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Strategies to mitigate indirect land use change:

Illustrated for palm oil production in North and East Kalimantan, Indonesia

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Colophon

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Table of Contents

Preface

Potential indirect land use change (ILUC) triggered by increased production of crops for biofuels became a critical point of discussion with respect to the sustainability of biofuels in recent years. Various studies have shown a wide variability in potential ILUC impacts of different crops and in different settings; and results remain uncertain. In addition, a key limitation of existing studies is that they exclude the impact of possible mitigation options and policies. Therefore, the *ILUC prevention* project aimed at providing insights into how ILUC risks can be mitigated, how this can be quantified and how this may be regulated. This project applied a regional approach that presumes that ILUC can be prevented if increased regional production (as a result of a biofuel mandate) is made possible without 1) diverting other crop production or 2) expanding on high carbon stock land. To do so, this approach accounts for the various uses of land for food, feed, fibre and fuels production and thereby takes an integral perspective of agriculture and bioenergy.

Within the *ILUC prevention* project, first a general methodology to quantify ILUC prevention measures was developed. Thereafter, four regional case studies were conducted to demonstrate, test and refine this methodology, as well as to assess the availability and reliability of data that are required for the analysis. The case studies also investigated policy and governance options that are relevant in the specific settings. The results were subsequently used to translate the key parameters and pre-conditions into a methodological framework and monitoring and policy options. The case-specific governance options were then used in the development of a general policy framework for governing ILUC mitigation. The present report describes the results of the case study on palm oil biodiesel production in North-East Kalimantan, Indonesian Borneo, conducted under the umbrella of the *ILUC prevention* project. Additional case studies focused on miscanthus ethanol production in Lublin Province of Poland, rapeseed biodiesel production in Eastern Romania and corn ethanol production in Hungary, which are reported separately. In addition, the methodology and a synthesis report (including the policy and governance framework for regional ILUC mitigation developed in this project) are published separately.

The *ILUC prevention* project was funded by Netherlands Enterprise Agency (the Dutch acronym is RVO) together with the Dutch Ministry of Infrastructure and the Environment and the Dutch Sustainable Biomass Commission (Commissie Corbey), and the Rotterdam Climate Initiative together with the Port of Rotterdam. The case studies were funded by industry partners that helped select the case study region based on recent and/or expected increases in production of the selected feedstocks. The case study on palm oil production in North and East Kalimantan (Indonesia) presented here was funded by Neste Oil.

Research for the *ILUC prevention* project was conducted by Utrecht University (Copernicus Institute of Sustainable Development) and followed the Netherlands code of conduct for scientific practice. The views expressed in this report are those of the authors and do not necessarily reflect those of the funding agencies.

Executive summary

Potential indirect land use change (ILUC) triggered by increased production of crops for biofuels has become a main point of the discussion on the sustainability of biofuels. ILUC occurs when food crops that have been displaced by biofuel feedstocks cause land use change somewhere else or when additional food or biofuel feedstocks are produced because of higher market prices induced by higher demand. The impacts of ILUC are particularly strong when it causes conversion of high carbon stock lands, such as peatlands or tropical forests. Because biofuels are considered to play an important role in future sustainable energy supply, mitigation or even prevention of ILUC is essential.

This case study focuses on **ILUC mitigation from palm oil production in the Indonesian provinces North and East Kalimantan** (North-East Kalimantan) until 2020. The **aim of the case study** is to provide insights into how the risk for ILUC by the production of palm oil (and unwanted LUC in general) could be mitigated, how this can be quantified and how this may be regulated. To do so, the case study assesses **key measures to reduce the extent of ILUC and control the type of land use change (LUC), considering biomass projections with an EU biofuel demand (i.e. target) and without (i.e. baseline) from the economic model MIRAGE.** The measures are assessed in terms of the low-ILUC-risk production potential of crude palm oil (CPO). This potential also accounts for additional crop production for food, feed and fibre as projected by MIRAGE. A *low*, *medium* and *high* scenario for developments above the business-as-usual (i.e. baseline) are defined for each measure in order to i) account for uncertainties in data and level of future efforts and investment to implement the measures and ii) to show the possible effects on the results.

The results show that multiple measures can be implemented in North-East Kalimantan to produce a large amount of additional crude palm oil (CPO) with low risk of ILUC. The results range from 1.5 million tonnes (Mt) CPO per year in the *low* scenario to 3.3 Mt CPO per year in the *high* scenario in 2020 (Figure ES1). Thus, this low-ILUC-risk potential can be compared to the projected additional demand for palm oil from EU biofuels (0.13 Mt CPO/yr). This shows that the low-ILUC-risk potential is 12 to 25 times the projected EU demand for palm oil for biofuels.

The high potential estimated in this study is a technical potential that considers important ecological aspects, such as no conversion of forest or peatland. The calculation of the low-ILUC-risk potential also accounts for other future demand for palm oil (e.g. for food and oleochemicals) so that displacement of these uses should not occur. However, a sustainable implementation potential would be lower as it needs to account for additional ecological, social, juridical and economic considerations. Still, our analysis shows that there are multiple measures that can be implemented to reach additional production of CPO that does not cause unwanted LUC, and these measures should be considered wherever possible.

The key measure for generating this low-ILUC-risk potential is **using under-utilised land for CPO production, combined with sustainable land zoning**. By applying the World Resource Institute's Suitability Mapper, we found that approximately 1.8 to 2.4 Mha of under-utilised land is considered suitable for oil palm cultivation. We consider only two-fifth, or 0.7 to 1 Mha, of the suitable area to be available for oil palm cultivation, based on field assessments conducted by the World Resources Institute in West Kalimantan. **Ground checks specifically for North-East Kalimantan are needed** to determine the share of the under-utilised land area actually available. In order to ensure that only under-utilised land is used for future conversion to oil palm, **land zoning (regulation)** is needed with detailed spatial and up-to-date data on land use and land cover, excluding high carbon stock, high conservation value, and important ecosystem service and cultural areas. At the same time, **land zoning must be strictly implemented and enforced in order to be effective**. Additional incentives must be considered to promote the cultivation of oil palm only on land that is currently under-utilised, so that missed opportunities from timber sales from cleared forest are compensated.

Also **yield increases** play an important role in providing low-ILUC-risk CPO, although to a smaller extent than under-utilised land. On the one hand, this is due to the very large under-utilised land area in North-East Kalimantan. On the other hand, this is because MIRAGE already accounts for high yield increases in the baseline scenario, which results in a relatively low impact of above-baseline yields. In the *high* scenario, an additional 0.5 Mt CPO can be produced from average FFB yield increases to 18 t FFB ha^{-1} yr^{-1}. Although this study applies high yield growth rates, the projected absolute yields are still conservative estimates compared to biophysically similar regions. Thus, if higher yields would be obtained, even higher low-ILUC-risk potentials can be expected from this measure. Strong yield increases are possible by using better planting material and knowledge transfer regarding better management practices, such as better plantation design, harvesting, nutrient and canopy management, and crop recovery.

These options to increase yields are relatively easily implemented at private plantations and dependent smallholders, but harder to organise and implement for independent smallholders who lack access to capital and high quality planting material, have limited awareness of new technologies or better management practices, and who are mostly not organised in co-operatives. Therefore, additional **policy and governance options and strong outreach to enhance the low yields of particularly the independent smallholders** are needed. Key options include supporting farmer cooperatives and the sharing of knowledge among farmers, providing support for capacity building, and funding for earlier replanting with better planting material. Independent and trustworthy sources for funding and information are important in order to ensure the success of such activities.

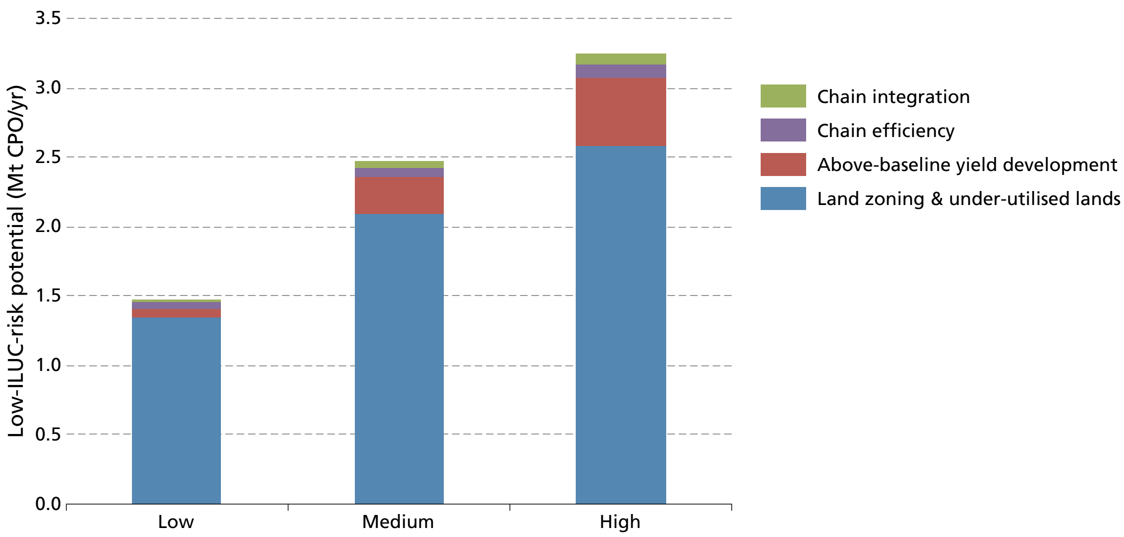


Figure ES1 Low-ILUC risk production potential of CPO in North-East Kalimantan, Indonesia in 2020. For reference purposes, the additional demand for palm oil from EU biofuels from this region is 0.13 Mt CPO by 2020 (disaggregated from the MIRAGE projections for the region IndoMalay).

The assessment of the ILUC mitigation measures and the resulting CPO production potential with low-ILUC risk in North-East Kalimantan shows that the **mitigation of ILUC and unwanted LUC in general is possible**. However, this is only possible when the close link between the agricultural, forestry and biofuel sectors is recognised and translated to **significant efforts in i) land zoning and enforcement so that only suitable and available under-utilised land is used for production and ii) increasing resource efficiency and productivity of agricultural production**. Therefore, an **integrated perspective on land use for all purposes** and a sustainable approach to all crop production are essential.

1 Introduction

Land use change (LUC) for the production of food, feed, fibre and fuel is ongoing as the world population and commodity consumption increases. Direct and indirect LUC induced by the production of feedstocks for biofuels has received special scrutiny as the greenhouse gas (GHG) emissions from LUC can result in more emissions than from the use of fossil fuels. ILUC occurs when food crops that have been displaced by biofuel feedstocks cause LUC somewhere else. The impacts of ILUC are particularly strong when this occurs on, for instance forest, high carbon stock or community lands [1].

Because ILUC cannot be observed directly, the relationship between biofuel policies and ILUC is estimated by economic models, such as by MIRAGE (Modeling International Relationships in Applied General Equilibrium), focusing on future projections, often until 2020 (see e.g. [2,3]). Such modelling efforts have estimated large GHG emissions from direct and indirect LUC [3,4]. Although outcomes vary across studies and uncertainties still remain, results from economic models are above zero (see Textbox 1). Given the uncertainties in the exact amount and location of ILUC induced by biofuel feedstock production, it is important to look into how ILUC and its effects can be mitigated.

Indonesia is experiencing large amounts of LUC, and the associated GHG emissions are high because of the conversion of tropical forests [5] and peatlands [6]. In this case study analysis, the aim was to provide insights into how the risk for ILUC by the production of crude palm oil could be mitigated in North and East Kalimantan[1], Indonesian Borneo; how this can be quantified; and how this may be regulated. For this, we quantified the land and GHG saving potential of six key ILUC mitigation measures to reduce the extent of ILUC related to oil palm (*Elaeis guineensis*) expansion in North-East Kalimantan for 2020. This potential accounts for projected additional crop production for food, feed and fibre, before looking at any additional crude palm oil production from oil palm. This additional production is based on projections by the economic model MIRAGE that accounts for baseline demand, and for biofuel demand due to the EU Renewable Energy Directive (EU-RED).

North-East Kalimantan is of specific interest because of the expectations of future palm oil developments in this region, and the potential to mitigate (I)LUC impacts of oil palm expansion by e.g. yield improvements and utilisation of marginal lands [7-9]. The choice for the region of interest will be further motivated in Chapter 2.

In Chapter 3, the overall methodology for ILUC mitigation and the definition of the case study specific baseline and target projections for the biofuel feedstock are described. Chapter 3 describes the general method, the agricultural production systems and the scenarios analysed. In Chapter 4 to 8, the methods and results of each estimation of the regional potential of these multiple ILUC mitigation measures will be presented and discussed, followed by an integration of the measures in Chapter 9. A discussion of the

1 North Kalimantan was previously part of East Kalimantan and was officially established on 25 October 2012. Because most of the data was available till 2012, both provinces were included in the analyses and were indicated in this report as North-Kalimantan..

BOX 1: VARIATION IN LUC-RELATED GHG EMISSIONS FROM CORN ETHANOL

Land use change emissions (including ILUC) have been studied for key first generation biofuel supply chains. Corn ethanol is the feedstock conversion route that has received most attention in these studies (Figure T1). The following is an excerpt from Wicke et al (2012) [1] describing how the results of different studies vary and what explanations for these differences are.

"With respect to corn ethanol production, the initial LUC effect of US corn ethanol was given as 104 g CO2-equivalent (CO2e) per megajoule (MJ) (for reference purposes, the emission factor of gasoline is 92 g CO2e/MJ) (3). However, the development and improvements of the Global Trade Analysis Project (GTAP) bioenergy model from Purdue University have resulted in a large reduction in the estimates of LUC-related GHG emissions (first to 32 g CO2e/MJ used in California's Low Carbon Fuel Standard (13) and more recently to 15 g CO2e/MJ (14,15). If California's Low Carbon Fuel Standard LUC emission factor of corn ethanol was to be adjusted accordingly, most corn ethanol production would be able to meet the required emission reduction percentage of 10% compared with fossil fuels by 2020 while this is not the case with the current factor of 32 g CO2e/MJ (13). The main improvements in the modeling relate to increased spatial resolution, updates in the global economic database used in GTAP (from 2001 to 2006), including pastureland as an option for conversion to bioenergy production, treatment of animal feed co-products, crop yields (both for agricultural crops and bioenergy crops) on existing agricultural land and newly converted land, and the fraction of carbon that is stored for a longer period in wood products (15). Several of these improvements are related to strategies for mitigating (I)LUC and its effects, such as the type of land being allowed to be converted to bioenergy feedstock production and increasing crop yields and help explain the reduction in LUC-related GHG emissions. Also Al-Riffai et al. (16) and, most recently, Laborde (17) have found significantly lower values for corn ethanol than originally proposed. Laborde (17) indicates even lower LUC-related emissions than calculated from the GTAP model, namely 7 g CO2e/MJ." The model improvements and the changes in results emphasize how sensitive the market equilibrium models are to underlying assumptions and datasets" [1]. A key aspect of all models used for assessing ILUC is that they are based on historical data and so any future changes that deviate from the historical data (e.g. stricter land use zoning and enforcement to reduce deforestation) are difficult to capture.

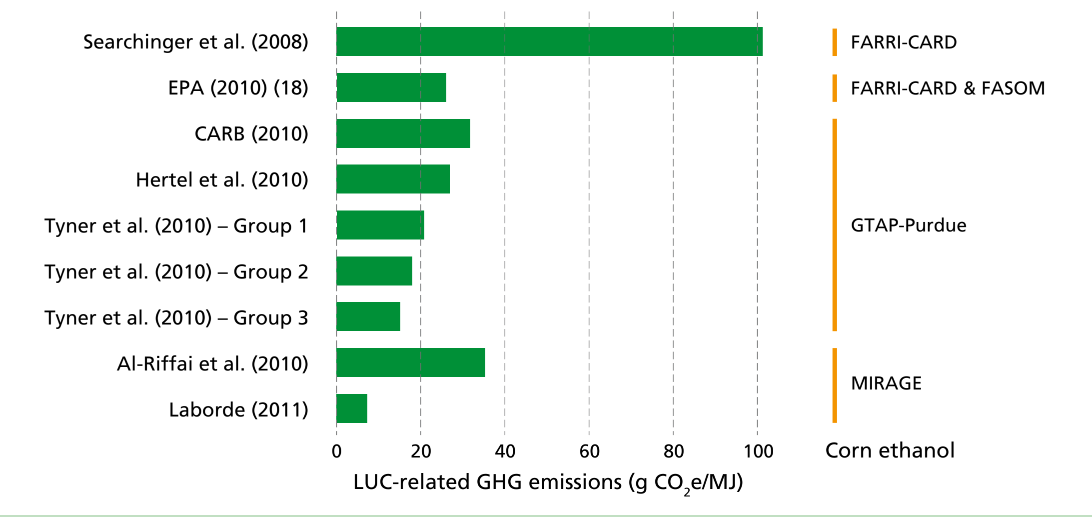


Figure T1 **Overview of (direct and indirect) land use change -related greenhouse gas emissions of first generation biofuels determined in the literature (30 year allocation period) (adapted from [1])**

References used in excerpt and figure: (3) Searchinger T, Heimlich R, Houghton RA et al. Use of US croplands for biofuels increases greenhouse gases through emissions from land use change. Science 319(5867), 1238 1240 (2008). (13) CARB. Low carbon fuel standard. California Air Resources Board, Sacramento, CA, USA (2010). (14) Hertel TW, Golub AA, Jones AD, O'Hare M, Plevin RJ, Kammen DM. Effects of US maize ethanol on global land use and greenhouse gas emissions: estimating market-mediated responses. BioScience 60(3), 223 231 (2010). (15) Tyner WE, Taheripour F, Zhuang Q, Birur DK, Baldos U. Land use changes and consequent CO2 emissions due to US corn ethanol production: a comprehensive analysis. Center for Global Trade Analysis, Purdue University, West Lafayette, IN, USA (2010). (16) Al-Riffai P, Dimaranan B, Laborde D. Global trade and environmental impact study of the EU biofuels mandate. International Food Policy Research Institute, Washington, DC, USA (2010). (17) Laborde D. Asessing the land use change consequences of European biofuels policies. International Food Policy Research Institute, Washington, DC, USA (2011). (18) EPA. Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis. United States Environmental Protection Agency, Washington, DC, USA (2010).

availability and quality of the data, and quality of the methods used in this analysis, as well as policy and governance recommendations to mitigate ILUC will be provided in Chapter 10. Conclusions are drawn in Chapter 11.

2 Case study

2.1 LAND USE CHANGE IN NORTH AND EAST KALIMANTAN

In the natural resource rich provinces of North and East Kalimantan (further referred to as North-East Kalimantan. See Table 33 in Appendix 1 for general geographic and demographic information), direct and indirect LUC contributes largely to greenhouse gas (GHG) emissions. These provinces have much potential to mitigate ILUC impacts of oil palm expansion, because of the potential gains in oil palm yields and because of the presence of under-utilised and marginal lands. Because of tropical deforestation and peatland conversion, the two provinces are currently the 3rd largest emitting provinces in Indonesia [9]. In 2008, approx. 60% of the GHG emissions was related to agricultural expansion, including oil palm [9]. By the end of 2030, emissions are expected to increase by 30% [9].

Abood *et al.* (2014) studied forest loss in industrial logging, oil palm, timber/fibre and coal mining concessions between 2000 and 2010 [5]. They found that in Kalimantan (i.e. all of Indonesian Borneo), 23% of total forest loss occurred in oil palm concessions, 15% in logging concessions and 15% in mixed (overlapping) concessions [5]. Plantation development for particularly palm oil production is thus an important contributor to LUC in the region [5]. Moreover, the contribution of oil palm is expected to increase because the cultivation area of oil palm has increased substantially in Indonesia [10], and is expected to increase further in the future due to the growing global demand for palm oil for food, cosmetics and fuel [11]. Logging is not only conducted through legal practices; illegal logging has also been substantial in the region, but is difficult to quantify [12].

Figure 1 shows the structural vegetation map of North-East Kalimantan, indicating the natural vegetation and developed plantations in 2008 (soil types are not visible on this map). The total area of estate crop[2] cultivation in North-East Kalimantan for the year 2011 was approx. 1 Mha, with the greatest portion of land planted with oil palm [13]. In 2011, approx. 0.8 Mha of land[3] was cultivated for oil palm, producing almost 4.5 Mt of crude palm oil (CPO) [13]. It is expected that oil palm expansion in North-East Kalimantan will continue to increase in the coming years.

Dewi *et al.* (2005) [14] identified a number of causes and drivers of LUC for several case study areas in North-East Kalimantan. These include migration, the establishment of forest, timber and estate crop (incl. oil palm) concessions, mining, and road building by projects and public investment. The contribution of each of these drivers is, however, not equal amongst all the regencies and districts in North-East Kalimantan. In the lowlands of North-East Kalimantan, for example, oil palm is cultivated on a large scale, such as in Kutai Timur and Kutai Kartanegara. In other areas, oil palm cultivation does not seem substantial, such as in Malinau and the highlands. For an overview of the planted area of oil palm per regency or district in North-East Kalimantan in 2008 and in 2011, see Table 1.

2 With estate crops we mean crops that are grown at large scale plantations for commercial purposes, often in distant markets rather than for local on-site consumption. Forest plantations were not included.

