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Aloysius Suratin

School of Environmental Science Universitas Indonesia Jakarta 10430, soeratin@gmail.com

Mahawan Karuniasa

School of Environmental Science Universitas Indonesia Jakarta 10430

Suyud Warno Utomo

School of Environmental Science Universitas Indonesia Jakarta 10430

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IS SUSTAINABLE OIL PALM PRODUCTION POSSIBLE FOR SMALLHOLDERS?

Aloysius Suratin*, Mahawan Karuniasa, and Suyud Warno Utomo

School of Environmental Science, Universitas Indonesia, Central Jakarta 10430, Indonesia

*Corresponding author: e-mail: soeratin@gmail.com

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Abstract

Decoupling resource use efficiency and ecological impacts are two challenges of oil palm smallholders in Indonesia. This study aims to find option for increasing productivity among smallholder and to reduce the environmental impacts of nutrient management in their plantations. We adopted UNEP's definition of resource and impact decoupling as a tool to estimate resource decoupling rate and impact decoupling rate. The average smallholder's resource decoupling rate from 2013 to 2017 is 0.86 kg fertilizer/kg fresh fruit bunch. This rate is 93.48% of the average of the companies (0.92 kg fertilizer/kg fresh fruit bunch) for the same period. Reducing the fertilizers dosages will reduce the resource decoupling rate and the impact decoupling rate by 58.14% (from 0.86 to 0.36 kg fertilizer/kg fresh fruit bunch) and by 67.32% (from 3.06 to 1.10 g CO₂e/kg fresh fruit bunch) respectively. Reducing the fertilizer dosage is the most appropriate approach to increasing the resource and impact decoupling rates. We conclude that a smallholder is able to produce fresh fruit bunches sustainably by changing nutrient management practices and increasing access to certified planting material. Further study is required to include the influence of land use change on the impact decoupling rate as this factor was not included in our analysis.

Keywords: efficiency; GHG emission; impact decoupling; oil palm; resource decoupling; sustainability

1. Introduction

Oil palm contribution to Indonesia export has been increasing since 2013, reaching US\$ 22.97 billion in 2017. However, the commodities' contribution to biodiversity loss and forest degradation (Schrier-Uijl et al., 2013; Lee, Ghazoul, Obidzinski, & Koh, 2014) remains an important challenge for Indonesia to achieve a sustainable production of fresh fruit bunches (FFB).

Nutrient management is an important factor that affects productivity of oil palm production and its environmental impact. Fertilizers account for 50-70% of operational budget in plantation (Pardamaen, 2017) and contributing to N₂O and CO₂ emission (Sakata et al., 2014) N fertilizer affects the N₂O emission of the oil palm plantation and the level of emission is correlated with palm age (Akhir, Kusin, Mohamat-Yusuff, Awang, & Ash'aari, 2015; Volpi, Laville, Bonari, di Nasso, & Bosco, 2017), soil type and dry and wet seasons (Sakata et al., 2015). Bah et al. (2014) concluded that the annual loss of N through runoff

reached 4.78 kg/ha with rainfall intensity as the main factors affecting the losses. A high N fertilizer rate will support microbial development in soil and that will increase N₂O emission (Clark, Buchkina, Jhurreea, Goulding, & Hirsch, 2012). The capacity to apply best management practices such as the appropriate fertilizer formulation (Tao et al., 2017) will reduce the emission and increase production.

Smallholders have an important role in the FFB production in Indonesia. The population of smallholders in Indonesia's oil palm production sub-sector in 2017 was 41% (Soliman, Lim, Lee, & Carrasco, 2016). The pull of demand at international crude palm oil market will increase this share by 120-156% in 2050 (RSPO, 2015). The increasing in the number of smallholder will increase the tradeoffs if their capacity to increase efficiency in FFB production is not followed by access to knowledge and technologies to reduce the impact for every unit increase of the production.

Studies about the decoupling potential of strategic commodities will benefit the country in shifting the current pathways of commodity production into a more sustainable way. Several studies have laid the basis for these efforts. In Thailand, Musikavong & Gheewala (2017) used ratio of economic benefit to ecological footprint as a commodity zonation tool to increase landscape productivity. In Indonesia, Harsono, Prochnow, Grundmann, Hansen, & Hallmann (2012) analyzed the nutrient management practices applied by the smallholders in Sumatera and Kalimantan and found out that the smallholders overdose on fertilizers to meet their oil palm nutrient requirements. Tao et al. (2018) conducted a field study in Central Kalimantan to measure the impact of fertilizers rate and frequency on fresh fruit bunches production. They concluded that the fertilizer rate and frequency have not effect on the fresh fruit bunches yield but have positive effect on the nutrient use efficiency.

