing of the data, calculating the friction surface, which is the basis for every approximation tool in ArcGIS, and the cost-distance analysis for every mill. The main output of a further tool is a yield estimation for a specific year, including age and management of the plantations. With one tool, all the hungry mills, based on the different catchments are identified and the last analysis tool covers the overlap problem. The following chapters are giving a detailed overview of these tools.

8.1.1 DEM CORRECTION

Inputs	**Type**	**Outputs**	**Type**
Digital Elevation Model (DEM)	Raster	Corrected DEM	Raster

Workflow:

1. A Terrain Ruggedness Index (TRI) is calculated
    a. S-factor: calculating the sum of the values in a 3x3 neighbourhood of the DEM using the focal statistics tool
    b. T-factor: calculating the sum of the values in a 3x3 neighbourhood of the DEM^2 using the focal statistics tool
    c. $TRI = \sqrt{T + (DEM^2 \times 9)} - (2DEM \ \times S)$
2. Calculate a correction raster by applying focal statistics (3x3 neighbourhood) with the average value
3. Use a conditional function to replace values in the DEM with the value in the correction raster if the value in the TRI raster is higher than 959 (see Riley et al., 1999)

8.1.2 FRICTION SURFACE

Inputs	Type	Outputs	Type
(corrected) DEM	Raster	Friction Surface	Raster
Classified OSM-Roads	Shapefile	Slope	Raster
Land Cover	Raster		
Output Coordinates	Projected Coordinate System		
Workspace	Folder		

Workflow:

1. Pre-Processing of the data
    a. Project and reclassify the land cover, assign a speed of 0.005 km/h to the not passable classes and normal walking speed to the other ones, set every class that is normally passable to null.

Classes land cover	Speed
Water, Mangrove, Swamp, Salt Pond, Paddy Field, Secondary Forest, Rain Forest, Freshwater Swamp, Dipterocarp, Tropical Peat Swamp	0.005 km/h
Artificial, Bareland, Cropland, Grassland, Shrubland, Palm Oil, Coconut, Rubber, Acacia, Eucalyptus, Agroforestry	5 km/h

    b. Project the DEM and calculate a slope raster with percent values
    c. Convert the classified road shapefile to a raster by the speed value, dividing it by 3.6 to get a cost factor [sec]
    d. Create an off-road slope raster (assign every pixel with no road with the slope value, everything else with null) and an on-road raster (assign every pixel with a road with the slope value, everything else with null)
    e. Get the cell size of the land cover raster which serves as a reference raster
2. Calculate transit rasters
    a. Reclassify the off-road raster with the slope values with speed values calculated with Tobler's speed equation. Again the cost factor is calculated which is the basis for the transit value: $Transit = cell\ size/(speed/3.6)$ This transit value states how many seconds it takes to cross the pixel.

Classes off-road (Slope [%])	Speed
0 – 2	4.9 km/h
2 - 5	4.4 km/h

5 - 8	3.9 km/h
8 - 15	3.3 km/h
> 15	0.005 km/h

b. Reclassify the on-road raster with the slope values with slope adjustment factor. Calculate the transit for road speed limits and multiply it with the slope adjustment factor

Classes on-road (Slope [%])	**Slope adjustment factor**
0 – 2	1
2 - 5	0.95
5 - 8	0.9
8 - 15	0.85
> 15	0.001

c. Calculate the transit value for the land cover cost factor raster

3. Calculate the friction surface by using the mosaic to new raster function and setting the priority to:
    1. Transit on roads
    2. Transit on not passable land cover
    3. Transit on off-road areas

8.1.3 ACCESSIBILITY ANALYSIS

Inputs	Type	Outputs	Type
Friction Surface	Raster	Classified Cost-Distance Catchments	Rasters named by UML-ID
Palm Oil Mills	Folder with Single Point Features named by UML-ID		
Workspace	Folder		

Workflow:

1. Set maximum distance to 172,800 seconds (48 hours)
2. Loop through the mill folder, calculate cost distance rasters and reclassify them to the classes of 8, 24, and 48 hours.

8.1.4 YIELD ESTIMATION

Inputs	Type	Outputs	Type
Land Cover Time Series	Folder with rasters	Age of Palm Stands	Raster
Year	Number	Management (SHP or IOPP)	Raster
Workspace	Folder	Estimated Yield based on Age	Raster
Output Coordinates	Projected Coordinate System	Estimated Yield based on Age and Management	Raster

Workflow:

1. Pre-processing
    a. Extract only the pixels with palm plantations from the land cover datasets and set these pixels to '1'
    b. Calculate the pixel area
    c. Make a list of all the rasters from the first year in the time series to the year of interest
2. Calculate the yield per pixel by age
    a. Summarize all the palm layers in the given list
    b. Extract by masking the summary grid with the palm raster from the year of interest

c. Reclassify the age with the associated yield values

Years	Estimated yield [t/ha*y]
0 – 3	0
4 - 8	19.7
9 - 14	31.2
> 15	21.1

d. Downscale it to square meters and multiply it with the pixel area

3. Get the management factor
    a. Convert the palm raster from the year of interest to a polygon dataset
    b. Add a field, get the area in hectares, and convert it back to a raster
    c. Reclassify by a chosen area-threshold to distinguish smallholders and industrial oil palm plantations

Area [ha]	Management factor
0 – 7	0.8
> 7	1

    d. Apply focal statistics and get the majority value of a 50x50 neighbourhood
    e. Extract by masking the result with the palm raster from the year of interest
4. Calculate a combined yield estimation by age and management
    a. Multiply the estimated yield by age with the management factor-raster

8.1.5 OVERLAP ANALYSIS

Inputs	**Type**	**Outputs**	**Type**
Classified Cost-Distance Catchments	Folder	Number of overlapping catchments, size ≤ 24 hours	Raster

Workflow:

1. Loop through the catchment folder by setting every pixel with a value not equal to 48 to null, and the other values to 1.
2. Summarize all the rasters in this folder.