3 This figure includes mature and immature plantations.

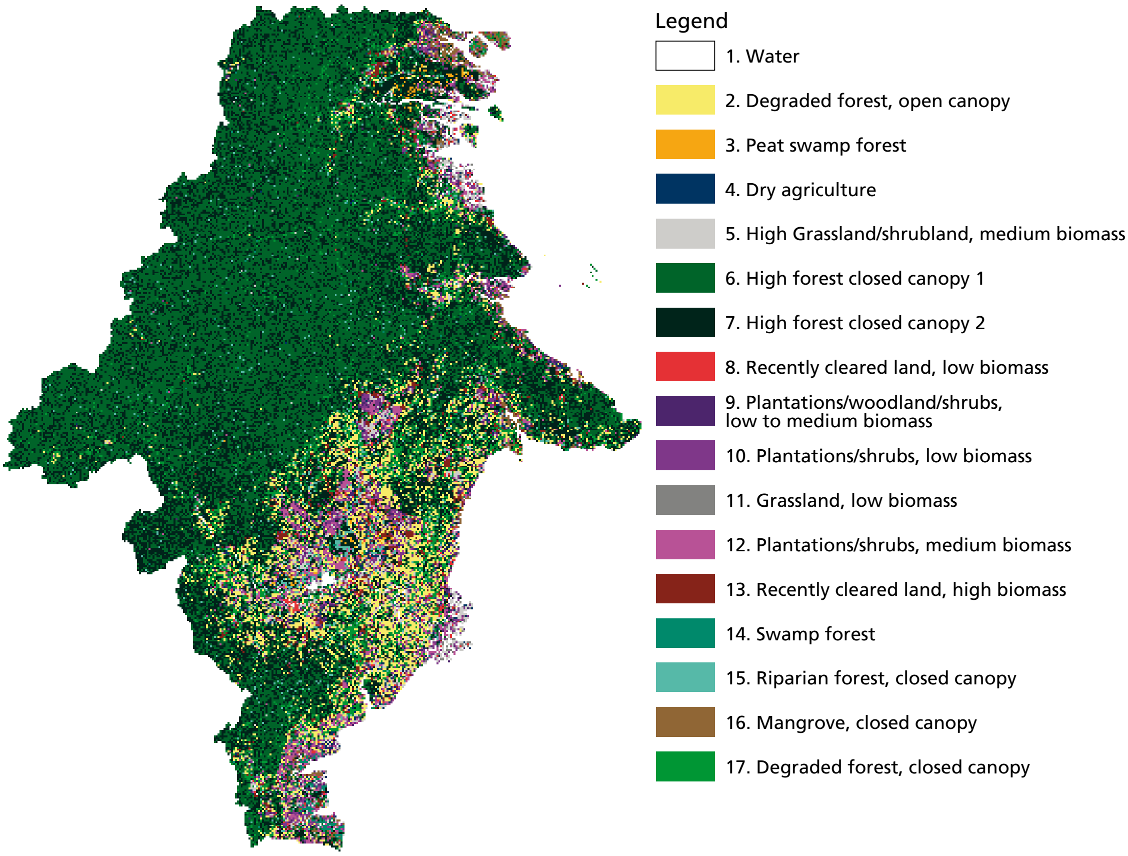


Figure 1 **Structural vegetation map of North-East Kalimantan indicating the natural land cover and the plantation areas for the year 2008 (does not show soil type). This map has been developed by SarVision within the framework of the JAXA Kyoto & Carbon Initiative. ALOS PALSAR data courtesy ALOS K&C (c) JAXA/METI.**

Table 1 **Planted area[4] of oil palm in the districts of North-East Kalimantan in 2008 and 2011.**

District/city	Land area (thousand ha)	In 2008 (thousand ha)	In 2011 (thousand ha)
1. Paser	773	66	124
2. Kutai Barat	3,570	6	29
3. Kutai Kartanegara	2,360	82	183
4. Kutai Timur	3,575	132	271
5. Berau	2,124	31	52
6. Malinau	3,977	-	1
7. Bulungan	1,318	9	39
8. Nunukan	1,425	54	67
9. Penajam P.U	333	29	57
10. Tana Tidung	483	-	4
11. Balikpapan	53	-	-
12. Samarinda	78	1	1
13. Tarakan	25	-	-
14. Bontang	41	-	-
Total (North-East Kalimantan)	**20,135**	**410**	**828**

Source: Badan Pusat Statistik (BPS) [13,15]

4 Including mature and immature oil palm plantations

2.2 AGRICULTURAL SITUATION

The cultivation area (ha) of estate and food crops with the largest share of land is shown in Figure 2B and C. The largest share of cultivated land in North-East Kalimantan is permitted for the production of timber, fuel wood, and pulp and paper (from HTI, Hutan Tanaman Industri or industrial forest plantations), and for the extraction of hardwood timber (from HPH, Hak Pengusahaan, or selective logging concessions) (see Figure 2A). The largest share of the agricultural land excluding forest plantations, was approx. 90%, and was utilised for the production of palm oil, wetland and dryland rice, and rubber.

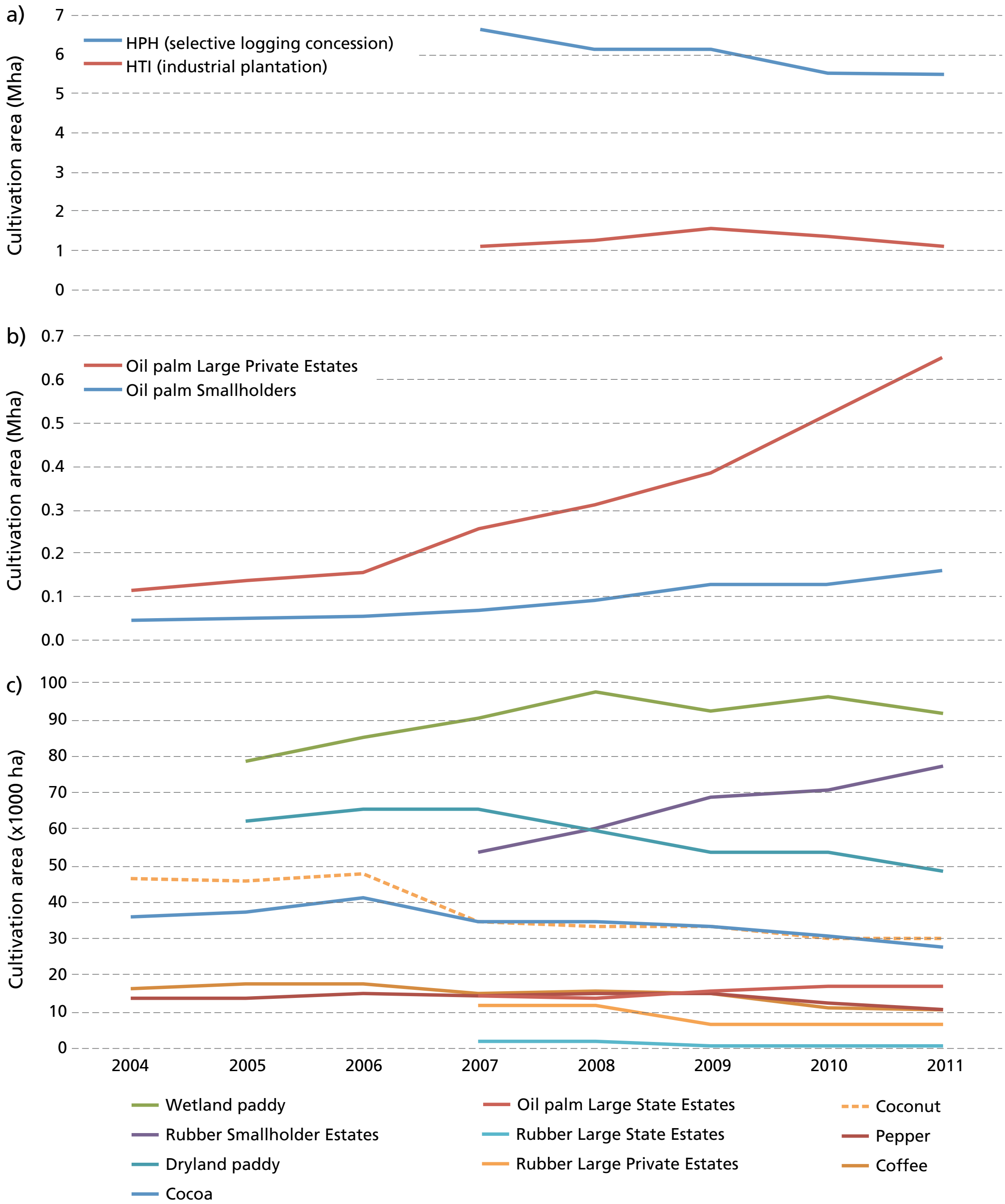


Figure 2 Cultivation area (ha) of the largest share of estate and food crops in North-East Kalimantan between 2004 and 2011 (before 2007 some data are missing). A) selective logging (HPH) and industrial forest plantation (HTI) concessions; B) oil palm (including mature and immature plantations), and; C) other agricultural production systems. Note: scale of the graphs is different. (Source: BPS [13,15])

2.3 DESCRIPTION OF THE MAIN AGRICULTURAL PRODUCTION SYSTEMS

Oil palm estates

In 2011, approx. 70% of the agricultural land in the study area (excluding forest and timber concessions) was cultivated for palm oil production. A distinction can be made between different oil palm estate types, namely State estates, Large Private Estates, Dependent/Contracted Smallholding Estates and Independent Smallholding Estates. In this analysis, the data on Private Estates and Dependent/Contracted Smallholding Estates were combined because the management practices are comparable. These were then compared with the Independent Smallholding Estates, or in short; Oil palm Smallholdings. In North-East Kalimantan, the area of oil palm under Large Private Estates has grown annually with approx. 29% between 2004 and 2011, with a steep increase of 63% between 2006 and 2007 (see Table 2 and Figure 2A) [13,15]. Smallholding Estates have grown slower with approx. 20% annually and State Estates remained rather stable [13,15]. Communities see oil palm cultivation as an opportunity to improve prosperity and their standard of living. Much support with regards to sustainability and compliance with sustainability initiatives and to yield improvements now goes to the Indonesian smallholding oil palm sector. It is expected that the oil palm cultivation area in East Kalimantan will continue to increase.

In 2011, Large Private Estate companies, including the dependent/contracted Smallholding Estates, held most of the total area under oil palm, namely 652,000 ha[5], producing approx. 3.3 Mt of fresh fruit bunches (FFB) (~80% of all oil palm cultivated land) (See Figure 2B and Figure 3 for the cultivation area of oil palm) [13]. Smallholdings produced approx. 863,000 tons FFB, using approx. 158,000 ha[5] of land (~20% of all oil palm plantations) [13]. The smallest fraction of FFB was produced under Large State Estates using 17,000 ha of land (~2%) [13]. By the end of 2012, North-East Kalimantan had issued 2.4 million ha (Mha) of oil palm concessions in the province of which only approx. 1 Mha was planted with oil palm [16]. There are therefore 1.4 M ha of oil palm concessions that are currently not used for palm oil production, but that may be developed later.

Table 2 Annual change (in %) in oil palm cultivation area between 2004 and 2011 [13,15] (including mature and immature plantations).

	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011	Average %
Oil palm Large Private Estates	23	12	63	22	24	35	25	29
Oil palm Smallholdings	7	15	27	32	39	-2	25	20

Wetland and dryland rice

In 2011, only approx. 12% of the agricultural land was being cultivated for rice production. Between 2007 and 2011, rice production slightly decreased, with the production of wetland rice (in 2011 ~65% of total rice cultivation) fluctuating and of dryland rice (in 2011 ~35% of total) slightly decreasing (See Figure 2C and Figure 3). In order to support the country's self-sufficiency in food, the provinces are now prioritising the investment in food crops, particularly rice estates [16]. In 2012, Indonesia was the 3rd largest rice producer in the world [10]. Because of the country's large population and rice being the country's main staple food grain, Indonesia was the world's 7th largest rice importer between 2007 and 2012 [17]. The national government pursuits rice self-sufficiency, however, total cultivation area stagnates while total rice consumption increases. Observers of the rice industry indicate that there are no quick or easy solutions to increase rice production growth rates at the farm-level in Indonesia [17].

Forest plantations

Several types of forest management systems exist in Indonesia, with the largest being selective logging

5 This figure includes mature and immature plantations.

systems in natural forests, namely HPH, and industrial forest plantations, namely HTI. The amount of hectares under HPH decreased in North-East Kalimantan, from approx. 6.6 Mha in 2007 to approx. 5.5 Mha in 2011 [13]. The amount of hectares under HTI increased between 2007 and 2009 in North-East Kalimantan, from approx. 1 Mha to 1.6 Mha, but decreased since 2009 to approx. 1.1 Mha (see Figure 2A) [13].

HPH is a forest management system in natural forests where selective logging is allowed. Because increasing the harvest of roundwood in these natural forests may contribute to an increase in logging activities, and may as a consequence diminish the quality of the natural forests, HPH are outside the scope of this study. HTI, on the other hand, are monoculture tree-based plantations, often *Acacia mangium* and *Eucalyptus spp.*, that have been developed for the production of pulp (HTI pulp), timber (HTI timber), and materials for carpentry and other wood industries (HTI carpentry).

The global demand for roundwood is expected to increase in the next two decades. Meanwhile, the contribution of Indonesia's roundwood production to the global production has decreased from 1990 to 2005, from, respectively, 2.3 to 1.8% [18]. To meet the growing national and global demand for wood-based products, the government of Indonesia has implemented various policies to promote the development of HTI, and has set ambitious targets for the roundwood, and pulp and paper industries [19,20]. To meet the growing national demand for roundwood, and to minimise the legal or illegal harvesting of roundwood from natural forests, improvements in the productivity of roundwood from and management of HTI plantations is very important. Particularly considering the ambitious plans of the government to expand the area under HTI [20], improvements in the productivity of roundwood may generate large land savings. Such 'saved lands' can be set aside for uses other than roundwood production, e.g. for forest restoration or forest conservation under the Reducing Emissions from Deforestation and Forest Degradation program of the United Nations (UN-REDD+, [21]). For these reasons, HTI plantations were accounted for in this study.

Rubber cultivation

Approx. 7% of the agricultural land in North-East Kalimantan was being cultivated for rubber production in 2011, with the largest share under Smallholding Estates (~90%) and Large Private Estates (~8%) (See Figure 3). Because of these substantial differences in oil palm and rubber cultivation area (ha) and in palm oil and rubber production (tons) between Large Private Estates and Smallholdings (see also previous paragraphs), we have made a distinction between these groups in the estimation of the regional potential of multiple ILUC mitigation measures. Also, because the potential gains in e.g. yield may be different between these two groups.

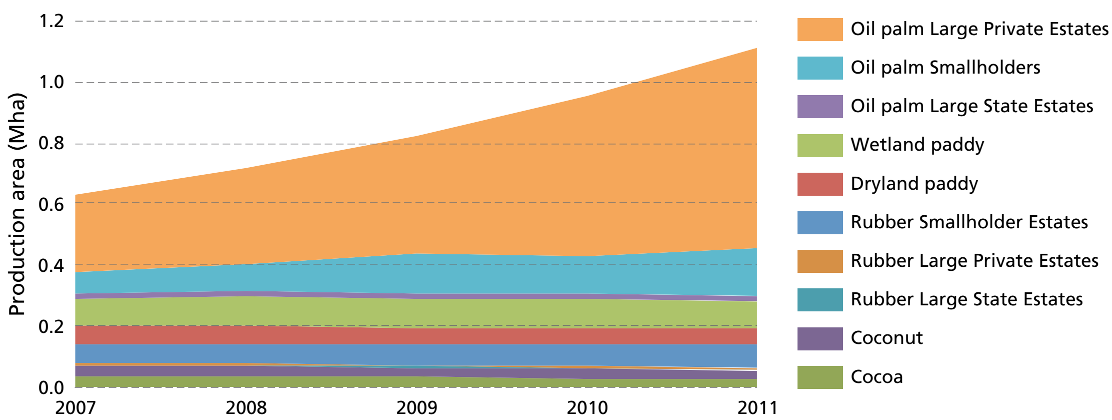


Figure 3 **Cultivation area (ha) of the main agricultural production systems (oil palm and rubber are subdivided in estate type) in North-East Kalimantan between 2007 and 2011 [13,15] (for oil palm, mature and immature plantations are included).**

3 General approach to the method

The approach applied here aims at analysing and quantifying ILUC prevention measures by assessing i) how much additional biofuel feedstock can be produced with these measures (herein after also called low-ILUC-risk potential) in a specific region in the future, and ii) how this production potential compares to the biofuel feedstock target of that region [22]. The approach is based on a combination of a top-down and bottom-up approach, and distinguishes three main steps (Figure 4):

1. From the economic models used to analyse ILUC factors (top-down approach), a biomass production baseline (without additional biofuels)[6] and target (with a biofuel mandate)[7] for each region is established. The difference between target and baseline is the amount of feedstock production induced by a biofuel mandate, which in the models is the cause of LUC (including ILUC) [8].
2. A bottom-up approach is used to assess the biomass production potential from key ILUC mitigation measures between 2008 and 2020. Three scenarios -*low*, *medium* and *high*- are applied in order to indicate the variability and uncertainty in the data and test its effect on the low-ILUC-risk potential.
3. This low-ILUC-risk potential is then compared to the difference between target and baseline bioenergy production from the economic model (see step 1). If the potential is equal to or larger than the induced feedstock production, the measures help prevent ILUC. If the potential is lower than the induced feedstock demand, ILUC cannot entirely be prevented by the measures included in this study alone and additional action needs to be taken in order to prevent ILUC.

In Figure 4, the baseline indicates the production of biomass for food, feed, and fibre applications in the absence of a biofuels mandate (i.e., assuming current biofuel production to remain constant, see footnote 6). The target refers to the total biomass production when a biofuels mandate is implemented (see also footnote 7). Thus, it includes food, feed and fibre demand as well as the extra feedstocks for biofuels needed to meet the biofuels mandate. The difference between the target and baseline (Figure 1) is the extra production due to the biofuel requirements (whether directly caused by increased demand for meeting the mandate or induced by increased crop prices due to the mandate). In the economic models, this amount is projected to cause LUC. In our approach, we assess how different measures related to sustainable intensification and modernisation of the agricultural sector and proper land zoning can

6 The biomass production baseline refers to the developments as a result of projected energy prices and economic growth. The baseline assumes biofuel production to remain approximately constant at current levels - although small variations may occur due to price developments in the baseline.

7 The target projection applies the same developments in energy prices and economic growth as in the baseline but adds a specific biofuel mandate.

8 Economic models assessing the indirect effects from biofuels do not distinguish indirect from direct LUC, so that total LUC induced by a biofuel mandate is modeled.

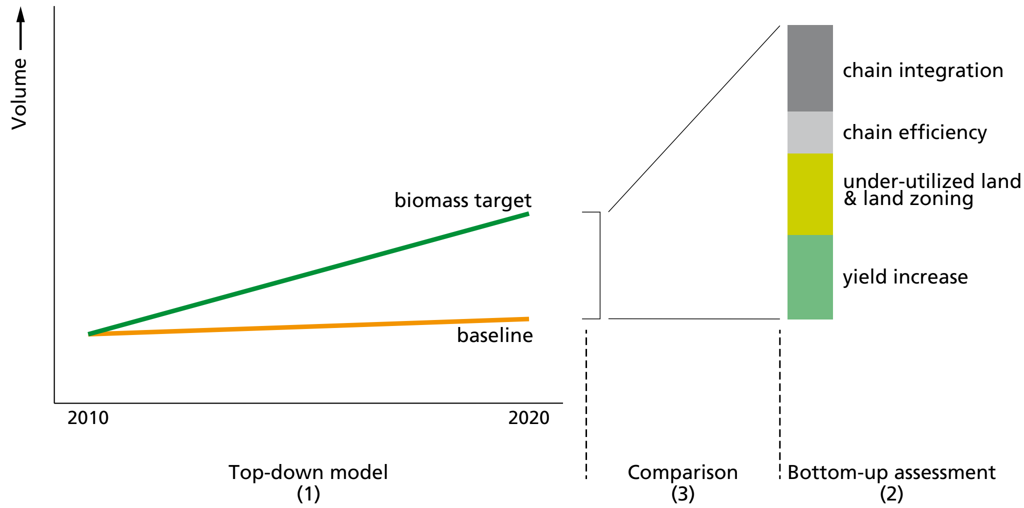


Figure 4 General approach to analyse and quantify biomass production potential with low-ILUC risks. The approach consists of three steps: 1) top-down establishment of additional biomass production in the target scenario in 2020 compared to the baseline scenario, 2) bottom-up assessment of potential biomass production in 2020 from ILUC. mitigation measures and 3) comparison of the required additional biomass production in the target scenario with the biomass production potential with low ILUC risk. The share of each measure in bridging this gap presented here is only for illustration purposes. The applicability of measures and their share in bridging the gap will differ per region and per scenario.

contribute to producing this amount of biomass without undesired[9] LUC. We thus take an integrated view on all land uses for food, feed, fibre and fuel production and look for synergies between agriculture, forestry and bioenergy.

Although we are primarily interested in how ILUC from biofuels can be mitigated, ILUC from biofuels is the direct LUC of another product and therefore all LUC actually needs to be addressed in order to mitigate ILUC from biofuels. Consequently, the integrated view of land use for all uses introduced above suggests that we compare the final results from the bottom-up assessment with the model projections of all demand increases (not just for biofuels). To do so, this study compares the total land area needed for food, feed, fibre and fuel production (i.e., the difference between projected target production in 2020 and current (2010) production in Figure 4) to surplus land from ILUC prevention measures in order to assess to what extent all additional land requirements can be met by the measures. This comparison is done in terms of land area to be able to account for all crops (as the summation of the production volumes of different crops is not logical).

In this study, biomass production in both baseline and target projections are based on outputs generated by the computable general equilibrium model MIRAGE (Modelling International Relationships in Applied General Equilibrium). In a study for DG Trade of the European Commission, MIRAGE[10] is used to project land use change until 2020 as a result of the European Union Renewable Energy Directive (EU RED), based on the National Renewable Energy Action [3]. Three scenarios are implemented: one reference scenario (here also referred to as baseline), which assumes no additional biofuel demand; and two scenarios for implementing the biofuels mandate, which are defined by the future trade policy (trade policy status quo vs. free trade policy) [3]. In the present study, the scenario

9 We specifically refer to *undesired* LUC here because not all LUC is undesirable. For example, using degraded land for woody and grassy bioenergy feedstock production can result in the re-vegetation and restoration of that land and can have positive impacts on e.g. carbon stocks, water quality and availability (Wicke *et al.* 2012).

10 The model version MIRAGE-Biof is applied in in this study. For clarity reasons, MIRAGE-Biof is referred to as MIRAGE in the remaining report.

based on trade policy status quo (leaving all currently existing import tariffs on biofuels unchanged in 2020) is used for establishing the biomass target.

Having defined the case study region and reviewing the current agricultural situation, the methodology for the case studies consists of the following steps:

1. Definition of the biofuel target for the region;
2. Selection of agricultural products and their projected production volumes;
3. Analysis of ILUC prevention measures;
4. Integrated analysis of all measures.

Each step is described in more detail in the following sections. Each section first provides the method used in all case studies and then explains in a sub-section the application and input data used in the case study specific to this report.

3.1 DEFINITION OF THE BIOFUEL TARGET

To establish the baseline and target production of the biofuel crop for the given region, results from the economic model MIRAGE are used. Given that the MIRAGE model outputs are only available on an aggregate level higher than the selected case studies (see Table 34 in Appendix 1), the baseline and target production of the world region, in which the case study is located, is disaggregated to the case study region.

Case-specific aspects
For this case study, the MIRAGE baseline and target FFB production volume was available only for the aggregated region of IndoMalay. Therefore, we disaggregated the IndoMalay baseline and target to North-East Kalimantan. There are several ways to disaggregate the production volumes. Because of the historical steep increase with regards to oil palm plantation area (Figure 3) and production volume, we assumed that the share (%) of production volume from North-East Kalimantan to the production volume from IndoMalay would remain increasing till 2020 with the same rate as the share between 2004 and 2011. Therefore, we first defined the share of the FFB production volumes for North-East Kalimantan (based on BPS data [15][13]) versus IndoMalay (i.e. Indonesia and Malaysia, based on

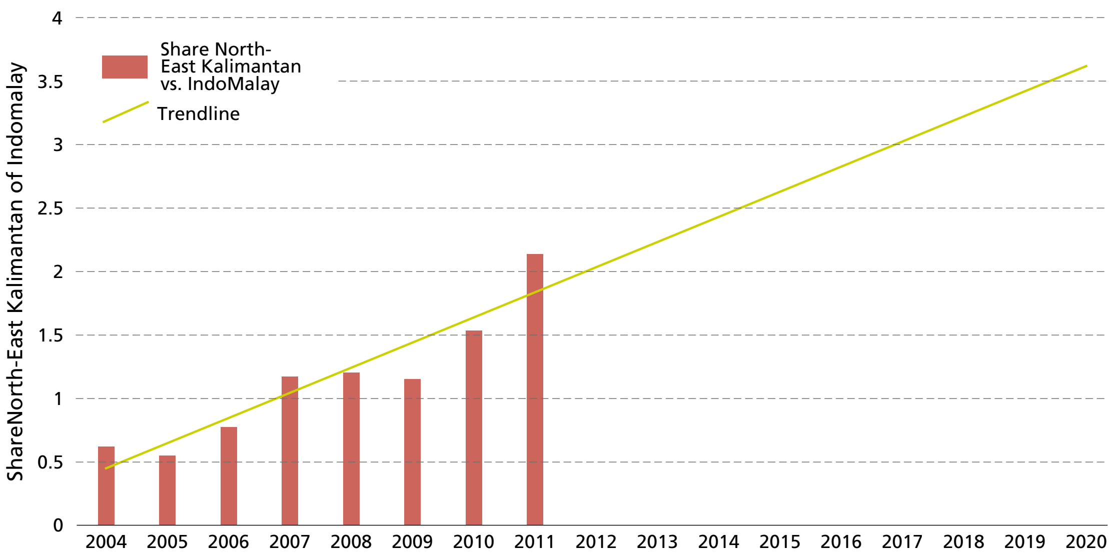


Figure 5 Share of the FFB production volumes for North-East Kalimantan versus IndoMalay (Source: FAOSTAT and BPS [10,13,15]).