Lack of knowledge about fertilizers rate limits the smallholders' capacity to implement best practices in nutrient management (Molenaar, Persch-Orth, Lord, Taylor, & Harms, 2013; Moulin, Wohlfahrt, Caliman, & Bessou, 2017). Other studies indicated that application of mineral fertilizers increases FFB production and reduces yield gap (Lee et al., 2014; Euler, Hoffmann, Fathoni, & Schwarze, 2016; Hoffmann et al., 2017; Woittiez, Wijk, Slingerland, Noordwijk, & Giller, 2017). Fertilizers application to reduce nutrient imbalances (Woittiez, Slingerland, Rafik, & Giller, 2018) and deficiencies (Woittiez, Turhina, et al., 2018) may increase greenhouse gas emissions (Kee, Goh, & Chew, 1995; Choo et al., 2011; Aini, Hergoualc'h, Smith, & Verchot, 2015; Akhir et al., 2015; Kusin, Akhir, Mohamat-Yusuff, & Awang, 2015; Bessou & Pardon, 2017; Kusin, Akhir, Mohamat-Yusuff, & Awang, 2017). Based on their study in Riau, Jelsma, Schoneveld, Zoomers, & Westen (2017) revealed that the *tenera* ratio of oil palm in the province ranges from 24.6% to 35.9%. The authors suggested that this low ratio of *tenera* shares to the total FFB yield at smallholder farm level reflects limited access of smallholders to good quality inputs to optimize their production.

This study aims to find options for smallholders to increase resource use efficiency and reduce environmental impacts of nutrient management in their oil palm plots. In this study, we measure resource decoupling and the impact decoupling as it is defined by UNEP (2011). The selected option will be the one with the smallest trade offs. Our work is considered new in the field as it tries to analyze the efficiency and impact of oil palm production by applying decoupling approach at smallholder's level.

2. Methods

This study is a national level review of the oil palm production system in Indonesia based on secondary data. Data for the oil palm areas and production was collected from the Tree Crop Estate Statistic of Indonesia Oil Palm 2013-2015 and the Tree Crop Estate Statistic of Indonesia Oil Palm 2015-2017 published by the [Directorate of Plantation of the Republic of Indonesia](#). Data on the rate fertilizer application by smallholders in Kalimantan and Sumatera was collected from [Harsono et al. \(2012\)](#) as shown in Table 1. The variables of the study and their measurement methods are described in the following section.

2.1 Distribution of Oil Palm Area

There are 25 provinces in Indonesia where oil palms are cultivated. The provinces are spread over 5 regions: Sumatera, Kalimantan, Sulawesi, Maluku/Papua, and Java. Distribution of the oil palm area in the given year (2013-2017) in each region is the sum of oil palm area in each province within the region in the year under consideration based on the equation below:

$$RA(i, t) = \sum_{i=1; t=1}^N PA(i, t) \quad (1)$$

RA(i,t) = oil palm area in region i in year t

PA (I,t) = oil palm area in province I in year t

i = 1, 2, ..., N

t = 2013, 2014, 2015, 2016, 2017

Calculation of oil palm area in each region for FFB productions managed by smallholder and company plantation is calculated based on Equation 2 and 3 below.

$$RAsp(i, t) = \sum_{i=1; t=1}^N PAsp(i, t) \quad (2)$$

$$RAcp(i, t) = \sum_{i=1; t=1}^N PAcp(i, t) \quad (3)$$

RAsp(i,t) = oil palm area in region i in year t

RAcp(i,t) = oil palm area in region i in year t

PAsp (i,t) = oil palm area in province I in year t

PAcp (i,t) = oil palm area in province I in year t

i = 1, 2, ..., N

t = 2013, 2014, 2015, 2016, 2017

2.2 Distribution of Oil Palm Production and Productivity

Oil palm production at regional level is calculated based on the total area of mature plan in each province within the region in a given year (2013, 2014, 2015, 2016, and 2017). Distribution of oil palm production for each region is calculated based on Equation (4) while the oil palm production based on land management (smallholder or company) is calculated according to equation (5) and (6). In the calculation, we convert the unit of production from

ton CPO to ton FFB by multiplying it with the oil extraction rate (OER). In this study, we use the OER value of 0.20 for smallholders and 0.22 for company plantations.

$$RY(i, t) = \sum_{i=1; t=1}^N PY(i, t) \tag{4}$$

RY(i,t) = Oil palm production in region i in year t
 PY(I,t) = Oil palm production in province I in year t
 i = 1, 2, ..., N
 t = 2013, 2014, 2015, 2016, 2017

The oil palm areas managed by smallholder and company plantations for FFB production is calculated based on Equations 5 and 6.

$$RYsp(i, t) = \sum_{i=1; t=1}^N PYsp(i, t) \times 0.20 \tag{5}$$

$$RYcp(i, t) = \sum_{i=1; t=1}^N PYcp(i, t) \times 0.22 \tag{6}$$

RPsp(i,t) = Oil palm production in region i in year t
 RPcp(i,t) = Oil palm production in region i in year t
 PPsp(i,t) = Oil palm production in province I in year t
 PPcp(i,t) = Oil palm production in province I in year t
 i = 1, 2, ..., N
 t = 2013, 2014, 2015, 2016, 2017