8.1.6 IDENTIFY HUNGRY MILLS

Inputs	Type	Outputs	Type
Classified Cost-Distance Catchments	Folder	Hungry Palm Oil Mills with Information on Yield and reached capacity per cost-distance-class	Shapefile
Estimated Yield	Raster		
Palm Oil Mills	Shapefile		
Capacity Information	Table		
Workspace	Folder		

Workflow:

1. Loop through the catchment folder with a 'zonal statistics as table' function with the catchment classes as zones and the estimated yield as value raster and add an empty field called 'ID'
2. Insert with an update cursor the UML-ID into the 'ID' field
3. Merge the resulting tables and split it again by the catchment class attribute ('Value')
4. Join the capacity information and the 'SUM'-field of the three resulting tables to the palm oil mill shapefile
5. Add fields for the yields and the reached capacity by the catchment classes each
6. Calculate these fields with an update cursor:

yieldnear (8 hours):	Summarized yield for class ´Value = 8'
fill8:	(yieldnear/capacity) *100
yieldmid (24 hours):	Summarized yield for class ´Value = 8' + summarized yield for class 'Value = 24'
fill24:	(yieldmid/capacity) *100
yieldlong (48 hours):	Summarized yield for class ´Value = 8' + summarized yield for class 'Value = 24' + summarized yield for class 'Value = 48'
fill48:	(yieldlong/capacity) * 100

8.2 ADDITIONAL MAPS

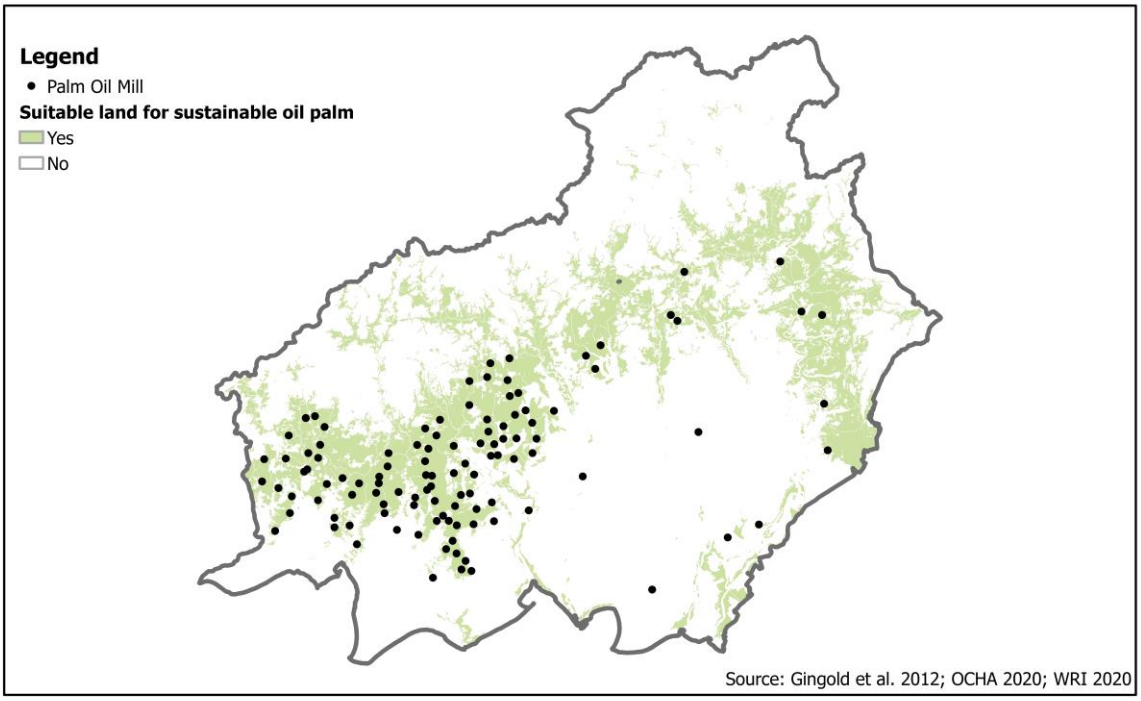

Figure 36: Suitable land for sustainable palm oil in Central Kalimantan, Indonesia in 2019, identified by Gingold et al. (2012) (own figure).

8.3 DECLARATION OF CONSENT

on the basis of Article 30 of the RSL Phil.-nat. 18

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Registration Number: 15-113-426

Study program: MSc in Geography

Bachelor ▪ Master **X** Dissertation ▪

Title of the thesis: Hungry Palm Oil Mills in Central Kalimantan, Indonesia - Key Players for Moving Towards Sustainability in the Palm Oil Supply Chain

Supervisor: Dr Andreas Heinimann

I declare herewith that this thesis is my own work and that I have not used any sources other than those stated. I have indicated the adoption of quotations as well as thoughts taken from other authors as such in the thesis. I am aware that the Senate pursuant to Article 36 paragraph 1 litera r of the University Act of 5 September, 1996 is authorized to revoke the title awarded on the basis of this thesis. For the purposes of evaluation and verification of compliance with the declaration of originality and the regulations governing plagiarism, I hereby grant the University of Bern the right to process my personal data and to perform the acts of use this requires, in particular, to reproduce the written thesis and to store it permanently in a database, and to use said database, or to make said database available, to enable comparison with future theses submitted by others.

Bern, 30. November 2020
Place, Date

C. Joss
....
Signature