FAOSTAT data [10]) between 2004 and 2011. Then we used the linear trendline for this share to extrapolate it to 2020 (see Figure 5). By means of this share, we disaggregated the FFB production volume baseline and target that were modelled for IndoMalay in 2020 to North-East Kalimantan by applying Equation 1. The biomass baseline and target are now expressed in tonnes FFB. Subsequently, we calculated the baseline and target for North-East Kalimantan in terms of CPO by multiplying the FFB volume by the oil extraction rate (OER). In this study, we assumed a baseline OER of 20% for the case study region, which is slightly conservative compared to the Indonesian average of FAOSTAT for 2008 (see also Section 6.1) [10].

Equation 1

$$P_{S,NEKal} = P_{S,IndoMalay} \text{ x } Share$$

Where $P_{S,NEKal}$ is the FFB production volume (t) in North East Kalimantan (*NEKal*) in scenario *S* (baseline or target),

$P_{S,IndoMalay}$ is the FFB production volume (t) in the aggregated region IndoMalays in scenario *S* (baseline or target) and

Share is the share (in %) of the current FFB production in North-East Kalimantan versus IndoMalay.

The baseline and target FFB and CPO production volumes for IndoMalay based upon MIRAGE, and for North-East Kalimantan based on the disaggregation by Equation 1 for 2020 are presented in Table 3 and in Figure 6. The FFB production volume is projected to significantly increase to approximately 10 Mt in the baseline scenario and approximately 11 Mt in the target scenario for 2020. Applying an oil extraction rate of 20%, this would result in a baseline CPO volume of 2 Mt and target CPO volume of 2.2 Mt. Although this is a very large increase from the current production volume, we expect these figures to be realistic given the historical exponential growth of oil palm cultivation area and palm oil production volumes, and ambitious provincial government plans for expansion of oil palm. Table 3 and Figure 6 also show that the difference in production volumes between the MIRAGE-based baseline and target scenario for 2020 is relatively small, namely approximately 0.7 Mt FFB or 130,000 t CPO (i.e. 6%). This indicates that the policy-generated additional demand for biofuel feedstock has a small impact on the total demand for palm oil, and that other uses, such as cooking oil and cosmetics, are more important.

Table 3 MIRAGE-projected palm FFB and CPO production (Mt) baseline (i.e. REF) and target (EU-RED mandate) for 2020 for IndoMalay and North-East Kalimantan based on Equation 1.

	Production volume in 2008 (Mt)	MIRAGE Baseline production volume in 2020 (Mt)	MIRAGE Target production volume in 2020 (Mt)
IndoMalay			
FFB	157	282	300
CPO	33	59	63
North-East Kalimantan			
FFB	2.0	10.2	10.9
CPO*	0.4	2.0**	2.2**

* assuming a baseline OER of 20%

** The figures in the table have been rounded off; the actual difference between the Baseline and Target CPO volume is 130,000 t

Source: FAOSTAT and BPS [10,13,15].

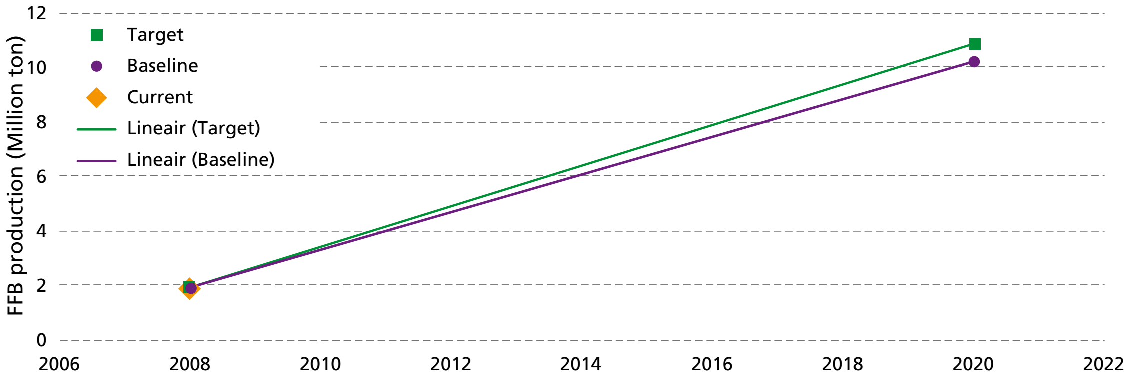


Figure 6 **MIRAGE-projected palm *FFB* production (Mt) Baseline and Target (EU-RED mandate under trade policy status quo) disaggregated for North-East Kalimantan for 2020.**

3.2 SELECTION OF AGRICULTURAL PRODUCTS AND THEIR PROJECTED PRODUCTION VOLUME

The impact of some ILUC prevention measures depends on (changes in) agricultural production and yield levels that are crop-specific. Therefore, in addition to oil palm (already addressed in the previous section), also production and yield data for other relevant crops are required for the calculations. Although in each case study a large number of different crops are produced, for most crops the production is very small and would have little effect on the overall results. Therefore, for each case study, an overview of the most important crops in terms of areal extent and their share in total agricultural land in the region is made. Based on this overview, those crops are selected that together cover at least 75% of the total arable land, depending on the case study.

For each of these other crops, the projected production in the case study in 2020 is determined by disaggregating the projected production in the world region (from MIRAGE) to the case study region based on the current share of crop production in the case study compared to the world region (Equation 2). Two key assumptions in this method are that i) the production share of the case study in the world region will not change, and ii) that crops that are important now will remain so in the near future and vice versa. Although this may not hold true for the long term, for the timeframe considered in this study (2020) these assumptions are likely to hold.

Equation 2

$$P_{\text{case study,future}} = \frac{P_{\text{case study,current}}}{P_{\text{world region,current}}} \times P_{\text{world region,future}}$$

where *P* refers to the production of the biofuel feedstock (in tons) at different times (currently or in the future) and for different regions (case study or the MIRAGE-world region where the case study is located).

In addition to a regional disaggregation, for some crops also a disaggregation of crop groups is needed because only the most important (biofuel) crops are modelled in MIRAGE, while others are aggregated to larger categories (see Table 35 in Appendix 1). Translating the production target for the crop category to the specific crop is based on the share of the current production of that crop within the category.

Case-specific aspects
This study focused on the key agricultural production systems in the region, namely: oil palm, wetland and dryland rice, roundwood, and rubber. The selected agricultural production systems and estate types, and their cultivation area and production volumes for the baseline year 2008 are shown in Table 4.

Table 4 The agricultural production systems and estate types, current cultivation area (for oil palm, only mature areas were accounted for), share of mature oil palm plantations in and current production volume (in t) in North-East Kalimantan in 2008.

Agricultural production system	Yielded product	% of mature plantations in 2008 (projected using BPS data [13])	Cultivation area (ha) in 2008	Current production volume (t) in 2008	Projected production volume (t) in 2020 (Baseline)
Oil palm Large Private Estates	**FFB**	34	311,393 (106,000*)	1,611,000	7,134,000
Oil palm Smallholdings	**FFB**	50	93,203 (46,000*)	481,000	3,109,000
Wetland rice	**Rice**	n/a	98,000	441,000	556,000
Dryland rice	**Rice**	n/a	60,000	145,000	182,000
Rubber Smallholdings	**Rubber**	n/a	60,000	43,000	49,000
Rubber Large Private Estates	**Rubber**	n/a	12,000	6,000	7,000
Total			382,000	2,727,000	11,038,000
HTI, industrial forest plantation	**Round-wood**	n/a	1.2 Mha	Unknown**	Unknown**

* In this figure only mature oil palm plantations are accounted for, as was calculated by Equation 3.
** The production volume and the exact share of roundwood from natural forest and from the different forest management systems, including HTI, could not be collected from BPS data or the literature and is thus unknown.
Source: BPS [13,15]

For roundwood, we focused only on roundwood sourced from industrial forest plantations, or HTI. A large share of the roundwood from Indonesia is sourced from HPH or from illegal logging practices in natural forests. Causes for this include the fast growth of the pulp and paper industry, the relatively slow growth of the establishment of industrial forest plantations and poor law enforcement [23]. Accurate data on production volume and the exact share of roundwood from natural forest and from the different forest management systems, including HTI, in Indonesia and in the study area could not be collected from BPS or from the literature. Therefore, we were not able to estimate the production volume of roundwood from HTI plantations for the study area.

The cultivation area for oil palm was calculated by applying a correction factor to account for the share of mature plantations (estimated based on BPS statistics [13]). This was necessary because of the very high establishment rates of new plantations in recent years, and therefore a very high share of immature oil palm plantations in the region [16]. The correction factor is shown in Equation 3.

Equation 3

$$MA_{oil\ palm,2008} = CA_{\text{oil palm,2008}} * S_{\text{mature,2008}}$$

Where MA is the area under mature oil palm cultivation expressed in *ha*,
$CA_{palm\ oil,2008}$ is the total area under oil palm cultivation (including immature and mature areas),
$S_{mature\ 2008}$ is the share of the cultivation area that is mature and producing oil.

3.3 POTENTIAL BIOMASS PRODUCTION PER ILUC MITIGATION MEASURE

Six key measures for preventing ILUC and mitigating effects of biofuel production are investigated. These are:

- **Above-baseline yield development:** increases in agricultural crop yield and livestock productivity efficiencies above the baseline projection result in a reduction of agricultural land required for crop and livestock productivity (assuming the production volume remains constant). On the resulting surplus land area, biomass can be produced with low ILUC risk. Yield increases can be achieved by, for example, improved fertiliser application, mechanisation and intensification of animal farming.
- **Improved chain integration:** integration of the biofuel chain in food and feed production. Examples of integration are multi-functional land use practices like agroforestry and the use of biofuel by-/co-products as animal feed. Such approaches increase the total output per hectare and reduce the demand for land.
- **Increased chain efficiencies:** Improving the efficiency of agricultural and bioenergy supply chains increases the productivity per hectare. Efficiencies can be improved through, for example, reduction of losses in storage and transport, and improvement of conversion and processing efficiencies.
- **Biofuel feedstock production on under-utilised lands:** under-utilised lands include set-aside land, abandoned land, degraded land, marginal lands and other land that does not currently provide services, i.e., "unused lands" [24]. This, often low-productive, land can be used to cultivate extra biomass for bioenergy.
- **Land zoning:** land zoning helps avoid the use of land with high carbon stocks, biodiversity or other ecosystem services for biofuel feedstock production. Land zoning is often combined with the measure on under-utilised land in order to define what is under-utilised and when is it available for conversion.
- **Lower GHG emissions in the biofuel supply chain:** improve the sustainability of the biofuel production system through, for example, better fertiliser application or measures to increase soil carbon sequestration.

The last two measures in this list, i.e. lower GHG emissions in the production chain and land zoning, are not directly related to preventing ILUC, but contribute to mitigating the effects of land-use change and the biofuel chain, and thereby improve the GHG emission performance of biofuels. In the following subsections, we describe how each measure is assessed.

3.4 SCENARIOS

For each measure, we defined three scenarios, namely *high*, *medium* and *low* for analysing the measure's ILUC prevention potential in order to indicate the variability and uncertainty in the data and test its effect on the results. As the goal of this study was to prevent ILUC from biofuel production, the performance of each measure needed to be better than in the baseline situation, i.e. baseline projections of MIRAGE. Therefore, the scenarios *low, medium and high* refer to, respectively, low, medium, high developments above this baseline. The *low* scenario is thus still an improvement compared to the current situation and baseline scenario. For each of the measures, the scenarios are described in more detail in the folowing sections.

4 Above-baseline yield development

4.1 METHODS

Increases in agricultural crop yield and livestock productivity efficiencies above the baseline projection result in a reduction of agricultural land required for crop and livestock productivity (assuming the production volume remains constant). On the resulting surplus land area, biomass can be produced with low ILUC risk. In this case study, the potential yield increases per scenario were defined based on a detailed investigation of past yield trends in the case study and neighbouring regions, current yields in regions with comparable biophysical conditions, yield projections in the literature and the maximum attainable yield.

4.1.1 Crops

Above-baseline crop yield development in North-East Kalimantan is one of the key ILUC mitigation measures because of its potential to generate surplus land in this region. Better management practices (BMPs) that are focused on increasing yields in agricultural production systems and specifically for oil palm can result in a reduced amount of land required to produce the same quantity of food, feed and biofuel feedstock. The surplus land that would result from this can contribute to the mitigation of additional land use and land cover change and associated GHG emissions. The analysis focuses on key crops (oil palm, rice and rubber, Section 4.1.1.1) and forest plantations (Section 4.1.1.2). Because of the lack of data, yield improvements from forest plantations were estimated separately from the key crops.

4.1.1.1 Oil palm, rice and rubber

In order to calculate the potential surplus agricultural area generated from above-baseline yield increases, the following formula was used:

Equation 4

$$SA_{ABY,crops} = A_{baseline} - A_{ABY} = \sum_{i=1}^{n} \frac{P_i}{Y_{baseline,i}} - \sum_{i=1}^{n} \frac{P_i}{Y_{\mathrm{ABY,i}}}$$

Where $SA_{\mathrm{ABY,crop}}$ – surplus area (ha) that becomes available from above-baseline yield increases (ABY) for crops;
A_{baseline} – area (ha) needed for projected baseline crop production, applying the baseline yield growth rate;
A_{ABY} – area (ha) needed for projected baseline crop production, applying an improved yield growth rate;
$Y_{\mathrm{baseline,i}}$ – projected baseline yield for crop *i* (t ha^{-1} yr^{-1});
$Y_{\mathrm{ABY,i}}$ – projected above-baseline yield for crop *i* (t ha^{-1} yr^{-1});
P – projected baseline production (tonne) for crop *i*, as derived from the MIRAGE baseline scenario (Section 3.2).

When it is assumed that the entire surplus area generated by improved yields will be used to produce the biofuel feedstock investigated in the case study, the low-ILUC-risk feedstock production potential from this measure can be calculated by Equation 5. This is foremost a theoretical concept to show the potential for low-ILUC-risk biomass/biofuel production. In practice, the surplus area will be intertwined with other areas/uses and thus will not be used for one crop only. Also from a biodiversity and prevention of monocultures perspective, the complete conversion to one crop would not be desirable.

Equation 5

$$Pot_{low\ ILUC\ risk} = SA \times Y_{\text{biofuel feedstock}}$$

Where $Pot_{\text{low ILUC risk}}$ – additional production potential of biofuel feedstocks with low ILUC risk (t yr^{-1});
SA – surplus area generated from ILUC prevention measures (ha), e.g. Equation 4;
$Y_{\text{biofuel feedstock}}$ – projected biofuel feedstock yield (t ha^{-1}).

Current yields

We estimated the current yield in 2008 of oil palm, rice and rubber production systems in North-East Kalimantan based upon production volume (t) and cultivation area (ha) data for 2008 (see Equation 6) [13,15].

Equation 6

$$Y_{i,2008} = \frac{P_{i,2008}}{A_{i,2008}}$$

With Y is the current yield for crop i expressed in t ha^{-1},
P is the production volume for crop i in t and A is the cultivation area for crop i in ha.

The yields of the production systems between 2007/2008 and 2011 in North-East Kalimantan based on Equation 6 are shown in Figure 7. The current yields for oil palm, rice and rubber for 2008 are shown in Table 5. The yields of rubber and rice estates have remained stable between 2007 and 2011, with a slight increase of the yields in large private rubber estates. The FFB yields of private oil palm estates fluctuated strongly between 2008 and 2011, which is likely due to a strong increase in cultivation area in the region between 2005 and 2006.

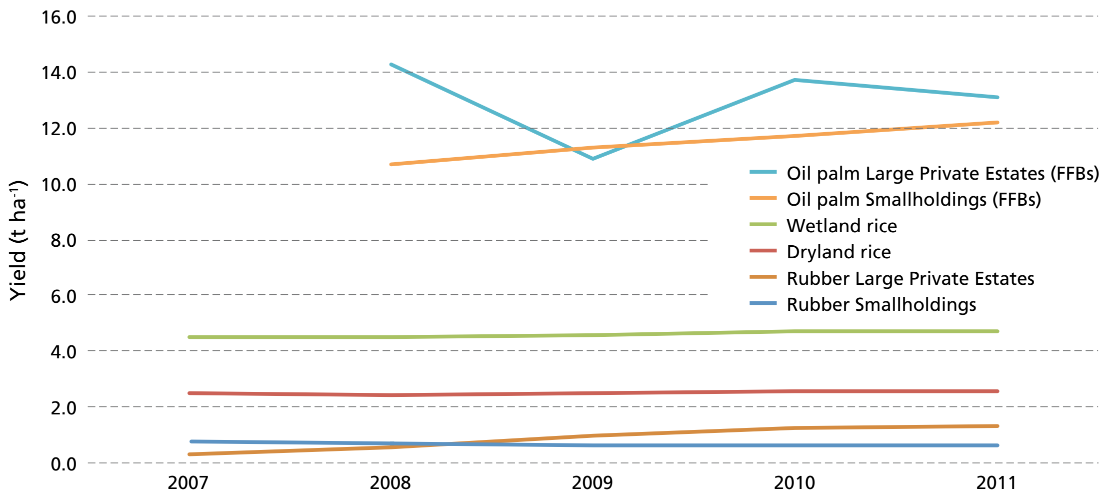


Figure 7 **Yields (t ha^{-1}) of the main agricultural production systems in North-East Kalimantan between 2007/2008 and 2011. To account for only mature oil palm plantations, we applied the correction factor that is shown in Equation 3 (Source: BPS [13,15]).**

Table 5 Current and maximum attainable yields.

Agricultural production system	Yielded product	Current yield (t ha^{-1}) in North-East Kalimantan in 2008 [13,15]	Current yield (t ha^{-1}) in Indonesia in 2008 [10]	Current yield Malaysia (t ha^{-1}) [10]	Yields national averages, found in the literature (t ha^{-1})	Maximum attainable yields (t ha^{-1}) according to the literature
Oil palm Large Private Estates	**FFB**	15.2	17.1	22.7	19 (dependent smallholders [28]) 21 (private companies [28]) 23-26 (excl. young plantings, no BMP [8])	36.7 in EaKal (with BMP) (37.9 in North Sumatra with BMP) [8]
Oil palm Smallholdings	**FFB**	10.4	17.1	22.7	17 (high yielding independent smallholders [28])	
Wetland rice	**Rice**	4.5	4.9	3.6	4.6 (average Indonesia [32])	6 (possible according to IRRI [32])
Dryland rice	**Rice**	2.4	4.9	3.6	4.60	6 (possible according to IRRI [32])
Rubber Smallholdings	**Rubber**	0.7	0.8	0.9	0.901-1.5 (Sumatra [34])	1.5
Rubber Large Private Estates	**Rubber**	0.5	0.8	0.9	0.901-1.5 (Sumatra, [34])	1.5

Causes yield gaps

The yields of most of the agricultural production systems were lower compared to the national averages [10] and compared to best practices yields in Malaysia, and much lower compared to the maximum attainable yields[11] (for an overview, see Table 5).

Oil palm yields in Indonesia were lower than estimated, resulting in a lower increase in production volumes of CPO between marketing year 2010-2011 (~ 24 Mt CPO) and 2011-2012 (~ 25 Mt CPO) [25]. This was because of so-called 'counterfeit seed stock' (fake seeds) that resulted in lower-than-estimated yields, particularly amongst smallholders. North-East Kalimantan is a relatively new region with regards to oil palm cultivation, with a high share of immature plantations. In addition, based on field studies in North-East Kalimantan and other provinces in Indonesia, Donough *et al.* (2010) [8] found three main components related to BMPs that explain the gap between actual yields and maximum attainable yields (See further Appendix 2):

1) inefficiencies during plantation development until the end of the immature period;
2) inaccurate assessment of nutrient needs, and;
3) inefficient management of mature stands.

Sheil *et al.* (2009) found that low yields can be caused by labour shortages, limited mechanisation, pests and droughts, poor crop management, inadequate fertiliser use, low-grade planting material, too old or tall palms, increased production costs, fluctuations in palm oil prices and economic instability [26]. In addition, Lee *et al.* (2014) found for smallholdings that harvesting only once a month resulted in the lowest annual FFB yields (~ 14.8 t ha^{-1}) [27]. Additionally, the type of smallholding management

11 *The maximum attainable yield* is the yield of a commodity that is cultivated on an experimental or on-farm plot that has no physical, ecological, or economic constraints and is managed with the best-known practices for a certain period of time and under specific agro-climatic conditions [91].

was important; independent smallholders obtained lower yields and consequently received lower gross monthly incomes compared to dependent smallholders [27]. This is also confirmed in the IIED report by Vermeulen and Goad (2006), who indicated that large palm oil companies favoured supported dependent smallholders over independent smallholders [28]. In general, the latter exist of an older age group, make greater use of family and non-mechanised labour, and use low quality seed stock.

Dryland rice yields in 2008 were low compared to the wetland rice yields and to the national averages. This can be explained by the information that most dryland rice farmers are not focused on yield maximisation, but instead produce for local use and often convert these lands to estate crop land. Rice yield gaps can also be caused by edaphic factors, such as high acidity, iron toxicity and poor drainage or droughts [29]. Laborte *et al.* (2012) made a distinction between yield gaps between average yields and 'climatic yield potentials', and between average yields and 'best farmers' yield potentials [30]. The authors found yield gaps of approx. 2 t ha^{-1} between average yields (~4.5 t ha^{-1}) and best farmers yields (~6.5 t ha^{-1}), and yield gaps of approx. 3.6 t ha^{-1} between average and the climatic yield potentials (~8.1 t ha^{-1}) [30]. Yield gaps may have been caused by differences in education, the use of fertilisers, and more efficient labour, and in differences between planting season [30]. The rice yields in the dry season were generally lower than the rice yields in the wet season. Wetland rice production yields are comparable to national averages probably because of national support related to the government's self-sufficiency goals.

Rubber in North-East Kalimantan is mostly produced by smallholders that are generally not applying BMPs and are not focused on yield maximisation. As a consequence, rubber yields were lower than the national averages [10].

Measures to increase yields

By means of capacity building and the implementation of BMPs, strong yield increases especially in the oil palm production systems seem possible. According to several literature sources, continuous improvement and evaluation of BMPs in oil palm plantations can increase FFB yields by the production of more and heavier FFBs [8,27,31]. Three broad BMP categories exist, namely crop recovery BMPs, canopy management BMPs and nutrient management BMPs (see Appendix 2 for more information). Particularly for smallholders, ownership status, securing financial capital, access to trustworthy and good technical information, and coping with market risks are fundamental to maximise the potential of oil palm cultivation [28].

Rice yield improvements are the subject of research already for decades [29,30]. Rice yield gaps in North -East Kalimantan can be bridged by better guidance, improvement of the technical skills of the farmers, good seeds and rice varieties, and, dependent on the season and geographic location, by drainage or irrigation systems [29,30]. Research with regards to rice yield improvement has been conducted on Java, with focus on improved irrigated farming systems and high-yielding varieties. Despite strong public sector investment over the past decades, most food crop yields are stagnating [17]. The Irrigated Rice Research Consortium (IRRI) though indicates that a yield increase would be needed [32].

International agencies have promoted high-yielding monoculture rubber plantations in the mid-1990s [33]. Yields and income improved over the years, while these large-scale monocultures were beginning to replace the jungle rubber gardens that are often managed by the smallholdings [33]. In the past years, research is going on about how to improve yields of smallholdings, while maintaining the social character and biodiversity of the jungle rubber gardens. This can be through e.g. the provision of high yielding clones, improved weeding and tapping once every two days (instead of every day) [33].

Projected yields in 2020 based on projected yield growth rates

Based on the description of the causes and potential solutions for reducing the yield gaps and by using the current yields in Table 5 and the yield change rates in Table 6, we defined three above-baseline yield development scenarios. These scenarios indicate the projected yields for all agricultural production systems for 2020 (see Table 7). The baseline scenario assumes the annual yield growth rate as used in the

Table 6 ***Projected annual yield change rates*** **(%) for the selected agricultural production systems between 2008 and 2020, based on BPS, FAOSTAT [10,13,15] and MIRAGE data.**

	Baseline scenario (MIRAGE-REF)	Low scenario	Medium scenario	High scenario
	Projected baseline yield change rate till 2020	Projected annual yield change rate till 2020	Projected annual yield change rate till 2020	Projected annual yield change rate till 2020
Oil palm Large Private Estates	1.8%	2%	2.5%	3%
Oil palm Smallholdings	1.8%	2%	2.5%	3%
Wetland rice	1.9%	2%	2.5%	3%
Dryland rice	1.9%	2%	2.5%	3%
Rubber Smallholdings	1.9%	2%	2.5%	3%
Rubber Large Private Estates	1.9%	2%	2.5%	3%

Table 7 ***Projected yields*** **(t ha^{-1}) for 2020, based on the Baseline and scenario calculations.**

Projected yields	Baseline scenario (MIRAGE-REF)	Low scenario	Medium scenario	High scenario
	Projected baseline yield till 2020 (MIRAGE-projected)	Projected yield in 2020	Projected yield in 2020	Projected yield in 2020
Oil palm Large Private Estates	18.8	19.3	20.4	21.7
Oil palm Smallholdings	12.9	13.2	14.0	14.9
Wetland rice	5.7	5.7	6.1	6.4
Dryland rice	3.1	3.1	3.3	3.4
Rubber Smallholdings	0.9	0.9	1.0	1.0
Rubber Large Private Estates	0.7	0.7	0.7	0.8

Table 8 ***Projected annual yield change rates*** **(%) for the selected agricultural production systems between 2008 and 2020 based on historical trends.**

Agricultural production system	North-East Kalimantan trendline [13]
	Projected absolute yield change rate till 2020 based on historical trends
Oil palm Large Private Estates	-6%
Oil palm Smallholdings	-1%
Wetland rice	1%
Dryland rice	1%
Rubber Smallholdings	-5%
Rubber Large Private Estates	45%

MIRAGE reference (i.e. MIRAGE REF) scenario, namely 1.8-1.9%. Three alternative yield development scenarios, that are different from MIRAGE yields in 2020, applied yields that were based on the literature.

The projected historical yield change rates for the agricultural production systems in North-East Kalimantan for 2020, based on BPS data, seemed unrealistic (Table 8). For instance, the yield increase for

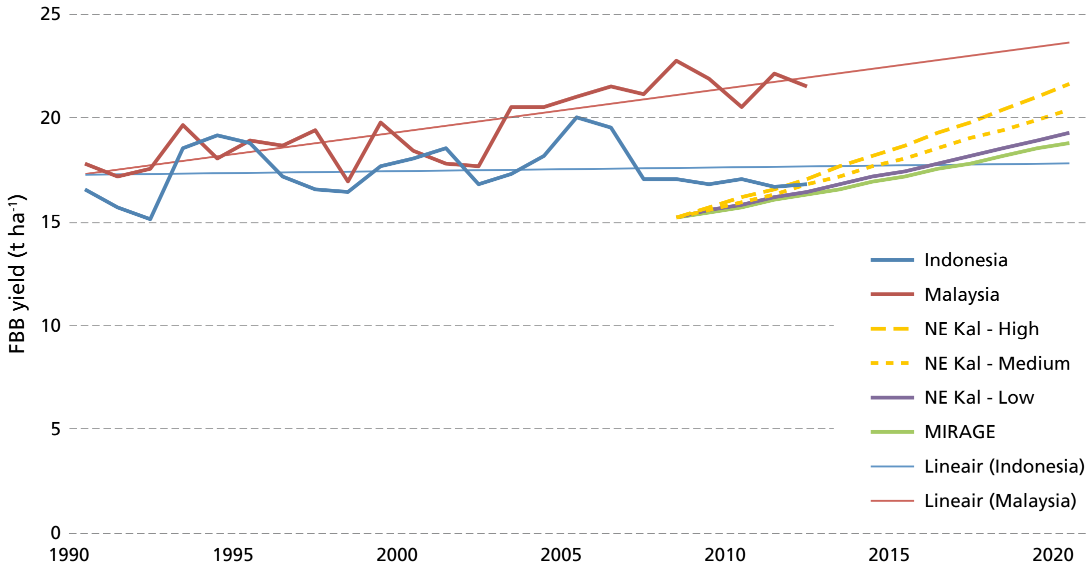


Figure 8 Oil palm FFB yield change of Large Private Estates over time between 1990 and 2012 in Indonesia and Malaysia [10], and projected for 2008 till 2020 in North-East Kalimantan under the three above-baseline yield scenarios.

rubber was extremely high and the yield change for oil palm was negative which are both unexpected. Therefore, we selected yield increases that resulted in yields similar to the national averages, and lower than or similar to the maximum attainable yields as are shown in Table 5. In North-East Kalimantan, where oil palm cultivation is a relatively new production system, high yield increases can be expected. Firstly, because of knowledge transfer within companies that are already producing in other, higher yielding locations and, secondly, assuming support from the national government with regards to BMPs for smallholders. We have chosen a gradual change in the annual yield growth rates, namely 2, 2.5 and 3% in, respectively, the Low, Medium and High scenarios (see Table 6).

Figure 8 shows the oil palm FFB yield change of Large Private Estates between 1990 and 2012 for Indonesia and Malaysia and the FFB yields projected for 2008 till 2020 in North-East Kalimantan under the Low, Medium and High scenarios. Under the Low scenario, the FFB yield remains below the trendline of the national yield averages, while in the Medium and High scenarios the yields increase to above this trendline, while these remain below the national averages in Malaysia till 2020.

4.1.1.2 HTI forest plantations

Although HTI constitutes a large share of cultivated land in North-East Kalimantan (Figure 2), this roundwood production system was not included in the overall above-baseline yield calculation. Firstly, large HTI concessions generally contain substantial areas of natural forest [5]. From an (I)LUC mitigation perspective it is therefore not desirable that the surplus land that results from improved roundwood productivity may be used for oil palm cultivation. Secondly, we identified a lack of accurate roundwood production volume data for HTI for the study area and we were not able to find consistent HTI yield data for Indonesia and for the study area. The yield data we found varied widely (see Table 9). Thirdly, in MIRAGE we could not find a projection for the baseline and target production volumes of roundwood or similar products. This hampered reliable estimates of future roundwood demand. However, because of the large HTI plantation area in the study area (Figure 2) and the assumed yield gap, we made a rough estimate of the potential 'land saving' instead.

Because we did not find a target production volume for roundwood in the MIRAGE model, $\text{Production}_{\text{future, 2020}}$ was defined based on figures we found in the literature [23]. In the paper of Obidzinski and Dermawan (2012) we found a national HTI plantation area target (14.7 Mha) and national production volume target for roundwood (~363 Million m^3 yr^{-1}) planned by the government

Table 9 Overview of industrial forest plantation yields found in the literature.

HTI yields from the literature		Actual harvest/yield in Indonesia
A. mangium [35]	1990 – national average	15-20 m^3 ha^{-1} yr^{-1}
A. Mangium [35]	2002 – national average	25-30 m^3 ha^{-1} yr^{-1}
[36]	2006 (commercial harvest, based on one concession example)	18 m^3 ha^{-1} yr^{-1} 80 air-dried metric tonnes (ADT) ha^{-1} OR 123 m^3 ha^{-1}/7-years in 2004 Max. potential: <100 ADT ha^{-1} for many years
[36]	HTI A. mangium plantation in North-East Kalimantan in 2005 (p 13 onwards)	Stands harvested in 2005 and planted in: 1995 yielded: 115 m3; 1996 yielded: 105; 1997 yielded: 95; 1998 and later: 60 (due to lack of maintenance); of commercial wood ha^{-1}

of Indonesia for 2030 [23]. We disaggregated these national figures for 2030 to the study area in 2020 by applying Equation 7. The outcomes are shown in Table 10. Based on the figures that result from Equation 7, we expect an HTI plantation area of approx. 2.7 Mha and an annual roundwood production volume of approx. 68 Million m^3 yr^{-1} in the study area in 2020.

Equation 7

$$P = Y \bullet CA$$

where the $P_{future,NEKal,2020}$ is the projected production volume of roundwood from HTI in the study area in 2020;

Y is the estimated HTI roundwood yield based on Barry (2002) [35], and

CA is the cultivation area planned for the study area in 2020 according to Table 10.

The management of forest plantations in Indonesia is often poor, because of topography, poor weather conditions, poor accessibility, particularly in the rainy season, conflicts with neighbouring communities, and the lack of daily workers [36]. Local people prefer to work in the growing and more profitable palm oil and coal mining industries [36]. Consequently, the distribution of wood is not always evenly spread throughout the year [36]. Between 1990 and 2000, the roundwood yields of forest plantations in Indonesia have improved though, from approx. 15-20 m^3 ha^{-1} yr^{-1} to approx. 25-30 m^3 ha^{-1} yr^{-1} [35], and with BMPs and improved genetic material the yields may improve further [35]. Because no consistent yield data was found for roundwood from HTI plantations in the study area (see Table 9), we assumed

Table 10 Plantation area and annual production volume of roundwood in Indonesia in 2010, planned for 2030, and projected for 2020, and projected for North-East Kalimantan in 2020 and 2030 (rough estimates because of uncertainty in the data).

	2008	2010	2020	2030
Plantation area Indonesia (Mha)	Unknown	5 [23]	10 (projected)	15 (planned, [23])
Plantation area NEKal projected (Mha)	1 [13]	1 [13]	3 (projected)	4 (projected)
Ratio IND-NEKal		3.6		
Annual production roundwood Indonesia (Million m^3 yr^{-1})	Unknown	Unknown	242 (projected)	363 (planned [23])
Annual production roundwood North-East Kalimantan (Million m^3 yr^{-1})	Unknown	Unknown	68 (projected)	102 (projected)

a baseline yield of 30 m^3 ha^{-1} yr in 2020, because we expected a slight improvement of the average mean annual increment in Indonesia in 2002, which was 25-30 m^3 ha^{-1} yr according to Barry (2002) [35]. For the improved yield we assumed an annual yield improvement of 1%, 1.5% and 2% till 2020 in, respectively, the Low, Medium and High scenarios. These rough estimates resulted in yields of approx. 34, 36 and 38 m^3 ha^{-1} yr^{-1} over the course of 12 years in, respectively, the Low, Medium and High scenario. With improved management practices and genetic material, this seems feasible [35].

Subsequently, we estimated the potential land saving area by using the formula in Equation 4. Because of the undesirability to use potential HTI concessions for oil palm expansion (in relation to deforestation within HTI concessions), and because of uncertainties in the data, we presented the land savings potential from yield improvements of HTI plantations separately and did not include it in the total low-ILUC-risk land output of the above-baseline yield development analysis. Instead, this 'saved land' area can be set aside for e.g. forest restoration or forest conservation under REDD+ projects [21].

4.1.2 Livestock

Surplus land can be generated through increasing the livestock density on meadow and pasture land. North-East Kalimantan had a substantial livestock population in 2011, namely 267,000 heads in total (Table 11). However, the area of meadow and pasture land could not be defined based on statistics, spatial data or the literature. Also, it was unknown what types of crops, crop waste or feed is fed to the livestock and in what quantities. The analysis of generating surplus land from increasing livestock productivity as conducted in the other case studies can therefore not be conducted.

Table 11 Livestock (heads) between 2007 and 2011 in North-East Kalimantan.

	2007	2008	2009	2010	2011
Cow	82,000	92,000	101,000	108,000	99,000
Milk cow	-	-	-	-	-
Goat	61,000	56,000	63,000	65,000	62,000
Pig	72,000	79,000	88,000	95,000	95,000
Other	10,000	13,000	14,000	15,000	11,000
Total	**225,000**	**240,000**	**266,000**	**283,000**	**267,000**

Source: BPS [13,15]

4.2 RESULTS

Increased yields of oil palm, rice and rubber

Based on the projected yield growth rates and projected production for oil palm, rice and rubber, we calculated the area that would be needed in 2020 to fulfil the baseline production demand as defined by the MIRAGE. The results are shown in Table 12 and Figure 9 (Panel C). The three above-baseline yield scenarios resulted in lower estimates of land needed and these scenarios may thus help avoid LUC induced by biofuel demand in the EU. In the Low scenario (with a 2% annual yield increase) already 51% of the EU biofuel policy-induced additional CPO demand (as projected by MIRAGE) can be produced (Table 13). The contribution of this measure is even more pronounced in the Medium and High scenarios (2.5 and 3% annual yield increases, respectively) (see Table 13). However, it is important to note that in MIRAGE palm oil production also increases strongly in the Baseline scenario (from 0.4 Mt to 2.2 Mt), independent of the demand for biofuels. Thus, the above-baseline yield developments can only avoid a small part of additional land use for the overall palm oil production increase (see also the integration of the analysis, Section 9). Therefore, also other measures must be considered.

Several remarks need to be made with regard to the projected area under oil palm cultivation. First, the historical growth rate of oil palm expansion has been much higher in North-East Kalimantan than

Table 12 ***Current* and *projected area needed* (ha) in 2020, based on the current and projected cultivation area (Table 4) and the current and projected yields (Table 5 and Table 7).**

	Current cultivation area	Target scenario (MIRAGE)	Baseline scenario (MIRAGE-REF)	Low scenario	Medium scenario	High scenario
Oil palm Large Private Estates*	311,000	484,000	455,000	444,000	418,000	395,000
Oil palm Smallholdings*	93,000	308,000	289,000	282,000	266,000	251,000
Wetland rice	98,000	97,000	98,000	97,000	92,000	86,000
Dryland rice	60,000	59,000	60,000	59,000	56,000	53,000
Rubber Smallholdings	60,000	54,000	56,000	55,000	52,000	49,000
Rubber Large Private Estates	12,000	11,000	11,000	11,000	10,000	10,000
Total	**634,000**	**1,013,000**	**969,000**	**948,000**	**894,000**	**844,000**

* For oil palm plantations, we accounted for a 20% share of immature plantations in 2020.

Table 13 ***Projected* surplus land *(ha)* and *potential FFB and CPO production (t)* in 2020, comparing the scenario calculations with the Baseline, and the share (%) of the extra CPO of the EU biofuel policy-induced (as projected by MIRAGE) CPO demand.**

	Low scenario	Medium scenario	High scenario
Oil palm Large Private Estates	11,000	37,000	60,000
Oil palm Smallholdings	7,000	23,000	38,000
Wetland rice	1,000	6,000	12,000
Dryland rice	1,000	4,000	7,000
Rubber Smallholdings	1,000	4,000	7,000
Rubber Large Private Estates	0	1,000	1,000
Total surplus land (ha)	**2,000**	**74,000**	**125,000**
Extra FFB production (t)*	**316,000**	**1,392,000**	**2,347,000**
Extra CPO production (t)**	**66,000**	**292,000**	**493,000**
Share of EU biofuel policy-induced CPO demand (0.13 Mt CPO per year, Table 3)	**51 %**	**225 %**	**379 %**

* assuming an average baseline yield of oil palm Large Private Estates and Smallholdings of ~16 t ha^{-1}.
** assuming a baseline OER of 20%

in the IndoMalay region applied in MIRAGE. This was accounted for in the disaggregation of palm oil production volume from the MIRAGE region to the case study region (see Section 3.1). Second, part of the 2020 production volume would result from the current immature, already planted oil palm plantations (which currently span 650,000 ha compared to 150,000 ha mature area). Therefore, the additional land requirements are smaller. Third, the analysis considers a replanting rate of 20%, which means that 20% of the oil palm area is added in order to account for immature plantations.

Increased yields of forest plantations

The rough estimate for the increased yields of forest plantations resulted in a total land saving of approx. 0.3-0.6 Mha in the Low to High scenarios (Table 14). This area can be set aside for e.g. forest restoration or forest conservation under REDD+ projects [21].

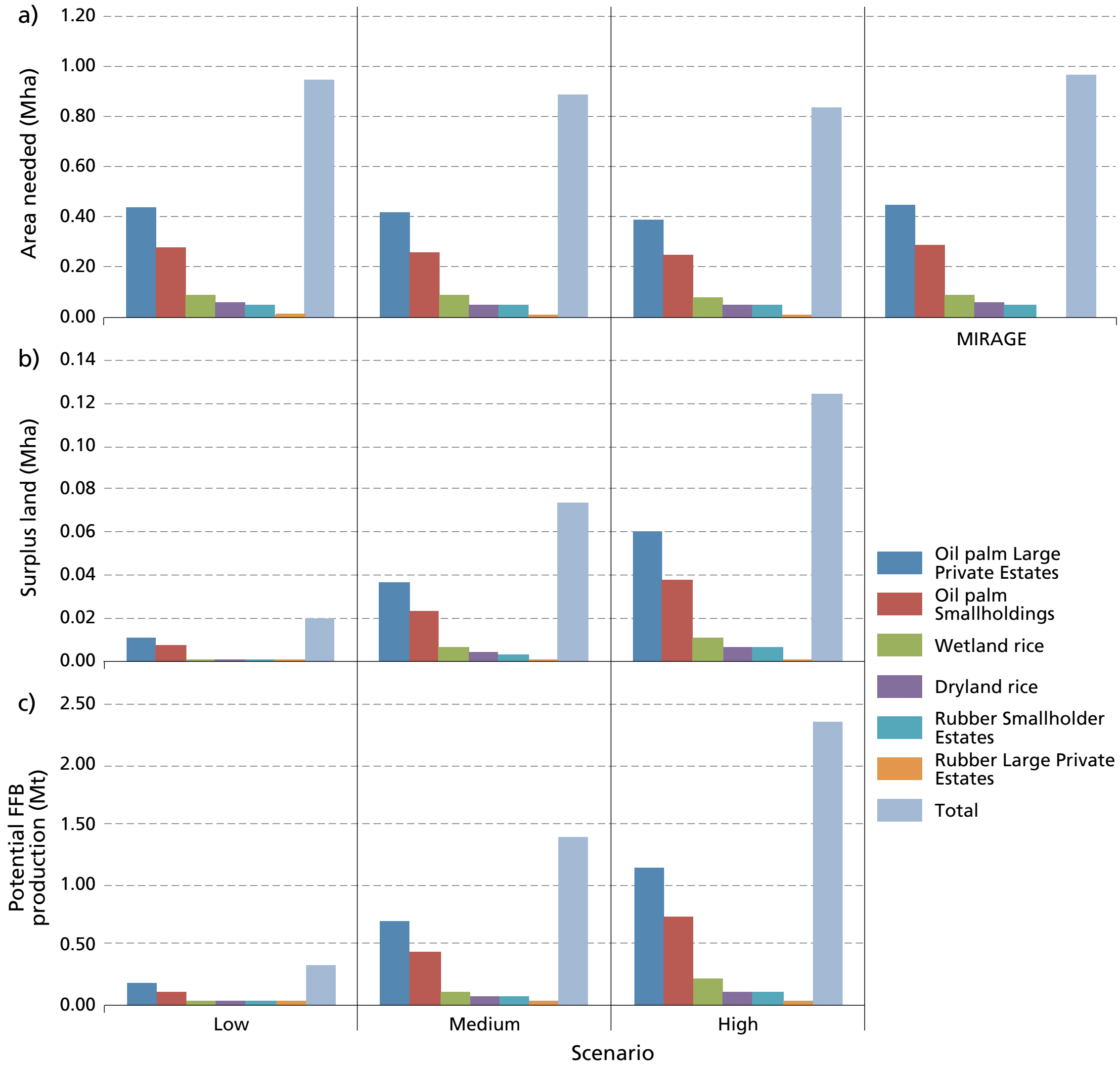


Figure 9 **A) Projected area needed (ha); B) projected surplus land (ha), and; C) potential FFB production (t ha⁻¹) in North-East Kalimantan in 2020, under the Low, Medium and High scenario.**

Table 14 **Projected land savings (Mha) from yield increases in HTI forest plantations in 2020.**

	Baseline scenario (MIRAGE-REF)	Low scenario*	Medium scenario*	High scenario*
Area needed (Mha)	2.8	2.4	2.3	2.2
Land saving (Mha)		0.3	0.4	0.6

* These estimates are based on very rough data (see Section 4.1.1.2).

5 Improved chain integration

5.1 METHODS

The production of biofuels generates various by/co-products. A by-product is a 'secondary product derived from a manufacturing process or chemical reaction' which results in smaller revenues than the main product (*Wikipedia, 2014*). A co-product is a by-product that results in similar revenues to the main product. Following the principles of consequential LCA, the more efficient use of by/co-products can be argued to reduce land demand and thereby help to mitigate ILUC. Focus of this section was not on potential GHG savings from the use of by/co-products.

Case-specific aspects
For this measure, the focus was on the effects of integrating by/co-products in the production chain of renewable diesel and on how currently under-utilised by/co-products can be used more efficiently and thereby replace other land using products. Replacing these products can then result in a reduction of land demand elsewhere and, therefore, in making land available for bioenergy production. In North-East Kalimantan, data availability on the exact use of by/co-products and revenues obtained is often low. Where no data could be found for North-East Kalimantan, we assumed that the utilisation of by/co-products in the study area to be similar to typical utilisation in Indonesia or Malaysia.

Overview of the by/co-products
By/co-products are produced in every step in the production of palm oil-based renewable diesel. In Table 15, an overview of by/co-products is provided, including their potential utilisation and current utilisation in Malaysia. At the plantation, the by/co-products produced are oil palm trunks (OPTs) and oil palm fronds (OPFs). At the mill, empty fruit bunches (EFBs), palm oil mill effluent (POME), palm kernel oil (PKO), palm kernel shell (PKS) and palm kernel fibre (PKF) are being co-produced. In the following, only those by/co-products are further defined that have a potential to free land or to produce extra palm oil for bioenergy production, or that have a potential to reduce GHG emissions in the supply chain of renewable diesel, and that are not yet fully utilised[12].

OPTs are available at the moment a plantation is felled and are an abundant source of biomass in countries where oil palm is planted extensively, such as in Indonesia and Malaysia. At the time of felling, a mature oil palm plantation of about 25-30 years old generates approx. 235 m^3 stems ha^{-1} [37]. Generally, after felling, the OPTs are burned or left to decompose [37], and the plantation site can be left for forest regeneration or can be replanted. Although oil palm is a non-woody plant and differs from hardwood/softwood species in its cellulose, hemicellulose and lignin content, it can be utilised as an alternative to wood or tree-based biomass. OPTs can be used for the production of compressed wood, plywood, particleboard, laminated board (laminated veneer lumbers, LVL) [38], fibreboard (medium density fibre,

12 Several by/co-products of the palm oil-based renewable diesel production chain are already in use. For example, PKS and PKF are used as a fuel for heat and power production to run the mill. Because no additional land or energy savings are expected, these are outside the scope of this study.

Table 15 Utilisation of the products in the biodiesel production chain for different regions.

By/co- products	Current and potential use Indonesia/Malaysia
Oil palm trunks (OPT) OPT 5.95 MJ kg^{-1} [42] OR: 87.3 GJ $ha^{-1}yr^{-1}$ [44]	- Livestock feed [42] - Lower digestibility, so limit of inclusion in ruminant diets to less than 20% [42] - Only available after felling for replanting, at an age of 25-30 yrs [42]
Oil palm fronds (OPF) OPF 5.65 MJ kg^{-1} [42] OR: 209.4 GJ $ha^{-1}yr^{-1}$ [44]	- Obtained during harvesting or pruning and felling of palms for replanting, is available throughout the year [42] - Traditionally, OPF is left to rot between the rows of palm trees, mainly for soil conservation, erosion control and ultimately for long-term benefit of nutrient cycling [42] - OPF is good fibre source for ruminant feeding [42] - Livestock feedstuffs, either freshly chopped, as silage, or processed into pellets and cubes [42]
POME – Palm Oil Mill Effluent POME 8.37 MJ kg^{-1} [42]	- POME is generally discharged to waterways or as fertiliser at plantation [46] - POME is the discharge from CPO extraction in the mill [42] POME has high organic content [46] - POME can be combined with PKC and OPF to provide a cost-effective and complete ration for feeding ruminant livestock [42] or used as liquid fertiliser [26] - it is envisaged that POME can be sustainably reused as fermentation substrate in the production of various metabolites, fertilisers, and animal feeds [47] - POME contains methane and can be used as a source of biogas for the production of electricity. Surplus electricity could be fed into the grid [48]
Palm oil sludge	Palm oil sludge, the solid in PKM, contains many kinds of essential amino acids and remains after decanting the POME
Empty Fruit Bunches (EFBs)	- EFBs can be used as mulch and can reduce the need for fertilisers by over 50% in immature stands and by 5% inn mature stands [26] - EFB is widely used as pulp for the production of paper [42] - Bio-methane production by fermentation of EFB (highly cellulosic components) [43]
PKO – Palm Kernel Oil 100 kg CPO à 10 kg PKO (~10%)	- PKO can be used as cooking oil or as feedstock for the oleochemical industry, such as in surfactant production - Extraction of oil, results in the production of palm kernel expeller, which can be used as animal feed [46]
PKS – Palm Kernel Shell	PKS and PKF can be used as fuel, e.g. in the mill, and source of pulp and paper or organic fertiliser [26] [46]
PKF – Palm Kernel Fibre	PKS and PKF can be used as fuel (in the mill), and source of pulp and paper or organic fertlised [26] [46]

MDF), furniture, and pulp and paper (See [37,39]. However, the commercial utilisation is still being tested. Additionally, OPTs can be used as a nutrient source, erosion control measure, animal feed [39], and biofuel and plastics [40]. One important note is that OPTs have a very high moisture, sugar and starch content, and this accelerates decomposition after felling which generates high transportation costs [37]. Nonetheless, positive economic analyses of the use of OPTs are shown, e.g. by [41]. OPT is selected for evaluation because it has the potential to generate indirect surplus land, given that the plywood can be used as a replacement for soft roundwood for non-construction materials. It could then reduce the pressure on natural forests and on forest plantations that are used for soft wood production. Additionally, the rotting of trunks at the plantation site can be prevented, minimising the spread of fungus and disease.

OPFs become available at pruning, harvesting or replanting time, and are thus available throughout the year [42]. OPFs are a good fibre source for feeding of ruminants [42]. Traditionally, OPFs are left at the plantation for soil conservation and erosion control, and long-term nutrient cycling [42]. At replanting, the crown can consist of about 41 fronds and can yield ~115 kg dry fronds/palm in total [39]. At an average plantation size of 113 trees per ha, this can generate approx. 13,000 kg of fronds per ha. Although this is a substantial amount of biomass, we do not expect OPFs to generate surplus land as a result of the current use for nutrient recycling. Therefore, OPFs are not considered in the analysis.

EFBs remain after oil extraction and can be used as mulch and can reduce the need for fertilisers by

Table 16 **Overview of by/co-products, the production volumes per ha (and yr) and energy production for a 10,000 ha oil palm plantation.**

By/co-product		Production volumes	Energy production (MWh per 10,000 ha)	Saving possibility in terms of area or energy?
FFBs	t $ha^{-1}yr^{-1}$	20-26		n.a.
Oil palm trunk	t ha^{-1} 30 yr^{-1} (t $ha^{-1}yr^{-1}$)	70 (70/30 = 2.3)	6.5 (30 yr cycle, power project time of 15 years	Savings expected in terms of area
Oil palm fronds	t ha^{-1}	10-16	10 (gasification)	Savings expected in terms of area
POME	t $ha^{-1}yr^{-1}$	4-5	1.25 (biogas)	Savings in terms of energy used from the GRID and in terms of decreased GHG emissions (see GHG-measure!)
Palm oil sludge				
Empty fruit bunches	t $ha^{-1}yr^{-1}$	5	3.5	No additional savings assumed
Dry weight	t $ha^{-1}yr^{-1}$	2		
Crude palm oil	t $ha^{-1}yr^{-1}$	4-5		n.a.
Crude palm kernel oil	t $ha^{-1}yr^{-1}$	0.6		Co-product already fully in use, however, the extra CPO production that results from the analyses in this report would generate a 10% additional palm oil production volume from PKO.
PKS – Palm Kernel Shell	t $ha^{-1}yr^{-1}$	0.7	1.4	No additional savings expected
PKF – Palm Kernel Fibre	t $ha^{-1}yr^{-1}$	1.6	2.7	No additional savings expected
Spent bleaching Earth (SBE)				No additional savings expected

Source: GIZ [43]

over 50% in immature stands and by 5% inn mature stands [26]. The use of EFB in Malaysia is generally very limited and can be utilised only after irradiation and culture-substrate treatments [42]. Biomethane can be produced by the fermentation of EFB because of its highly cellulosic components [43]. Energy produced from EFBs can be used as input for the palm oil mill [44]. The production of EFBs increases with the production of CPO. However, because EFBs are often used as an energy source in the mill, no surplus land was expected, and therefore these were not included in the evaluation.

POME is the discharge from CPO extraction in the mill [42] and, if discharged untreated, is considered harmful for the environment because of its high organic content [45]. However, this high organic content is also what makes more optimised use and treatment of POME beneficial [46]. POME can be combined with palm kernel cake (PKC) and OPF to provide a cost-effective and complete ration for feeding ruminant livestock [42]. Additionally, POME may be sustainably reused as a fermentation substrate in the production of various metabolites, fertilisers, and animal feeds [26,47]. The treatment of POME in open ponds results in high amounts of CO_2 and methane being emitted to the atmosphere. The methane in POME, however, can be collected when POME is treated in closed anaerobic digesters and used as a source of biogas for the production of electricity for the palm oil mill or, if surplus electricity is generated, for the grid [44,48]. Although POME has a list of potential utilisations, it is assumed to have no surplus land potential. Instead, and because of its emission reduction potential by methane capture, POME was evaluated in the measure: 'Lower GHG emissions in the biofuel supply chain' in Chapter 8.

PKO is co-produced in the palm oil mill and the production volume is about 10% of the CPO volume produced. PKO is currently fully in use and processed in the commercial cooking industry and the oleochemical industry; it is also suitable for the production of PKO biodiesel. Additional PKO production would not reduce land requirements, however, the extra CPO production that results from the analyses in this report would generate a 10% additional production of PKO that involves low-ILUC-risk. This 10% extra low-ILUC-risk PKO is included in the integration step in Table 32.

In Table 16, an overview of the by/co-products is shown, including the production volumes per ha and per year, and energy production for a 10,000 ha oil palm plantation [43].

Potential surplus land generated by the utilisation of oil palm trunks

The surplus land generated by utilising OPT for the period 2008-2020 were calculated by taking the following steps:

1. Estimate the cultivation area to be available for clearing and available for replanting between 2008 and 2020 (*Oil palm area*$_{replanted}$). To do so, we extrapolated the cultivation area of oil palm from 1998 [49] and 2004-2011 [13,15] to 1995, as the actual data could not be obtained from BPS or other sources (See Figure 10). The extrapolation of the data shows that by 1995 approx. 25,000 ha of oil palm have been planted in North-East Kalimantan (Figure 10). We assume that by 2020, 25 years later, this area is ready for felling and replanting.
2. Define the share of the cultivation area at which felling will take place for the utilisation of OPT for plywood production in the three scenarios Low, Medium and High. In the Baseline scenario, we assumed that no OPT will be utilised for the production of plywood by 2020, because no evidence was found that smallholders and companies currently utilise OPT in the study area. Under the Low scenario, we assumed a minimum, but just above-baseline (10%), increase in the utilisation of by/co-products, in this case OPT. Under the Medium scenario, we assumed a 40% higher utilisation of by/co-products, and under the High scenario, we assumed a 70% higher utilisation of by/co-products.
3. Estimate the total volume of OPTs that can be generated from a cultivation area to be cleared and replanted (*stem yield*$_{OPT}$). According to Hromatka and Savage (2010), a mature oil palm plantation can generate approx. 235 m^3 OPT ha^{-1} 25 yr^{-1} [37].
4. Estimate percentage of amount of stems that would be suitable for plywood production for non-construction materials (*fraction*$_{suitable}$).
5. Estimate the average annual yield of a HTI forest plantation (*stem yield*$_{HTI}$). Based on the literature, this is assumed to be 25 m^3 roundwood ha^{-1} yr [35] and 175 m^3 roundwood ha^{-1} for a 7-years rotation cycle.
6. Calculated the surplus land area that can be generated if the HTI forest plantation would not have to be planted to supply this amount of wood. This is done by applying Equation 8.

Equation 8

$$Land\ saved = \frac{Oil\ palm\ area_{felled} \star stem\ yield_{OPT} \star Fraction_{suitable} \star RR_{OPT\text{-}HTI\ wood}}{stem\ yield_{HTI}}$$

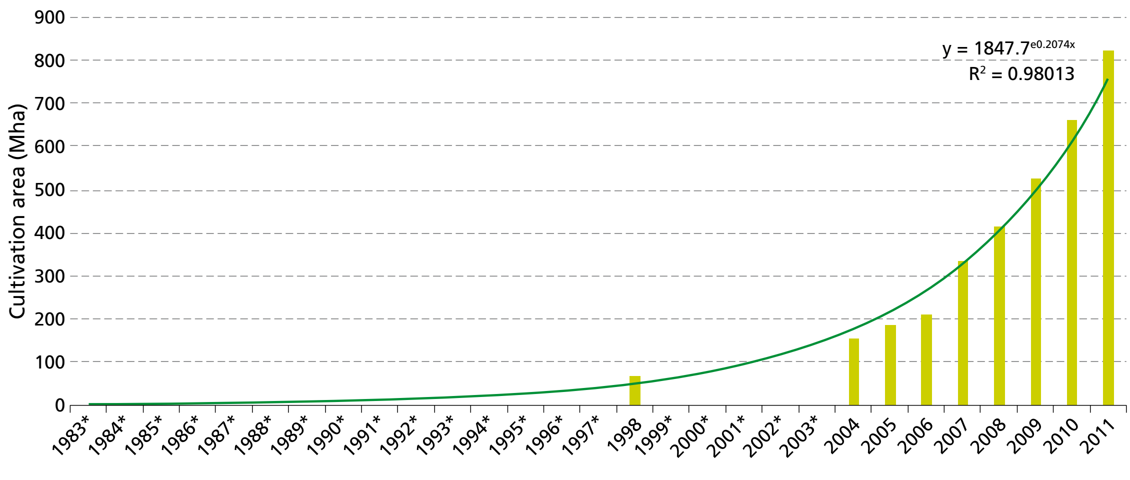


Figure 10 Oil palm cultivation area in North-East Kalimantan extrapolated (* and trendline) based on data from 1998 [49] and 2004-2011 [13,15].

5.2 RESULTS

The results of integrating the utilisation of OPTs from an old oil palm plantation into the palm oil supply chain are shown in Table 17. Under the three scenarios Low, Medium and High, the area that can be felt for OPT utilisation for the production of plywood would result in, respectively, 2,500 ha, 10,000, 18,000 ha of land in the study area (Table 17). Because ~235 m³ stems per ha could be harvested from these areas, and 40% of the OPT is assumed suitable for plywood for non-construction materials, respectively, ~235,000 to 1,645,000 m³ of plywood can be produced from OPT under the Low to High scenarios. This would result in a surplus land area of approx. 3,000 to 24,000 ha and an extra CPO production volume of approx. 10,000 to 80,000 t in, respectively, the Low to High scenarios.

Table 17 Surplus land area generated by to the utilisation of oil palm trunks (OPTs) under three scenarios.

By/co-product		Baseline scenario	Low scenario*	Medium scenario*	High scenario*
			10% of selected by/co-products is additionally utilised	40% of selected by/co-products is additionally utilised	70% of selected by/co-products is additionally utilised
1. Total cultivation area ready for felling and replanting between 2008 and 2020 (ha)	~25,000				
2. The oil palm area that will be felled for the utilisation of OPT (ha)	ha	0	~2,500	~10,000	~18,000
Stem yield$_{OPT}$ (m³ stems ha^{-1}) [37]	235				
3. Total volume of OPT (m³)		0	~588,000	~2,350,000	~4,113,000
4. Fraction of OPT suitable for plywood (%)	40 [50]	0	~235,000	~940,000	~1,645,000
5. Stem yield$_{HTI}$ (m³ stems ha^{-1})	175 (m³ ha^{-1} 7 yr^{-1}) [35]				
6. Surplus land generated if OPT wood would replace HTI roundwood	Assuming all roundwood results in plywood	No surplus land generated	~3,000	~ 13,000	~24,000
Extra FFB production (t)*			~50,000	~200,000	~400,000
Extra CPO production in 2020 (t)**			~10,000	40,000	80,000

* These estimates are based on very rough data.
** assuming an average baseline yield of oil palm Large Private Estates and Smallholdings of ~16 t ha^{-1}.
*** assuming a baseline OER of 20%

6 Increased production chain efficiency

6.1 METHODS

Food losses and food waste are often thought to be around half of the food produced [51]. Food losses, the term used to indicate the pre-consumer losses, are mostly associated with developing countries and there is large room for improvement (Appendix 3). Food waste, the term used for post-consumer losses, is the largest cause of supply chain inefficiencies in industrialised countries [52,53]. Although the gains of limiting food waste could be very large, it would involve behavioural changes by consumers. This falls outside the scope of this project. However, in the agricultural supply chain in industrialized countries, there is also still potential for improvement. Therefore, this ILUC mitigation measure on increasing chain efficiency addresses the reduction of losses in transport, storage, (un)loading, etc. Reducing the losses in the chain between production and consumption will help to fulfil food demand with less land. Thereby, surplus land is generated that could be used for biofuel production (as described in Equation 9 and Equation 10).

Equation 9

$$P_{saved,i} = \sum_{i=1}^{n} P_i \text{ x } (L_{i,baseline} - L_{i,reduced})$$

Where $P_{saved,i}$ – amount of crop i prevented from being lost due to efficiency improvements in the food chain (tonne);

P_i – production of crop i in MIRAGE baseline (tonne);

$L_{i,baseline}$ – share of biomass lost in the food chain in the baseline (without efficiency improvements) (%);

$L_{i,reduced}$ – share of biomass lost in the food chain in 2020 after efficiency improvements (%).

Equation 10

$$SA_{efficiency} = \sum_{i=1}^{n} \frac{P_{saved,i}}{V_i}$$

Where $SA_{efficiency}$ – surplus area generated from chain efficiency improvements (tonne);

$P_{saved,i}$ – amount of crop i prevented from being lost due to efficiency improvements in the food chain (tonne);

Y_i – projected yield of crop i (t ha^{-1}).

The potential production of the biofuel feedstock on the surplus land area is calculated by Equation 5. The calculations for cattle are similar to crops; in this case the beef and milk productivity and cattle density are equal to the baseline scenario applied for the measure *above-baseline yield development* (Section 4).

Case-specific aspects

For this case study, we aimed to define measures to reduce losses in the chain between production and consumption of palm oil and rice in order to reduce the amount of land needed to cultivate these production systems. We focused on palm oil and rice because these are the most important crops in terms of volume and land area used (~2 Mt of FFB from ~152,000 ha and ~586,000 t of rice from ~158,000 ha in 2008 [13]). Besides, for these crops relatively reliable data was available.

Palm oil

The crude palm OER can be calculated by the percentage of CPO extracted from the FFBs (Equation 11).

Equation 11

$$\textit{Oil extration rate (OER)} = \frac{\textit{Oil extracted}}{\textit{FFB processed}} \star 100\%$$

Globally, the range of the OER is approx. 17 to 27%, dependent on the region [10]. The OER for North-East Kalimantan that was calculated based on the BPS-based production area and production volumes for 2008 to 2011 [13] varied from 10 to 23%. Because this high variation over time seems unrealistic, we have not used these OERs in this analysis. Additionally, the average OER for Indonesia that was based on FFB and CPO data from FAOSTAT seemed rather high (see Table 18), e.g. compared to the Malaysian averages. Therefore we used a more conservative value of 20% for the baseline OER in 2008. This value is similar to the Malaysian national average for the same period (20%, [10]), and slightly lower than the OER in Sabah, Malaysia between 2012 and 2013 (~21%) [54].

Table 18 The estimated crude palm oil extraction rate (%) between 2006 and 2013 for North-East Kalimantan, Indonesia and Malaysia based on different sources.

Region, country	Crude palm oil extraction rate (OER) (%)					
	2008	2009	2010	2011	2012	2013
Indonesia*[10]	21	21	22	22	24	unknown
Malaysia*[10]	20	20	20	20	19	unknown
Peninsular Malaysia [54]					20	20
Sabah/Sarawak, Malaysian Borneo [54]					21	21

Note: for the calculation of the OER for Indonesia and Malaysia, see Table 36 in Appendix 4.

The most important factors that have a negative impact on the crude palm OER, are poor plantation management, sub-optimal time of harvesting, and poor milling operations. Harvesting should take place at an optimal ripeness of the FFBs so that these contain the maximum quantity of oil [26]. Additionally, the FFBs must be delivered at the palm oil mill within 24 hours after harvesting, so that the amount of free fatty acid (FFA) in the CPO is as low as possible [55]. FFAs are naturally released in CPO, however, because of the presence of lipolytic enzymes and microbial lipases the FFA content can increase, thus decreasing the quality of CPO [56]. It is therefore important to make sure to deliver the FFBs at the mill within 24 hours as to keep the FFA content below 5%, as required by e.g. the Palm Oil Refiners Association of Malaysia [56].

Key measures to increase the OER in North-East Kalimantan are capacity building, particularly for smallholders, e.g. on plantation management and optimal time of harvesting [57]. For the analysis of how much surplus land can be generated by increasing the OER, we defined three scenarios, namely Low, Medium and High, and compared these to the CPO production under the Baseline scenario in 2020. In the Baseline scenario we set the OER to approx. 20%, assuming that the OER in North-East Kalimantan would remain constant till 2020 (see Table 19). Based on the average OER for Sabah/Sarawak, Malaysia we assumed for the Low scenario an increase in the OER to approx. 21% by 2020. In the High scenario, we assumed that a nation-wide program with capacity building on better management and harvesting would be adopted in North-East Kalimantan and that consequently the OER would increase to 22% in 2020. For the Medium scenario, we selected an intermediate OER of 21.5%. These OERs seem within reach over the course of 12 years, as the national average OER in Indonesia was approx. 23% between 2011 and 2012, according to FAOSTAT. No distinction in OER was made between Large Private Estates or Smallholdings, as we assume that no distinction is made in the mill between the FFBs and OERs of these two production systems. See Table 22 for an overview of the scenarios. To estimate the surplus land generated by increasing the OER, Equation 9 was adjusted to estimate the gains from increasing the OER as follows (see Equation 12).

Equation 12

$$CPO\ saved_{2020} = FFB \times (OER_{scenario} - OER_{baseline})$$

Where *CPO saved* is the amount of additional CPO produced by increasing the oil extraction rate;
FFB is the projected FFB production in 2020 in the Baseline scenario from MIRAGE (Table 3);
$OER_{scenario}$ is the increased OER for the Low, Medium and High scenario;
$OER_{Baseline}$ is the OER in the baseline.

The amount of CPO saved from increasing the OER was then translated to the surplus land area applying Equation 10 where the baseline oil palm FFB yield as determined in Table 7 was applied.

Table 19 The estimated OER under the Baseline, Low, Medium and High scenarios.

	Baseline scenario	Low scenario	Medium scenario	High scenario
Description	Estimated OER in North-East Kalimantan in 2008 (conservative value, compared to statistics)	Approx. average OER in Sabah/Sarawak, Malaysia in 2012-2013	Intermediate OER	Lower than national average OER in Indonesia between 2011 and 2012 (according to FAOSTAT)
OER	20	21	21.5	22

Rice

By this measure we estimated the surplus land area generated when post-harvest rice losses would be reduced between 2008 and 2020, and thus the same rice could be produced by a smaller land area. The post-harvest rice losses in Indonesia were 7.8% in 2008 and 7.9% in 2011 [10] (Table 20). Because specific data of rice post-harvest losses could not be found for North-East Kalimantan, we projected the national rice loss percentages for this time period to the study area in the same time period.

Most of the rice is being lost before harvesting (i.e. pre-harvest) during cultivation, and after harvesting (post-harvest) during drying and storage, and transportation. In the pre-harvest stage, rodents are known as one of the most damaging pests in the food industry, and are contributing to high quantities of rice losses in Indonesia [58]. Because of the lack of data on pre-harvest losses and on potential implemented measures to control for rodents in Indonesia and in the study area, we excluded pre-harvest losses from the analysis. For this reason, it is thus assumed that pre-harvest losses will remain the same till 2020.

Prior to transportation, the rice harvested is often traditionally dried by sun-drying in the field or spread out on mats or pavements [29]. At a water content of ~13%, rice can be stored for approx. 12 months, however, if the water content is above 16%, the rice cannot be stored for more than 20 days [59]. Considerable amounts of rice is being lost during *transportation* because it frequently arrives on board not sufficiently dry for shipment. To keep the risk of rice losses as low as possible, the bags should be clean, dry and well-stitched. In tropical climates like in Indonesia, rice must be transported under dry, cool and well ventilated conditions (5-25 degrees Celsius), to protect from moisture, spoilage and self-heating [59]. Transportation should therefore take place mainly in the dry season; postponement to the wet season can result in considerable losses due to the development of molds, self-heating and premature germination.

Table 20 **Rice production volumes and losses in Indonesia, and nearby countries and regions, between 2008 and 2011.**

		2008	2009	2010	2011
Indonesia	Production volume (t)	60,251,000	64,399,000	66,469,000	65,741,000
	Post-harvest losses	4,674,000	4,963,000	5,144,000	5,172,000
	% of losses	7.8	7.7	7.7	7.9
Malaysia	Production volume(t)	2,353,000	2,511,000	2,465,000	2,576,000
	Post-harvest losses	178,000	195,000	186,000	198,000
	% of losses	7.6	7.8	7.5	7.7
South-east Asia	Production volume(t)	192,600,000	197,777,000	204,305,000	202,942,000
	Post-harvest losses	13,2021,000	13,611,000	14,248,000	14,400,000
	% of losses	6.9	6.9	7.0	7.1
Lao People's Democratic Republic	Production volume(t)	2,970,000	3,145,000	3,071,000	3,066,000
	Post-harvest losses	148,000	189,000	184,000	184,000
	% of losses	5.0	6.0	6.0	6.0

Source: FAOSTAT [10]

General measures to minimise rice losses are: optimal drying of rice; pests and disease control during cultivation; and storage and transport under dry conditions, e.g. by optimal surface ventilation with fresh dry air.

Under the Baseline scenario, we assumed a post-harvest rice loss percentage in the study area that is similar to the current rice loss percentage in Indonesia in 2008 (~7.8% [10]). Because the percentage of rice losses in Indonesia remained more or less similar between 2008 and 2011, we expected in the Baseline scenario that this percentage will remain the same in 2020 in the case study area. The comparison of post-harvest losses in Indonesia with other Southeast Asian countries and the sub-continental average indicates that losses in Indonesia are potentially high. Therefore, we used post-harvest losses from this region in the above-baseline scenarios. Under the Low scenario, we assumed the rice losses in North-East Kalimantan in 2020 to become similar to the regional average in Southeast Asia currently (i.e. 7% [10], see Table 20). For the High scenario, rice losses were assumed to be reduced to the rice losses currently experienced in Lao People's Democratic Republic, (~6% [10], see Table 20). An intermediate rice loss percentage (i.e. 6.5%) was selected for the Medium scenario. The amount of rice saved from reducing post-harvest losses and resulting surplus land was determined by Equation 9 and Equation 10 above.

6.2 RESULTS

Palm oil

The total extra CPO produced by increasing the crude palm OER in North-East Kalimantan under the selected scenarios Low, Medium and High is, respectively, approx. 37,400, 56,200 and 75,000 tonnes (see Table 21). Because the Large Private Estates constitutes the largest farming system, these are expected to produce the largest share of the CPO in 2020.

Additional rice production and surplus land area resulting from minimising rice losses under the selected scenarios

The surplus land that resulted from minimising the rice losses in the rice production chain, and thus by increasing the efficiency of rice production in North-East Kalimantan, is shown in Table 22. The results

Table 21 Extra crude palm oil (CPO) produced in 2020 under the selected scenarios compared to the Baseline.

	Low	Medium	High
Oil palm Large Private Estates	28,800	43,300	57,800
Oil palm Smallholders	8,600	12,900	17,200
Extra CPO production in 2020 (t)	37,400	56,200	75,000
OER	21%	21.5%	22%
Extra FFB production in 2020 (t)	179,000	261,000	341,000

Table 22 Baseline and projected rice losses (%), and the estimated surplus land area under the selected scenarios.

		Low	Medium	High
Rice losses (%)		7% vs 7%	6.5% vs 7%	6% vs 7%
Crop saved 2020 (t)	Wetland rice	4,500	7,200	10,000
	Dryland rice	1,500	2,400	3,300
	Total	6,000	9,600	13,300
Surplus land 2020 (ha)*	Wetland rice	800	1,300	1,800
	Dryland rice	500	800	1,100
	Total	1,300	2,100	2,900
Extra FFB production (t)**		20,800	33,600	46,400
Extra CPO production in 2020 (t)***		4,160	6,720	9,280

* assuming the baseline yields for wetland and dryland rice for 2020.
** assuming an average baseline yield of oil palm Large Private Estates and Smallholdings of ~16 t ha^{-1}.
*** assuming a baseline OER of 20%

show that under the Low to High scenarios, respectively, 6,000 to 13,300 tonnes of rice can be saved, generating approx. 1,300 to 2,900 ha of surplus land. Assuming an average baseline yield of oil palm Large Private Estates and Smallholdings of ~16 t ha^{-1} and the baseline OER of 20%, this results in approx. 4,160 to 9,280 tonnes extra CPO.

7 Land zoning and biofuel feedstock production on under-utilised lands

7.1 METHODS

7.1.1 Biofuel feedstock production on under-utilised lands

Under-utilised land includes set-aside land, abandoned land, marginal lands or degraded land. The share of this land type that does not provide other services (e.g. agriculture, biodiversity, high carbon stocks or other ecosystem services) – i.e., "unused lands" [24] – can be used for the production of biomass with low risk of ILUC. To define the amount of under-utilised land available in the case study area, information about location and extent of these types of land, its current uses and functions, and its suitability for the biofuel feedstock investigated in the case study is needed. Partially, this information may be found in statistics and existing literature, but in some cases spatially-explicit analysis is used.

For determining the amount of extra biofuel feedstock production from using this type of land, also its productivity needs to be assessed. In most cases, this is expected to be lower than average, however, not in all cases yields on under-utilised land are actually lower than on agricultural land as it depends on the soil and climate conditions. For instance, the *Imperata* grasslands in Indonesia are often considered degraded land because the grass alang-alang is hard to remove. However, Fairhurst and McLaughlin (2009) have found no significant differences in key soil fertility parameters between grassland or secondary forest soils in Kalimantan and Sumatra [31].

Equation 13

$$Pot_{low\ ILUC\ risk,UUL} = A_{\mathrm{UUL}} \times Y_{\mathrm{biofuel\ feedstock}}$$

Where $Pot_{\mathrm{low\ ILUC\ risk,\ UUL}}$ – additional production potential of biofuel feedstocks with low ILUC risk on under-utilised land (t yr^{-1});

A_{UUL} – area of under-utilised land available and suitable for biofuel production (ha);

$Y_{\mathrm{biofuel\ feedstock}}$ – projected biofuel feedstock yield (t ha^{-1});

In some cases of degraded lands, the re-vegetation of the land (particularly by cultivation of perennial crops) can lead to net storage of carbon in the soil, thereby increasing the GHG emission performance of the biofuel.

7.1.2 Land zoning

Land zoning is a measure that helps reduce impacts of LUC, specifically the associated GHG emissions (unlike the previously described measures that attempt to prevent ILUC). This study includes land zoning in order to prevent the conversion of (primary and secondary) forest, other high carbon stock land, important biodiversity areas or land with other ecosystem services for biofuel feedstock production. Land zoning criteria do not include specific conditions on maximum carbon stocks to allow land use conversion. However, the analysis excludes all areas that are prohibited by the EU-RED to be used for biomass production because of high carbon stocks (i.e. wetlands, forested areas, and peat land). Also existing nature conservation regulations and plans for the expansion of protected areas in the case study region are taken into account.

The land zoning measure is closely linked to the previous measure, i.e. biofuel feedstock production on under-utilised land, as it can limit the amount of under-utilised land that could be available for biofuels production. Therefore, in this case study, the analyses of these two measures are linked.

Case-specific aspects

To define the amount of under-utilised land available in the case study area, information is needed about location and extent of these types of land, its current uses and functions, and its suitability for the biofuel feedstock investigated in the case study. For determining the amount of extra biofuel feedstock production from using this type of land, also its productivity needs to be assessed. In some cases, this is expected to be lower than average. However, because we accounted for soil quality parameters, such as pH and soil type, during the selection of the surplus land area by the Suitability Mapper, and following the study results of Fairhurst and McLaughlin (2009) [31], we assumed that the oil palm FFB yields in this area will be similar to the FFB yields in other areas. Interesting to note is that in some cases of degraded lands, the re-vegetation of the land, particularly if cultivation with perennial (energy) crops takes place, can lead to net storage of carbon in the soil, thereby further increasing the GHG emission performance of the biofuel.

In this Chapter, we estimated through land zoning how much land in North-East Kalimantan may be suitable and legally available for oil palm expansion, while the future needs for food, feed and fuel are met and negative ecological, social and economic impacts are minimised.

Regarding the sustainable expansion of oil palm cultivation in Indonesia, focus in the literature is mostly on the potential utilisation of low-carbon marginal, degraded or set-aside land in order to mitigate greenhouse gas emissions (e.g. [31,60-62]. Kartodihardjo and Supriono (2000) estimated that approx. 17 Mha of degraded forest was present in forest concessions [63]. Kartawinata *et al.* (2001) estimated approx. 21 Mha of degraded forests in Kalimantan and Sumatra, Indonesia [64]. However, these estimates focus on forest lands which may still store high carbon stocks and biodiversity, and thus not all may be considered as available or suitable for oil palm expansion in this study. Also important social aspects, such as land ownership were not considered in these studies. The estimates for low-carbon and low-biodiversity marginal, degraded or set-aside lands, including *Imperata cylindrica* grasslands or *alang-alang* in Indonesia are scarce, but do exist. Garrity *et al.* (1996) estimated 8.5 Mha of *Imperata cylindrica* grasslands in Indonesia in 1994 and approx. 600 thousand ha in North-East Kalimantan [7]. The authors, however, indicated that for the rehabilitation of these grasslands, a better understanding of their distribution and characteristics would be necessary. Also in this study, land availability or land ownership were not included. Unfortunately, besides the study by Garrity *et al.* (1996), no recent estimates of degraded lands or *Imperata cylindrica* grasslands were found for North-East Kalimantan [7].

The previous studies [7,63,64] show that the definition or agricultural availability and suitability of marginal, degraded or set-aside lands is not always consistent or clear. To define how much land is available and suitable for oil palm expansion, it is important to consider whether focus on set-aside, marginal or degraded lands is sufficient and whether a clear definition would actually be needed. Instead, in such a complex multi-used tropical forest landscape such as North-East Kalimantan, it might be more appropriate to apply specific land zoning with focus on land availability and suitability for oil palm expansion with consideration of minimising negative ecological, social and economic impacts.
In this study, we applied *available land* to refer to land that is currently not in use for existing cash crop cultivation, forest plantations or agriculture, and is not owned by local communities through *Adat* or traditional land rights. By *suitable land* we mean land that is i) biophysically suitable for oil palm cultivation, considering climate, terrain and soil variables, and ii) suitable from an environmental impact perspective, i.e. avoiding peatlands, forested lands and high conservation value (HCV) areas.

Ramdhani and Taufik (2006) have conducted such an estimation for entire Kalimantan (i.e. Indonesian Borneo), by overlaying several biophysical spatial layers, including terrain, climate, soil and land cover variables [65]. This resulted in an estimation of approx. 9.2 Mha of suitable and available land for oil palm expansion in the region. Smit *et al.* (2013) [66] and Gingold *et al.* (2012) [67] have gone one step further, by additionally incorporating a set of sustainability criteria (among others, the Roundtable on Sustainable Palm Oil (RSPO), the Roundtable on Sustainable Biofuels (RSB) and the Renewable Energy Sources Directive or RES-D) and thus more spatial and locally collected information in their analysis. With the 'Responsible Cultivation Method', Smit *et al.* (2013) [66] have estimated that approx. 2.6 Mha of land in West Kalimantan Province has a 'low risk' for non-compliance with the sustainability criteria. This land is therefore considered suitable and available for responsible oil palm expansion in West Kalimantan. The authors indicate, however, that it is important to account for land availability and estimated an amount of 0.9 Mha of low risk land within existing inactive concessions and an amount of 0.5 Mha of low risk within options for new concessions [66]. With the 'Suitability Mapper', Gingold *et al.* (2013) [67] have estimated that approx. 7 Mha of land in West and Central Kalimantan are potentially suitable.

Such extensive analyses are, however, not yet conducted for North-East Kalimantan. In this study we therefore estimated how much land is suitable and legally available for oil palm expansion, while minimising negative ecological, social and economic impacts. We have selected a spatially-explicit approach so we could estimate the amount of suitable and available land at the landscape or provincial level and meanwhile minimising the time and costs that would be required if such an analysis would be entirely conducted on the ground. By applying land zoning that excludes unavailable and unsuitable sites through such an approach, local assessment costs can be minimised.

Several methods can be utilised to apply such land zoning to define how much land is available and suitable for the expansion of oil palm in such a way that negative ecological, social and economic impacts will be minimised. We identified three methods, namely the Responsible Cultivation Areas (RCA) method [66], the Suitability Mapper tool of WRI [67], and analysis of the structural vegetation map of North-East Kalimantan (SarVision, 2011). In Table 23 an overview of the key characteristics, advantages and limitations of the three methods are presented. Although the RCA method and the Suitability Mapper tool are closely related from a methodological perspective, we have selected the Suitability Mapper for this desktop analysis because of its easy applicability and medium time investment.

It is important to note that the Suitability Mapper, and this also counts for the other two methods, results in an estimate of the amount of under-utilised lands in 2009, (as the land cover map was developed for 2009 (see Table 38), and does not provide a projection for 2020. Additionally, the methods are a first step in the site selection process and includes land within existing concessions. Additional activities, such as field assessments, need to be conducted to determine map accuracy regarding High Conservation Values (HCVs), quality of the soil (e.g. soil degradation levels), community claims and rights, social impacts, and other local scale aspects that cannot be defined by the analysis of landscape-scale maps. At the local level, the suitability of each site should be confirmed or rejected. Such additional assessments and activities are described by WRI [67] in more detail and are beyond the scope of the analysis in this report.

The Suitability Mapper was applied assuming three scenarios with some fixed and some varying environmental and crop criteria (see Table 24). In all three scenarios, peatland depth was set to zero in order to minimise carbon emissions and carbon payback time [68]. The distance to conservation areas was set to >1000 m to maintain High Conservation Values (HCVs) and the buffer to water resources was set to >100 m to minimise impacts on water quality and quantity. The soil depth in the areas is > 50 cm, which is the minimal soil depth required. Land cover was limited to grassland and shrubs as to exclude forests and wetlands from the analysis. In all scenarios, settlements, plantations and agricultural lands were considered unavailable for oil palm expansion, as oil palm expansion into these areas may induce ILUC when the original land use or commodity moves to another location. The Low scenario represented optimal growth conditions for which areas were selected with slopes of <10%, elevations < 300m [64],

Table 23 **Overview of the key characteristics, advantages and limitations of three methods to quantify available and suitable land for the expansion of oil palm.**

Methodology	Key characteristics	Advantages	Limitations	Data availability
Responsible Cultivation Areas (RCA) method [66]	- spatially explicit method - estimates amount of suitable and available land for responsible oil palm cultivation - indicates low-risk for non-compliance with set of sustainability indicators - based upon sustainability criteria of the RSPO, RSB and RES-D	- medium accuracy - readily available - additional spatial data can be added	- biophysical, legal and social field checks needed - high data requirement - knowledge of Geographic Information Systems needed	- most of data is available - HCV and social assessments would be needed
Suitability Mapper **Online and publicly available tool developed by the World Resources Institute and Sekala [67]**	- spatially explicit method - estimates the amount of potentially suitable sites for sustainable oil palm cultivation, considering a variety of aspects (carbon and biodiversity maintenance; soil and water protection; crop productivity; financial viability; zoning; rights; land use; and local interests) - based upon e.g. the RSPO; relevant Indonesian laws and policies; and proposed national REDD+ strategies	- medium accuracy - readily available - desktop applicability	- biophysical, legal and social field checks needed	- all necessary data incorporated in tool - HCV and social assessments would be needed
Use of Structural Vegetation Map North-East Kalimantan (SarVision, 2011)	- spatially explicit analysis - estimates the amount of land that constitutes degraded open canopy forests and low to medium biomass grasslands and shrublands Vegetation classes included: - Grassland/shrubland low-medium biomass (or plantations medium biomass) - Shrubs low biomass (or plantations low biomass) - Recently cleared areas low biomass - Recently cut high biomass	- readily available – easy applicable	- low accuracy; provides rough estimation - indication of vegetation structures and not of specific land use types, e.g. existing plantations - legal, social or HCV aspects cannot be accounted for	- Structural vegetation map is available

well to excessive soil drainage and rainfall between 1500 and 3000 mm annually. The pH of the soil is set as optimal between 4-6, so that acidification of the soil is not needed. Growth limitations for oil palm are not expected in these areas [64].

Under these Medium and High scenarios, it is expected that additional soil preparation and drainage measures are needed, however, more intensive under the High scenario. No negative impacts on yields are expected. Compared to the Low scenario, the settings were as follows; higher altitudes (resp. < 500 and <750m), steeper slopes (resp. <20 and <25%), higher rainfall (resp. <4000 and 5000 mm yr^{-1}) and less optimal drainage (resp. well-excessive and poor-excessive). For more specific information about the scenarios, see Table 24). After the estimations of the amount of suitable and available land, we estimated how much FFBs and CPO can be produced by utilising these lands in 2020 with minimum ILUC potential.

Table 24 Input settings for the land zoning by the Suitability Mapper of WRI, indicating suitability and oil palm crop criteria under three scenarios; Low, Medium and High (for data descriptions, data layer resolutions and data sources, see Table 38 in Appendix 5).

Scenarios and settings	Low*	Medium*	High*
	Optimal growth conditions	Drainage and soil preparation measures needed to obtain similar or higher yields	Drainage and soil preparation measures needed to obtain similar or higher yields
Peat depth (cm)	0 – in order to minimise C emissions		
Conservation area buffer (m)	> 1000		
Water resources buffer (m)	> 100		
Elevation (m)	0-307 (increasing climatic restrictions on cultivation above 200-300m [69])	0-505	0-750
Land cover	Grassland/shrub (No forest, No HCVs, No land in use by plantations or agriculture)	Grassland/shrub (No forest, No HCVs, No land in use by plantations or agriculture)	Grassland/shrub (No forest, No HCVs, No land in use by plantations or agriculture)
Slope (%)	0-10 (Apply terracing if slope >10%)	0-20 (Apply terracing if slope >10%; do not plant if slope >25%)	0-30 (Apply terracing if slope >10%; do not plant if slope >25%)
Rainfall (mm yr^{-1})	1500-3000 (No growth limitations [69])	1500-4005 (None to moderate growth limitations [69]) Drainage needed	1500-5012 (None to moderate growth limitations [69]) Drainage needed
Soil drainage	Well, moderately well, excessive	Well, moderately well, excessive	Poor, imperfect to excessive (drainage may be needed)
Soil depth (cm)	> 50 (or 75??) (sufficient depth)	> 50	> 50
Soil acidity (pH)	pH 4-6 (no measures to acidify soil are needed)	4-7.3 (Excessively acid- Neutral) (measures to acidify the soil may be needed)	4-7.3 (Excessively acid- Neutral) (measures to acidify the soil may be needed)
Soil type	Inceptisol, Oxisol, Alfisol, Ultisol, Spodosol, Entisol (no rock or Histosols – the latter because of poor drainage and rich in non-decomposed organic material)		

* In the estimates for this measure, the scenarios refer to the surplus land potential. For instance, the Low scenario results in a relatively lower surplus land potential compared to the other scenarios.

7.2 RESULTS

In this section, the results are shown for the combined output of the two ILUC mitigation measures 'Biofuel feedstock production on under-utilised lands' and 'Land zoning'. According to the output generated by the three settings for the Suitability Mapper, approx. 1.8 to 2.4 Mha of land in North-East Kalimantan are considered suitable for sustainable oil palm expansion (see Table 25). The High scenario generated approx. 2.4 Mha, the Medium scenario approx. 2.2 Mha and the Low scenario approx. 1.8 Mha. The highest estimates of suitable land were generated under the High and Medium scenarios, because with these settings oil palm cultivation can expand into areas with higher altitudes and steeper slopes. Measures such as drainage and terracing will be needed to obtain similar or higher yields than in the baseline scenario.

Again, it is important to stress that local field assessments are required to confirm or reject the site suitability and availability. While this has not yet been done for North-East Kalimantan, the field assessments conducted by Gingold *et al.* (2012) for West Kalimantan have shown that 13 of the 22 sites investigated were actually found to be unavailable or unsuitable for oil palm plantation development [67]. This was because of e.g. the presence of existing oil palm plantations, culturally important sites, intensive land use and/or extreme flooding. In the same study, 9 out of 22 sites were found to be potentially suitable and available, indicating that approx. two fifth of the initially selected sites were suitable on the ground. Applying this percentage to the outputs of the Suitability Mapper for North-East Kalimantan, results in a production potential of approx. 2.3 Mt CPO (Low scenario) to 3.1 Mt CPO (High scenario) (Table 25).

Table 25 Output of the Suitability Mapper of WRI, indicating the amount of suitable under-utilised land for oil palm cultivation and the potential FFB and CPO production on these lands in 2009 (the land cover map in the Suitability Mapper has been developed for 2009, see Table 38).

Setting	Low scenario*	Medium scenario*	High scenario*
	Optimal growth conditions	Conditions where medium intensive measures are needed	Conditions where high intensive measures are needed
Total land area in North-East Kalimantan (ha)	20 Mha	20 Mha	20 Mha
Estimated amount of suitable and available land in North-East Kalimantan (ha)	1.8 Mha	2.2 Mha	2.4 Mha
Local land claims/rights/interests	Unknown. To be determined through field assessments		
Ground-estimated amount of suitable and available land in North-East Kalimantan** (ha)	726,000	898,000	975,000
FFB production (t)***	11,600,000	14,400,000	15,600,000
CPO production (ton)****	2,300,000	2,900,000	3,100,000

* In the estimates for this measure, the scenarios refer to the surplus land potential. For instance, the Low scenario results in a relatively lower surplus land potential compared to the other scenarios.

** Portion of land area that is estimated to be suitable and available on the ground was estimated to be 41% for West Kalimantan [67]. The same percentage was applied here for North-East Kalimantan. The actual portion for North-East Kalimantan needs to be determined by field checks.

*** assuming an average baseline yield of oil palm Large Private Estates and Smallholdings of ~16 t ha^{-1}.

**** assuming a baseline OER of 20%

8 Lower GHG emissions in the biofuel supply chain

8.1 METHODS

The previous sections investigated how different measures can contribute to minimising ILUC. Another important aspect of improving the performance of biofuel value chain is focusing on reducing its impacts. Lowering the GHG emissions in the biofuel value chain is a key component of that: it increases the GHG emission reduction potential of biofuels compared to fossil fuels. To assess possibilities for GHG mitigation, first GHG emission data for the production chain and overall GHG balances are collected from literature. Key data to be included are:

- direct land use change, including soil organic carbon changes due to cultivation;
- fertiliser management in the crop cultivation (type and amount of fertiliser);
- consumption of fossil energy during crop production (e.g. due to use of machinery);
- transportation method(s) and distances;
- GHG emissions from feedstock conversion and credits from co-products; and
- biofuel end-use (e.g. transport to refuelling station).

The overview of emissions from the chain is made with the BioGrace GHG calculation tool [70]. Then, the GHG balance is used to identify the key sources of emissions and potential strategies to mitigate emissions in the different parts of the value chain. Finally, the GHG balance is compared to the GHG emissions of fossil fuels. As LUC is a large contributor to GHG emissions, LUC-related GHG emissions are treated separately. They are assessed from the literature and data collection for North East Kalimantan.

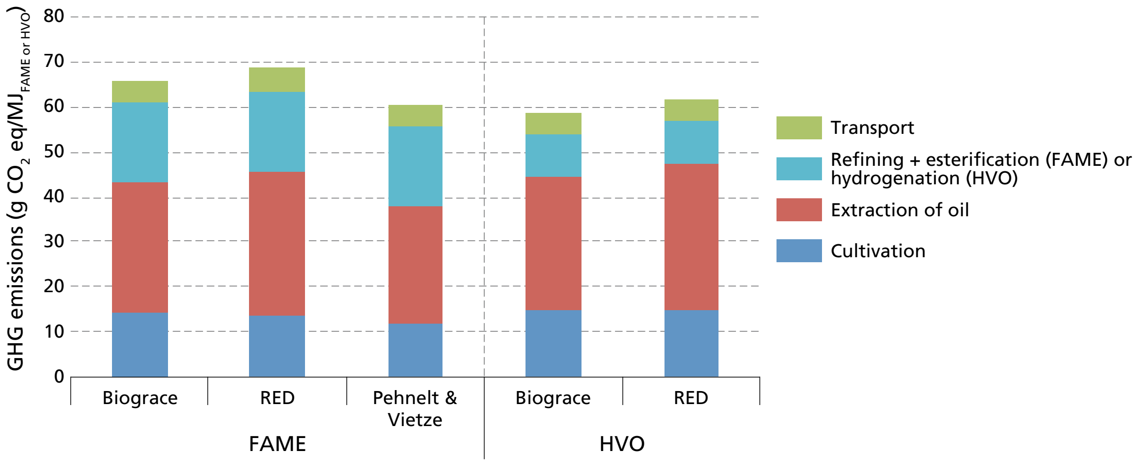
8.1 RESULTS

GHG emissions from palm oil-based biofuel supply chains (without LUC[13]) are presented in Figure 11. The largest source of emissions is the extraction of the palm oil at the mill – more specifically, these emissions come from the treatment of the mill waste water, the so-called palm oil mill effluent (POME; see also Section 5.1). Reducing the emissions from POME is thus a key entry point for reducing emissions in the supply chain. This is possible by implementing anaerobic digestion of POME in a closed system so that the generated biogas (a mixture of methane and carbon dioxide) can be collected and flared, or burned for producing electricity so that additional benefits can be reaped. Another option for reducing POME-related emissions is the prevention of the organic materials from the mill entering the ponds by separating solid and liquid materials and returning the solid material to the plantation as fertiliser.

Default settings in BioGrace [70], and resulting emissions and emission reductions indicate that with methane emissions. Supply chain GHG emissions can be reduced from 66 to 37 g CO_2-eq/MJ biodiesel

13 LUC emissions are dealt with later in this section.

Figure 11 GHG emissions of palm oil-based biofuel supply chains by source of emissions comparing default values from BioGrace and EU-RED [70] with results from Pehnelt and Vietze [71] without land use change.



Note: BioGrace, EU-RED [70] and the study by Pehnelt and Vietze [71] account for the possibility to capture methane emissions from POME treatment. For FAME, this reduces emissions by 29.0, 31.5 and 25.7 g CO2-eq/MJ_{FAME}, respectively.

or from 59 to 29 g CO2-eq/MJ hydrotreated vegetable oil (HVO). In terms of emission reduction compared to fossil diesel, oil palm biodiesel without methane capture reduces emissions by 21% (30% for HVO). With capture, this increases to 56% for biodiesel and 65% for HVO.

Besides emissions in the supply chain, a key issue for the GHG balance of palm oil is land use change [48,61]. LUC can be caused directly and indirectly. As this case study is about preventing indirect land use change, emissions from ILUC are not applicable. However, direct land use change can still result in very large emissions. Including direct LUC emissions, a study on GHG emissions from palm oil from Sabah (Malaysian Borneo) shows that the type of land converted to oil palm plantations has a large impact on whether and how much emissions can be saved compared to a fossil reference system or not ([48], see Table 26). However, the size of LUC-related GHG emissions depends on what type of land is converted (see e.g., [48,61]) and the carbon stocks of that land (Table 27). Particularly the conversion of natural rainforest and peatland forest to palm oil plantations would generate such high emissions (not to mention all the other negative effects of deforestation) that it makes them unsuitable for conversion for biofuels production. Multiple studies in North-East Kalimantan have shown that tropical rainforests store high amounts of carbon, aboveground and belowground [72,73]. Even secondary or logged-over forests often contain high carbon stocks and are generally not suitable for conversion [74]. However, under-utilised land (as defined in Section 7.1.1) has low carbon stocks and conversion to oil palm plantations can lead to a net gain in carbon stocks [48]. Using under-utilised land with low aboveground and belowground biomass densities, and thus excluding forests and peatlands, is thus a key strategy for reducing emissions

Table 26 GHG emissions, emission reduction and carbon payback period for biodiesel from palm oil (produced in Sabah, Malaysia; adapted from [48].

	Emissions	Emission reduction	Payback time
	g CO_2-eq MJ^{-1} CPO	%	years
Peatland forest	391	-337	169
Natural rain forest	107	-20	30
Logged-over forest	32	65	8
Degraded land	-51	157	0

Table 27 Aboveground carbon stocks (t ha^{-1}) by land type for Kalimantan (North-East Kalimantan) in comparison with data from Southeast Asia and emissions from peat oxidation.

	Kalimantan	SE Asia – average default values IPCC [48]	SE Asia [61]	Malaysia, Indonesia and Papua New Guinea [77]
Land type	Carbon (t ha^{-1})*	Carbon (t ha^{-1})	Carbon (t ha^{-1})	Carbon (t ha^{-1})
tropical rainforest – avg	209[1]	172	-	-
- lowland	239[1]	239	222	-
- montane	231[1]	231	-	189
- heath	171[1]	171	-	-
Logged (~3-40 years post-logging, logging intensity not considered)	122-144[2]	86	-	104
degraded/grassland	6-8[3]	2.5	-	30
Peat swamp forest	171[1]	172	222	162
Emissions from peat oxidation	CO_2 (t ha^{-1})*	CO_2 (t ha^{-1})*	CO_2 (t ha^{-1})*	CO_2 (t ha^{-1})*
Forest conversion to oil palm plantation	-	39	55	43

Sources: 1. Budiharta *et al.* (2014) [74], 2. Morel *et al.* , 2011 [78], 3. Syahrinudin (2005) [79]
* Carbon stocks are estimated based on the general assumption that half of the biomass exists of carbon.

from the palm oil supply chain. The variability of aboveground biomass across North-East Kalimantan provinces is illustrated by the aboveground biomass map and soil map of the area in Quinones *et al.* (2011) [75] and van der Laan *et al.* (2014) [76].

9 Integration of measures

9.1 METHODS

Having evaluated the individual measures, the total potential biomass production with a low ILUC risk is analysed (Figure 2). This is an integrated assessment that accounts for the interactions and feedback between different measures. Key interactions and feedback between measures are:

- Reducing food losses decreases the food production volume required for supplying the same amount of food. As a result, above-baseline yield developments result in lower surplus area.
- Using co-products from the biofuel supply chain more optimally reduces the production of crops that are substituted by the biofuel co-product. The crop yield determines the reduction in the land demand.
- Above-baseline yield developments in existing food, feed and biofuel production result in surplus agricultural area when projected demand is met. The biofuel crop yield is then used to

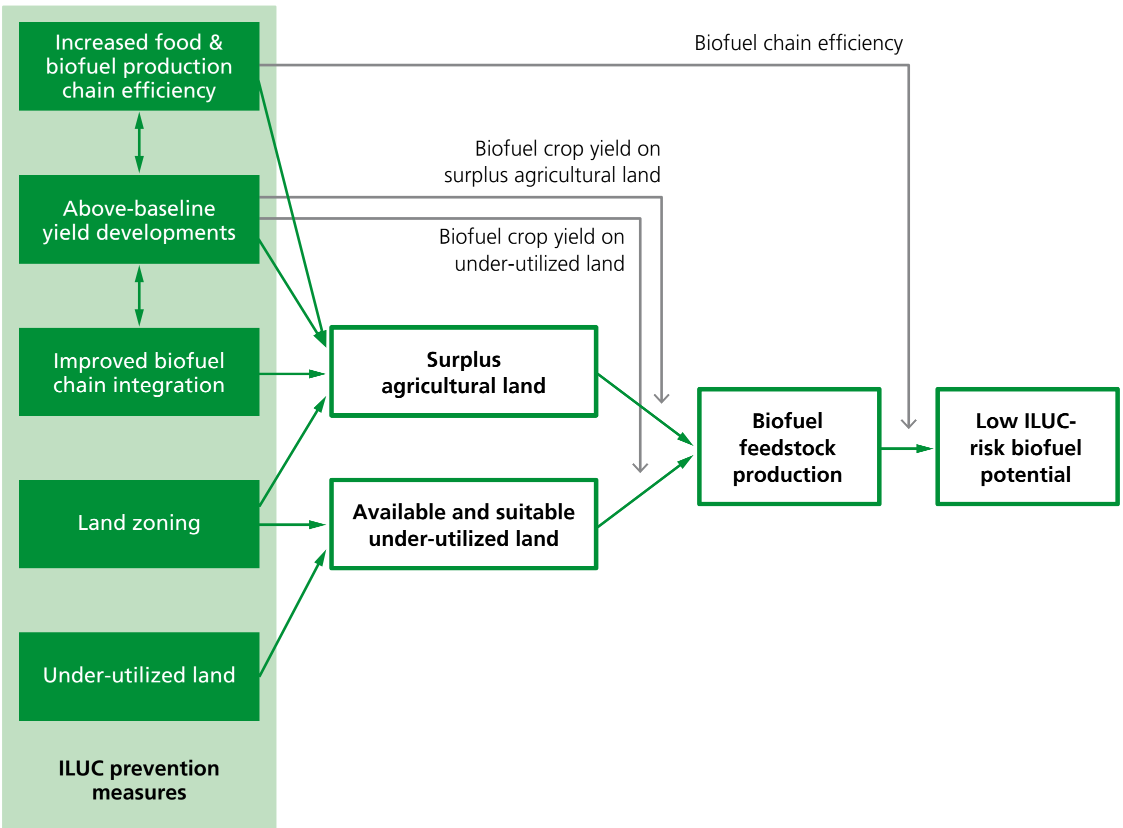


Figure 12 **Schematic illustration of integrated analysis.**

assess how much low-ILUC-risk biofuels can be produced on the surplus agricultural land and under-utilised land. For the assessment of the potential on under-utilised land a potentially lower yield on under-utilised land compared to surplus agricultural land is considered.

- The improvements in the chain efficiency for food and biofuel production result in making surplus land area available for biofuel feedstock production. The biofuel chain efficiency is also used in the conversion of feedstock to biofuel low-ILUC-risk potential.
- Land zoning affects the availability of under-utilised land by excluding certain land areas (e.g. primary and secondary forest, other high carbon stock land, high conservation value areas, protected areas or other land not legally available for the production of biomass) and land biophysically unsuitable for the specific crop assessed in the case study.
- Land zoning also affects the availability of surplus agricultural. Although one might consider all surplus agricultural land to be available for biofuel feedstock since it is already in agricultural use, this is not necessarily the case. This is because sometimes land is legally available for food crop production but not for second generation energy crop production.

The main result of the integration is the comparison of the low-ILUC-risk potential with the increase in production projected by the economic model in the target scenario (Section 3.1). If higher than the target, the case study region can provide biomass for biofuels without causing ILUC. If the potential is lower than the projected increase in production, the region cannot provide the required biomass without undesired (direct or indirect) LUC. This can happen either as a result of diversion of baseline production or deforestation and conversion of other natural land. In these cases, additional action needs to be taken in order to prevent or mitigate ILUC.

Case-specific aspects
To define the total surplus land and total extra FFB and CPO production that have resulted from the ILUC mitigation measures, one needs to integrate the outcomes of the ILUC mitigation measures. The integration steps are illustrated in Figure 13. The integration was conducted as follows: in Steps 1,

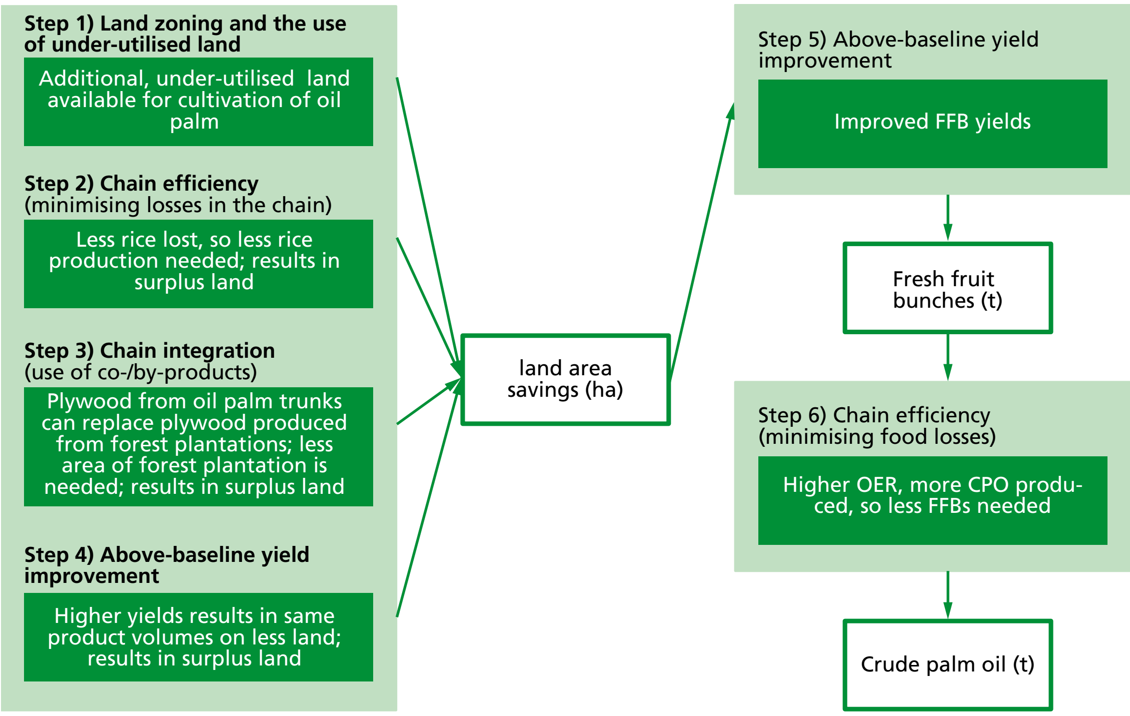


Figure 13 Integration steps of the outcomes of the ILUC mitigation measures (blue boxes: type of measure, green boxes: explanation of measure, yellow boxes: output of each integration step).

2, 3 and 4 of Figure 13, total surplus land area was estimated under the three scenarios when under-utilised lands would be used; rice losses would be decreased; OPTs would replace roundwood from HTI plantations; and the yields of the selected agricultural production systems would be improved. The potential FFB volume that may be produced from this total surplus land depends, however, on the FFB yield improvements (Step 5). Subsequently, the amount of CPO produced from the FFB volume under the three scenarios depended on the increased OER in Step 6. Chain efficiency resulted in extra CPO production, which is added to the total CPO volume.

The potential surplus land area generated by the increased yields of forest plantations, was not integrated in the total surplus land area and CPO production volume potential, because estimates were based on uncertain data and rough estimates. Instead these outcomes were indicated separately to give an indication of the extra amount of land area and CPO production volume that could be generated. Further research is needed. An overview of the low, medium and high scenarios per measure is provided in Table 28.

Table 28 The Baseline and Low, Medium and High scenarios that have been analysed in this study for each of the ILUC mitigation measures.

	Above-baseline yield increase	Improved chain integration	Increased production chain efficiency	Land zoning and biofuel feedstock production on under-utilised lands
Baseline	Yields as defined by MIRAGE in the Baseline scenario (MIRAGE-REF)	No additional chain integration; no additional utilisation of by/co-products	No increased chain efficiency; Crude palm OER = 20%; Rice losses of 7.8%	No under-utilised lands available and/or suitable
Low	2% annual yield increase till 2020	10% of selected by/co-products is additionally utilised	Crude palm OER = 21% (average Indonesia); Rice losses of 7%	Land zoning, land suitable and available, optimal growth conditions
Medium	2.5% annual yield increase till 2020	40% of selected by/co-products is additionally utilised	Crude palm OER = 21.5% (intermediate OER); Rice losses of 6.5%	Land zoning, land suitable and available, additional measures needed to obtain similar or higher yields than in the baseline scenario
High	3% annual yield increase till 2020 (results in yields that are lower than or similar to the maximum attainable yields)	70% of selected by/co-products is additionally utilised	Crude palm OER = 22% (assuming a Nation-wide program implemented) Rice losses of 6%	Land zoning, land suitable and available, additional measures needed to obtain similar or higher yields than in the baseline scenario

9.2 RESULTS

The total surplus land that can be generated technically by integrating the ILUC mitigation measures is approx. 0.8-1.1 Mha under the selected scenarios (see Table 29). Subtracting the additional land needed to meet the baseline demand for all crops in 2020 (Table 4 and Table 12), results in a total surplus land area of 0.4-0.8 Mha (Table 29). The CPO production volumes that can be produced from these areas and from increasing the OER resulted in approx. 1.5 to 3.3 Mt under the three scenarios (Table 30). The PKO that is co-produced is assumed to be about 10% of the CPO volume produced and is shown in Table 30 as well. Not included in the integration is the rough estimate for above-baseline yield development of forest plantations, which can generate additional savings of land that can be set aside for e.g. forest restoration or forest conservation under REDD+ projects (Section 4.2). This is because HTI concessions generally contain large areas of natural forest and because too many uncertainties are involved in the estimation.

Table 29 Estimated total surplus land by the measures.

ILUC mitigation measures		Low	Medium	High
Land zoning and under-utilised land		726,000	898,000	975,000
Increased production chain efficiency	Less rice losses	1,300	2,100	2,900
Improved chain integration	Use of OPTs instead of roundwood from forest plantations (ha)	3,000	13,000	24,000
Above-baseline yield development	Oil palm Large Private Estates	11,000	37,000	60,000
	Oil palm Smallholdings	7,000	23,000	38,000
	Wetland rice	1,000	6,000	12,000
	Dryland rice	1,000	4,000	7,000
	Rubber Smallholder Estates	1,000	4,000	7,000
	Rubber Large Private Estates	0	1,000	1,000
	Subtotal	21,000	75,000	125,000
Subtotal surplus land (ha)		751,000	988,000	1,127,000
*Additional land demand to meet baseline in 2020**		-335,000	-335,000	-335,000
Total surplus land (ha)		416,000	653,000	792,000

* Baseline 2020 minus current land area 2008 (See Table 4 and Table 12).

Table 30 Overview of low-ILUC risk potential of FFB and CPO production in North-East Kalimantan.

ILUC mitigation measures		Low	Medium	High
FFB production (Mt FFB yr^{-1})	Above-baseline yield* under the scenarios (t FFB ha^{-1} yr^{-1})	16.3	17.2	18.3
Land zoning and under-utilised land**		6.37	9.68	11.71
Chain efficiency	Less rice losses	0.02	0.04	0.05
	Increased OER (for current production)	0.18	0.26	0.34
Chain integration	Use of OPTs instead of roundwood from forest plantations (ha)	0.05	0.21	0.38
Above-baseline yield development	Oil palm Large Private Estates	0.18	0.64	1.10
	Oil palm Smallholdings	0.11	0.40	0.70
	Wetland rice	0.02	0.10	0.22
	Dryland rice	0.02	0.07	0.13
	Rubber Smallholder Estates	0.02	0.07	0.13
	Rubber Large Private Estates	0	0.02	0.02
	Subtotal Above-baseline yields	0.34	1.29	2.29
Total low-ILUC-risk FFB production potential (Mt FFB yr^{-1})		7.0	11.5	14.8
	OER under the scenarios	21%	21.5%	22%
Total low-ILUC-risk CPO potential (Mt yr^{-1})		1.5	2.5	3.3
Total low-ILUC-risk PKO potential (Mt yr^{-1})***		0.15	0.25	0.33

* The average baseline yield of the Large Private Estates and Smallholdings for 2020.
** The area available, and thus the FFB volume, from this measure is reduced in order to exclude the additional land needed to meet the baseline demand (see discussion in text).
*** The PKO volume is assumed to be 10% of the CPO volume

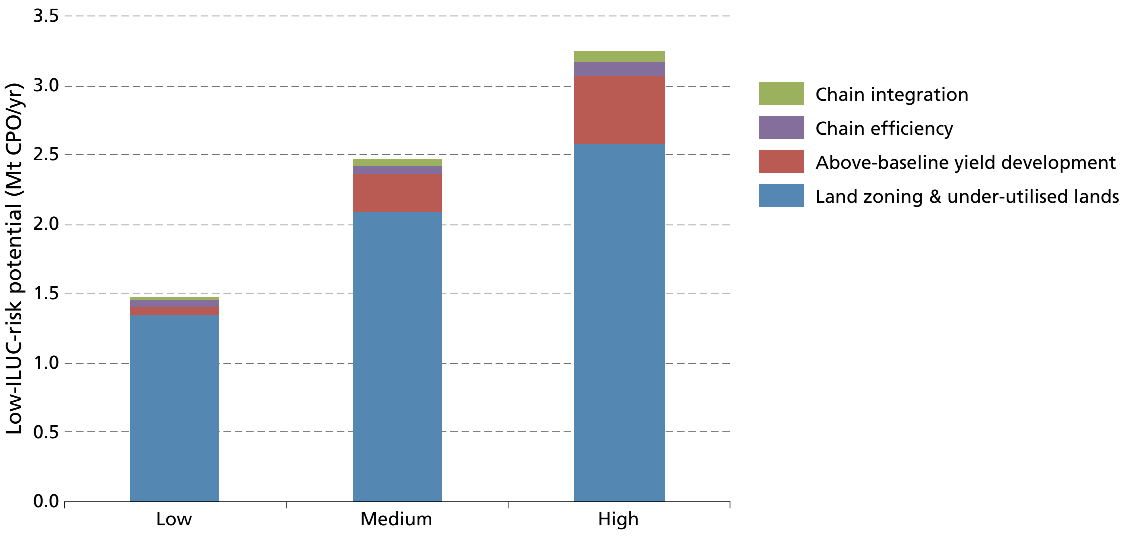


Figure 14 **Low-ILUC-risk production potential of CPO in North-East Kalimantan, Indonesia. For reference purposes, the additional demand for palm oil from EU biofuels from this region is 0.13 Mt CPO by 2020 (see also Table 3) (the area available and CPO volume for the 'Land zoning & under-utilised lands' measure is reduced in order to exclude the additional land needed to meet the baseline demand; see discussion in text).**

Comparing the low-ILUC-risk potential with the projected additional demand for palm oil from EU biofuels (0.13 Mt CPO/yr) shows that 12 to 25 times the projected EU demand for palm oil for biofuels can be produced with the measures assessed in this study.. The measures 'land zoning and the use of under-utilised land' resulted in the largest contribution to the low-ILUC-risk potential and was therefore identified as the most important ILUC mitigation measure in this study.

10 Discussion

10.1 DATA AVAILABILITY AND RELIABILITY

Because of the extensiveness of the analyses, a large amount of data and a variety of data sources were needed. The key parameters in this study were yield, production volume and cultivation area of each agricultural production system, crude palm OER and land area of degraded or under-utilised lands. Although in recent years regional spatial data and regional BPS statistics are becoming available on a larger scale, data gaps existed. The spatial data used in the Suitability Mapper is assumed to be reliable, as intensive ground checks were conducted in West Kalimantan by WRI [67]. Reliable local statistical data were, however, missing for e.g. yields of the agricultural production systems, OER, CPO volumes, HTI roundwood volumes, pasture land area, livestock density and rice losses. Most of these parameters were therefore estimated in this study based on regional or national-based data. Yields were estimated by subdividing the production volume of each crop by its cultivation area in the study area. These estimates seemed realistic, if compared with national and Malaysian averages. The oil palm FFB yields seemed too low, however, and because of the existence of many immature oil palm plantations in the study area, we applied a correction factor to account for the share of mature/immature areas. This resulted in similar, but slightly lower estimates than the national averages. This correction factor seemed useful given the recent agriculture developments in the study area. The exact source and the accuracy of each data entry from BPS could, however, not be defined. Uncertainties in the data thus exist and this should be considered during the interpretation of the results.

Accurate and reliable regional statistics and spatial data are a prerequisite for further analyses on ILUC mitigation strategies. BPS data is the most consistent and extensive regional data set available for the study area, with regards to production volumes and cultivation area of the main regional agricultural production systems. It is important, though, that BPS is more specific about the exact data source of each data entry. Spatial data are widely available for the region and are made available online by research institutes such as ESRI [80], SarVision [81] and WRI [82]. However, as land use, land use regulations and spatial planning are constantly changing in Indonesia, spatial data are needed on a more regular basis, preferably annually. This is challenging, though, particularly in tropical areas where permanent cloud cover is hampering the use of optical remote sensing data for the production of land use and land cover maps. New technologies are under development and will provide for more accurate and more regular spatial data in the near future. Scientific institutions and local nongovernmental organisations that focus on the mitigation of undesired LUC would be supported if these data become available on a wide scale and for an affordable price.

We were only able to provide a first approximation for surplus land potentials from improving the livestock productivity, improving HTI roundwood yields and utilising OPT. These may provide large land savings as our first estimates have shown. However, more information on livestock pasture land and on HTI round wood production, and more research on the commercial production and utilisation potential of OPT plywood would be needed in order to provide more accurate estimations.

10.2 APPLICATION OF THE METHOD TO OTHER REGIONS IN INDONESIA

The ILUC mitigation measures presented in this report may also have a substantial impact in other areas where LUC and ILUC are common, particularly in Riau and in the other provinces of Kalimantan. Spatial planning by different levels of the government has promoted the expansion of logging, forest and oil palm plantations into these regions. Rice farmers in Riau [83], and mixed agriculture and smallholder rubber farmers in East Kalimantan have converted their lands to monoculture plantations, such as oil palm [84]. Although in general the concessionaires and communities may find an agreement for the concessionaire to use the land, this may cause ILUC if these communities move into forest frontier areas to provide for their livelihood. If, however, new lands are not opened up to compensate for the lost cultivation of rice or other food crops, this may cause a decrease in local food production. Particularly, in remote rural areas in Sumatra and Kalimantan this may jeopardize local food proficiency. The ILUC mitigation measures presented in this report would thus be very useful in mitigating ILUC in these regions.

The aforementioned provinces exhibit much under-utilised degraded lands that have resulted from large-scale deforestation, and forest and land degradation by logging and large-scale fires [85,86]. Therefore, the enforcement of land allocation zoning and the use of under-utilised lands for agricultural expansion is also expected to obtain the best results in these areas. As yields obtained by companies, and more importantly by smallholders, are generally much lower than the maximum attainable yield, increasing yields seem realistic and may result in more efficient production and higher financial returns. It should be considered, though, that increased yields of tropical crops and the related higher financial returns may motivate farmers or attract migrants to convert more land to oil palm or other cash crops, as was found by e.g. [87]. This is already very common in Sumatra and Kalimantan, where many farmers are converting their rice plantations to oil palm [83]. Sustainable land zoning and land use planning is crucial [88]. Improving chain efficiency by government support programs that are focused on improving rice yields and the prevention of rice losses may improve financial returns and, consequently, motivate smallholders to maintain their rice cultivation areas.

11 Policy and governance options

In this study, we did not only focus on improvements in the production of biofuel feedstock, but also in the other main agricultural systems that exist in the study area. Consequently, we were able to address ILUC in a more integrated way, accounting for land use and land use change related to the production of food, feed, fibre and fuels. We have shown that ILUC risk mitigation is technically possible. The next step following this analysis would be the implementation of such measures in practice.

Firstly, with regards to land zoning and the identification of under-utilised lands, we recommend to align spatial planning and sustainable land allocation zoning with suitable and available areas for oil palm cultivation, such as under-utilised lands as defined in this study. High carbon stock lands, namely peatlands and forests, and High Conservation Value areas need to be avoided, and local communities' lands need to be respected. The Responsible Cultivation Area method of Smit *et al.* (2013) [66] supported by thorough ground checks may support the identification of suitable and available lands for oil palm expansion. If concessions contain a large forest cover, we recommend the implementation of land swaps, in which concessions are moved from high carbon stock lands to under-utilised low carbon stock lands. This is currently being promoted by local civil society organisations in the study area. The use of under-utilised lands can be incentivised by e.g. subsidies or financial support programs that are initiated by the local government to support land and soil restoration, and plantation development.

Secondly, for yield improvements of all crops in this study we recommend the local government to support independent smallholders with resources and better planting material, and by knowledge transfer and capacity building on BMPs regarding better plantation design, harvesting and nutrient management. For oil palm cultivation this would additionally mean knowledge transfer on crop recovery and canopy management. Smallholders often have limited access to capital and high quality planting material, and limited awareness of new technologies and BMPs. Policies and programs to improve farming practices exist for all kinds of sectors in Indonesia. However, at the local level in North-East Kalimantan implementation of these programs are currently experienced as insufficient or not useful, especially by independent smallholders. The outreach to these independent smallholders may be more challenging than private plantations and dependent smallholders, however, as a large number of them are not organised in co-operatives. The outreach of support programs thus needs to be improved by focusing on awareness raising on BMPs and building upon the requested and required knowledge and resources of these farmers.

The implementation and success of the ILUC mitigation measures as presented in this report strongly depends on political and societal will to prevent undesired LUC or ILUC. More awareness may be needed among local government officials, companies as well as local communities on the importance of sustainable land use and maintenance of land productivity, and the positive side-effects of the mitigation of undesired LUC or ILUC on land productivity. The mitigation of undesired LUC is important for the maintenance of forest-based ecosystem services, while the mitigation of ILUC is important for local food proficiency. The latter is particularly important with regards to the government's pursuit of rice self-sufficiency. Besides strong will, also strong law enforcement, policy implementation and tackling of corruption are fundamental to the success of ILUC (risk) mitigation. Finally, future analyses on ILUC mitigation and impacts would be strongly supported by regularly collected accurate regional spatial data and statistics, soil maps and local ground checks.

12 Monitoring of ILUC

12.1 MONITORING OF ILUC AND ILUC RISK

It is important to define whether a high risk for ILUC exists and to monitor whether ILUC is taking place. Land use change, for example, is an important indicator that can be defined by analysing well-validated regional land use/land cover maps with optimal pixel size, sufficient land use classes, and on specific time intervals, e.g. every year or two years. For example, the loss of forest and the conversion from rice to rubber, and subsequently to oil palm or forest plantations, shows that LUC is taking place. However, these LUC trajectories may also indicate a high risk of ILUC, especially in areas where small-scale land use types such as rice and mixed agriculture seem to move into forest frontier areas. In West Kutai district, East Kalimantan, such land use change trajectories have already been identified, where mixed agriculture is increasingly being converted into smallholder rubber, and on a smaller scale are being converted into oil palm plantations (van der Laan *et al.*, *submitted*). Ekadinata and Vincent (2006), found similar results in Jambi province, Sumatra, where smallholder rubber has been converted into oil palm plantations on a very large scale. Meanwhile, new smallholder rubber plantations have moved into forest frontier areas.

An important indicator of ILUC is the presence of discrepancies in the land allocation zoning, the local and nationally distributed concession permits, and actual land use on the ground. Oil palm expansion is only allowed in the land allocation zone 'other land use' (or APL) and only within oil palm concessions

Table 31 **Key parameters for monitoring of ILUC and ILUC risk, the purpose for monitoring and the frequency and spatial scale of the data.**

Key parameters for monitoring	Purpose for monitoring	Frequency	Data source and spatial scale
Land use and land cover	What land use change is taking place and where? Does loss of forest and conversion from rice to rubber, and subsequently to oil palm or forest plantations occur?	Annually – two years	Validated provincial-scale land use/ land cover maps with optimal pixel size and sufficient land use classes
% of land use classes within specific land allocation zones and concession areas	Do discrepancies exist between land allocation zoning, the locally and nationally distributed concession permits, and actual land use on the ground?	Annually	Land allocation zoning, concession, and land use data at the district to provincial level
Food/feed production/ demand balances	Did a shift occur in the food/ feed/fibre/fuel balance from less food to more feed, fibre and fuel production, while demand remains similar or changes in opposite direction? What is the import/export balance	Annually	Accurate food, feed, fibre and fuel production volume and demand figures at country to global level

as defined by the government of Indonesia. Discrepancies in spatial planning at the different levels of the government, however, exist. Additionally, land allocation zones and concession areas do not always overlap with areas that seem suitable and available for oil palm cultivation.

The food/feed production/demand balances are identified as another important ILUC monitoring parameter. Particularly a (substantial) shift in the food/feed/fibre/fuel balance from less food to more feed, fibre and fuel production, while the demand remains similar or changes in opposite direction, may indicate that less land is used for food production and more land is used for the production of feed, fibre and fuel. This is an indication that ILUC is occurring. Accurate food, feed, fibre and fuel production volume and demand figures are needed. Also the import/export balance is important, since declining food exports or increasing food imports may indicate that local food demand is increasing or food production volumes are declining; the latter can indicate declining yields, increasing losses or a declining cultivation land area, which can be related to ILUC. It is thus recommended to monitor import and export statistics on an annual basis.

12.2 MONITORING OF THE IMPLEMENTATION OF THE MEASURES

The implementation and success of the ILUC prevention measures need to be monitored in order to enhance the success of the ILUC risk mitigation measures. Firstly, continuous monitoring of the landscape needs to be undertaken to support the identification and potential use of under-utilised lands. This can be conducted by the regular analyses of local and regional remote sensing data and intensive ground-checks. Secondly, yield developments would need to be monitored as to define whether capacity building programs on BMPs with the aim of yield improvements have been effective. The five-year moving yield averages could be analysed to account for fluctuations of yields due to external factors, such as droughts and floods. Because of aforementioned reasons, a distinction should be made between yields of independent smallholdings and dependent smallholdings and private plantations. If average yields have not improved over time, the yield improvement programs need to be re-evaluated and additional measures to improve yields need to be undertaken. Thirdly, production chain losses and efficiencies should be monitored to make sure these remain stable or improve. Finally, GHG emission levels should be monitored, which can be easily conducted at the mills. Here we refer back to the need for monitoring of the current land use type and land use change, and the need for accurate spatial data.

Table 32 Key parameters for monitoring of the implementation of measures, the purpose for monitoring and the frequency and spatial scale of the data.

Key parameters for monitoring	Purpose for monitoring	Frequency	Spatial scale
Land zoning and use of under-utilised lands	To quantify land availability and suitability of these lands	Annually – every two years	Validated provincial-scale land use/land cover maps with optimal pixel size and sufficient land use classes
Yield	To define whether capacity building programs on BMPs have been effective to increase the yields to above-baseline	Annual collection of data; calculation of five-year moving yield averages to account for annual variation in climate	District to provincial-scale
Chain efficiency	Are production chain losses and efficiencies improving?	Annually – every two years	Provincial-scale
Use of by/co-products	How are oil palm trunks used at the end of the plantation lifetime? Are old and unproductive oil palm plantations being cleared and replanted?	Every two years	District to provincial-scale

13 Conclusions and recommendations

The objectives of this study were to provide insights into how the risk for ILUC by the production of palm oil could be mitigated in North-East Kalimantan, how this could be quantified and how this may be regulated. For this, we estimated the low-ILUC-risk potential of oil palm expansion and biofuel production by the analyses of six key ILUC mitigation measures applied to the study area for 2020. The results show that a large amount of additional crude palm oil (CPO) can be produced in North-East Kalimantan with low risk of ILUC. From the *low* to *medium* and *high* scenario, this low-ILUC-risk potential ranges from 1.5 Mt CPO per year to 2.7 and 3.3 Mt CPO per year. This potential is 12 to 25 times the projected additional EU demand for palm oil for biofuels (0.13 Mt CPO/yr). While in MIRAGE this production target may induce large GHG emissions due to land use change, particularly with regards to the conversion of forest and peatlands, we show that this additional amount can be produced without such land use change but rather on currently under-utilised land and through yield increases. Thus, our results suggest that by means of implementing the six selected ILUC prevention measures, it is possible to minimise ILUC that may have been caused by the production of biofuel feedstock and actually minimise LUC by the production for food, feed and fibre in general.

The high potential estimated in this study is a technical potential that considers important ecological aspects, such as exclusion of forest and peatlands. However, a sustainable implementation potential must account for additional ecological, social, juridical and economic considerations and is therefore lower. Still, this study shows that there are multiple measures that can be implemented to reach additional production of CPO that does not cause unwanted land use change, and that these measures should be considered wherever possible.

Land zoning and the use of underutilised lands was found to be the most important ILUC prevention measure in terms of allowing additional production, making up approx. 85% of the low-ILUC-risk potential. This was expected, because North-East Kalimantan provinces have large areas of so-called degraded lands as a consequence of wide-spread mining, logging, and the large-scale forest fires that occurred during the 1981-82 and 1997-98 El Niño events. By the implementation of this measure, oil palm would be developed in areas that have low carbon stocks, no High Conservation Values and are not owned by local communities.

Above-baseline yield improvement by implementation of best management practices has also shown to be an important measure, although to a smaller extent than under-utilised land. On the one hand, this is due to the very large under-utilised land area in North-East Kalimantan. On the other hand, this is because MIRAGE already accounts for high yield increases in the baseline scenario, which results in a relatively low impact of above-baseline yields. In the *high* scenario, 0.5 Mt CPO can be produced additionally from average FFB yield increases to 18 t FFB ha^{-1} yr^{-1} on existing land under oil palm cultivation. Strong yield increases are possible by means of using better planting material and knowledge transfer regarding better management practices, such as better plantation design, harvesting, nutrient and canopy management, and crop recovery. These options to increase yields are relatively easily implemented at private plantations and dependent smallholders, but harder to organise and implement for independent smallholders who lack access to capital and high quality planting material, have limited awareness of new technologies and better management practices, and who are mostly not organised in co-operatives. Therefore, additional policy and governance options and strong outreach to enhance the low yields of particularly the independent smallholders are needed. Key options include supporting farmer cooperatives and the sharing of knowledge among farmers, providing support for capacity building, and funding for replanting. Independent and trustworthy sources for funding and information are important in order to ensure the success of such activities. Also for other production, particularly rice, rubber and timber plantations for timber, pulp and paper, yield increases must be stimulated in order to meet additional demand with less land and increase income and livelihood particularly for independent smallholders.

The assessment of the ILUC prevention measures and the resulting CPO production potential with low ILUC risk in North-East Kalimantan shows that the mitigation of ILUC and undesirable LUC in general is possible. However, this is only possible when the close link between the agricultural, forestry and biofuel sectors is recognised and translated to significant efforts in i) land zoning and enforcement so that only under-utilised land is used for production and ii) increasing resource efficiency and productivity of agricultural production so that more can be produced on the land. Therefore, an integrated perspective on land use for all purposes in planning and implementing policies on ILUC prevention specifically, as well as on land use in general, is essential. Implementing the ILUC prevention measures assessed in the present study would allow realising a significant palm oil production potential with a low risk of causing ILUC while at the same time also reducing the impact of land use change in general. Achieving sustainable production of oil palm also entails implementing better management practices, avoiding high carbon stock and high conservation value lands, and respecting communities' lands.

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15 Appendices

APPENDIX 1. GENERAL APPENDICES

Table 33 General geographic and demographic information for East and North Kalimantan.

Name Province	North Kalimantan	East Kalimantan	Total/average
Indonesian abbreviation	KalTara	KalTim	
Capital	Tanjung Selor	Samarinda	
Land area (ha)	~7,117,672	~13,946,182	~21,063,854
Population size (2010)	524,526	3,026,060	3,550,586
Population density (individuals/km^2)	~10	~22	~17

Table 34 Regional aggregation in MIRAGE

Abbreviation	Description of region
Brazil	Brazil
CAMCarib	Central America and Caribbean
China	China
CIS	Commonwealth of independent states, former Soviet Union
EU27	European Union with 27 member states
IndoMalay	Indonesia, Malaysia
LAC	Latin American Countries without Brazil
RoOECD	rest of the OECD
RoW	rest of the world
SSA	Sub-Saharan Africa
USA	USA

Table 35 Crop aggregation in MIRAGE

Palmfruit
Rice
OthCrop (other crops)

APPENDIX 2 'ABOVE-BASELINE YIELD DEVELOPMENT'

Best Management Practices implemented [8]
BMPs chosen for implementation are those that have been proven over time to benefit palm growth and productivity, and to conserve soil, water and nutrients. They can be grouped into 3 broad categories according to purpose

(a) Crop recovery BMPs,
(b) Canopy management BMPs, and
(c) Nutrient management BMPs.

Crop recovery

(1) Harvest interval (HI) of 7 days, (+1.6 FFB ha^{-1})
(2) Minimum ripeness standard (MRS) = 1 loose fruit (LF) before harvest,
(3) Same day transport of harvested crop to palm oil mill,
(4) Harvest audits to monitor completeness of crop recovery and quality (i.e. ripeness) of the harvested crop,
(5) Good in-field accessibility (clear paths, bridges wherever needed)
(6) Clean weeded circles,
(7) Palm platforms constructed and maintained wherever needed, and
(8) Minimum under-pruning in tall palms to ensure crop visibility.

Canopy management

(1) Maintenance of sufficient fronds to support high palm productivity,
(2) Removing abnormal, unproductive palms,
(3) In-filling unplanted areas,
(4) Selective thinning in dense areas, and
(5) Monitoring and management of pests (leaf eaters) and disease (Ganoderma).

Nutrient management

(1) Spreading pruned fronds widely in inter-row area and between palms within rows,
(2) Eradication of woody perennial weeds,
(3) Mulching with empty fruit bunches (EFB),
(4) Management of applied fertilisers (i.e. type, dosage, timing and placement), and
(5) Monitoring of plant nutrient status and growth.

RICE [32]
In January 2011, the Indonesian minister of agriculture gave citations to IRRC scientists Grant Singleton and Roland Buresh for their contribution to food security in the country. At this time, Indonesia and IRRI also developed a four-year work plan off a meeting held in Jakarta. Both parties agreed that previous areas of collaboration will continue, but also agreed to focus on the following in the next four years:

- varietal development to mitigate the effects of climate change;
- a national strategy for hybrid rice development;
- research on abiotic stresses tolerance particularly submergence, drought, salinity, and low temperature damage in high elevation areas;
- support to implementation of integrated crop, pest, and resource management;
- support to dissemination of proven NRM technologies including postharvest technologies; and
- support to socio-economic policy research.

APPENDIX 3 'INCREASED PRODUCTION CHAIN EFFICIENCY' A

"Definition of 'Losses': Amount of the commodity in question lost through wastage (waste) during the year at all stages between the level at which production is recorded and the household, i.e. storage and transportation. Losses occurring before and during harvest are excluded. Waste from both edible and inedible parts of the commodity occurring in the household is also excluded. Quantities lost during the transformation of primary commodities into processed products are taken into account in the assessment of respective extraction/conversion rates. Distribution wastes tend to be considerable in countries with hot humid climate, difficult transportation and inadequate storage or processing facilities. This applies to the more perishable foodstuffs, and especially to those which have to be transported or stored for a long time in a tropical climate. Waste is often estimated as a fixed percentage of availability, the latter being defined as production plus imports plus stock withdrawals" Source: FAOSTAT [89]

APPENDIX 4 'INCREASED PRODUCTION CHAIN EFFICIENCY' B

Table 36 **CPO (Oil, palm) and FFB (Oil, palm fruit) production volumes and the calculated oil extraction rates, for Indonesian and Malaysia, based on FAOSTAT, 2014 [10].**

	FAO product definition	2008	2009	2010	2011	2012
Indonesia	Oil, palm	17,539,788	19,324,293	21,958,120	23,096,541	26,900,000
	Oil, palm fruit	85,000,000	90,000,000	97,800,000	1.05E+08	1.13E+08
	OER	21	21	22	22	24
Malaysia	Oil, palm	17,734,441	17,564,937	16,993,717	18,911,520	18,785,030
	Oil, palm fruit	88,672,000	87,825,000	84,965,000	94,557,600	97,700,000
	OER	20	20	20	20	19

Source: FAOSTAT [10]

Table 37 **Percentage of post-harvest rice (paddy) losses in South-east Asian countries**

	2008	2009	2010	2011
Cambodia	15.0	15.0	15.0	15.0
Indonesia	7.8	7.7	7.7	7.9
Lao People's Democratic Republic	5.0	6.0	6.0	6.0
Malaysia	7.6	7.8	7.5	7.7
Myanmar	3.0	3.0	3.0	3.0
Philippines	1.0	1.0	1.0	1.0
Thailand	7.7	7.4	7.4	7.5
Timor-Leste	5.1	5.0	5.0	3.0
Viet Nam	9.2	9.2	9.3	9.2

APPENDIX 5 'LAND ZONING AND BIOFUEL FEEDSTOCK PRODUCTION ON UNDER-UTILISED LANDS'

Table 38 **Data layers and sources used for Suitability Mapper. [67]**

Date	Data layers used	Data resolution/ quality	Original data sources (all included in WRI Suitability Mapper
Peat depth (cm)	Peat depth	1:250,000	Wetlands International (2004). Data available in Minnemeyer *et al.* (2009). Interactive Atlas of Indonesia's Forests CD-ROM. Washington, DC: World Resources Institute.
Conservation area buffers (m)	Conservation areas map	1:250,000	Conservation Forest and Protection Forest categories identified in Legal classification dataset from the Ministry of Forestry Indonesia (see below). Prepared by the World Resources Institute (2012).
Water resources buffer (m)			
Slope (%)	Slope	90 m	Shuttle Radar Topography Mission (2008). Original data available at [90]
Land cover	Land cover map	1:250,000	Ministry of Forestry Indonesia (2009). Land cover Indonesia 2006. Forestry Planning Agency of the Ministry of Forestry, 2009. Provided and processed by Greenpeace. Prepared by the World Resources Institute (2012).
Elevation (m)	Elevation	90 m	Shuttle Radar Topography Mission (2008). Original data available at [90]
Rainfall (mm yr-1)	Rainfall	1000 m	WorldClim Global Climate data (1989-2009, 1000 m resolution). Data available at http://www.worldclim.org.
Soil drainage **Soil depth (cm)** **Soil acidity (pH)**	RePPProT map	1:250,000	Regional Physical Planning Program for Transmigration (RePPProT) (1990). Data provided and processed by Daemeter Consulting. Prepared by the World Resources Institute (2012).
Soil type	RePPProT map	1:250,000	Regional Physical Planning Program for Transmigration (RePPProT) (1990). RePProT data provided and processed by Daemeter Consulting. Reclassified according to FAO Digital Soil Map of the World by the World Resources Institute. Prepared by the World Resources Institute (2012).
	Legal classification	1:250,000	Ministry of Forestry Indonesia (year unknown). Kawasan Hutan (Forest Estate) land use maps, General Direktorat of Planning, Ministry of Forestry; downloaded from http://appgis.dephut.go.id/appgis/kml.aspx. Processed and provided by Greenpeace. Prepared by the World Resources Institute (2012).
	Concession map		Ministry of Forestry Indonesia (year unknown). IUPHHK_HA (logging concessions), IUPHHK_HT (timber plantation concessions), and kebun (estate or oil palm concessions) provided by the Planning Department of the Ministry of Forestry, Indonesia (Direktorat Jenderal Planologi Kehutanan, Kementerian Kehutanan Republik Indonesia). Downloaded from: http://appgis.dephut.go.id/appgis/kml.aspx. Provided and processed by Greenpeace. Prepared by the World Resources Institute (2012).
	Population density		Center for International Earth Science Information Network (CIESIN) at Columbia University, in collaboration with Centro Internacional de Agricultura Tropical (CIAT). Data available in Minnemeyer *et al.* (2009). Interactive Atlas of Indonesia's Forests CD-ROM. Washington, DC: World Resources Institute