2.3 Oil Palm Productivity

Oil palm productivity is estimated by the ration of oil palm production to the oil palm area. Oil palm productivity at regional levels is calculated by dividing total oil palm production of all the studied provinces in the region to the total oil palm area of the provinces in the region in a particular year (2013, 2014, 2015, 2016, and 2017). Distribution of oil palm productivity for each region is calculated based on Equation (7) while oil palm production based on land management (smallholder or company) is calculated according to Equation (8) and (9).

$$RP(i, t) = \sum_{i=1, t=1}^N \frac{PY(i, t)}{PA(i, t)} \tag{7}$$

RP(i,t) = Oil palm productivity in region i in year t
 PY(i,t) = Oil palm production in province I in year t
 PA(I,t) = Oil palm area in province I in year t
 i = 1, 2, ..., N
 t = 2013, 2014, 2015, 2016, 2017

Calculation of oil palm productivity managed by smallholder and company plantation in each region for FFB productions is calculated based on the Equation (8) and (9).

$$RPsp(i, t) = \sum_{i=1, t=1}^N \frac{PYsp(i, t)}{PAsp(i, t)} \quad (8)$$

$$RPcpp(i, t) = \sum_{i=1, t=1}^N \frac{PYcp(i, t)}{PAcp(i, t)} \quad (9)$$

RPsp(i,t) = Oil palm productivity managed by smallholders in region i in year t

RPcp(i,t) = Oil palm productivity managed by companies in region i in year t

PYsp (i,t) = Oil palm production managed by smallholders in province I in year t

PYcp (i,t) = Oil palm production managed by companies in province I in year t

PAsp (I,t) = Oil palm area managed by smallholders in province i in year t

PAcp (I,t) = Oil palm area managed by companies in province i in year t

i = 1, 2, ..., N

t = 2013, 2014, 2015, 2016, 2017

2.4 Fertilizers Rate

Data on the rate of fertilizers application by smallholders and company plantations in FFB productions was considered a basis to estimate economic efficiency and GHG emissions. Fertilizers rate used in this study refer to actual rates applied by smallholders and companies in Sumatera and Kalimantan based on the result of an LCA conducted by [Harsono et al. \(2012\)](#) and [Zulkifli, Halimah, Chan, Choo, & Mohd Basri \(2010\)](#) as presented in Table 1.

Table 1. Fertilizers rate applied by smallholders and companies in oil palm plantation

Fertilizers	Smallholder Sumatera (kg/ha)	Smallholder Kalimantan (kg/ha)	Company Sumatera (kg/ha)	Company Kalimantan (kg/ha)
N	75	46	18.5	53
P	104	102.5	55	114
K	93.5	100	39	110
Mg	91	92	36	92

(Source: [Harsono et al., 2012](#))

Fertilizers used by smallholders and companies in each region were estimated by multiplying the fertilizers rate in Table 1 with the oil palm area in the provinces in a respected year. Distribution of fertilizers usage for each region is calculated based on Equation (10), while the fertilizers used by smallholder and companies at the regional level is calculated according to Equation (8) and (9).

2.5 Decoupling Rates

Decoupling of the FFB production is estimated by estimating the resource decoupling and impact decoupling rates. Resource decoupling rate is defined as the proportion of fertilizers inputs for each unit of FFB (kg fertilizer/kg FFB), the impact decoupling is defined as the proportion of CO₂ emission equivalent for each FFB produced (g CO_{2e}/kg FFB). We use the emission factors 6056.3 g CO_{2e} per kg for N fertilizer; 1017 g CO_{2e} per kg for P fertilizer;

and 583.2 g CO₂e per kg for K fertilizer (Patyk & Reinhardt, 1996). To find the best option for smallholders, we estimate the contribution of increasing access to better planting materials and good practices in fertilizer management on the increase in decoupling rate. Estimation of the contribution was carried out according to scenario in Table 2.

Table 2. Scenario used to optimize decoupling rate of FFB production in Indonesia from 2013-2017

Criteria	Baseline	Scenario 1	Scenario 2	Scenario 3
Fertilizer rate (FR)	FR smallholder in Sumatera > FR company in Sumatera	FR smallholder in Sumatera = FR company in Sumatera	FR smallholder in Sumatera = FR company in Sumatera	FR smallholder in Sumatera = FR company in Sumatera
Oil Extraction Rate (OER)	0.19 for smallholders 0.21 for companies	0.22 for smallholders and companies	0.22 for smallholders and companies	0.22 for smallholders and companies

3. Results and Discussion

Oil palm plantations in Indonesia are spread over 5 regions in Sumatera, Kalimantan, Sulawesi, Maluku/Papua, and Java. Based on the data published by the Directorate of Plantation of the Republic of Indonesia in 2017, the total oil palm plantation area reached 9.26 million hectares. Of the total area, 3.40 million hectares (36.72%) is managed by smallholders (independent and supported ones) and 5.86 million hectares (or 63.28%) is managed by company plantations (public and private companies). The data revealed that company plantations remain the main FFB producers in the country; however, the contribution of smallholders is increased from time to time. Spatially, the highest proportion of the FFB produced in Sumatera (70.46%) followed by Kalimantan (26.21%). The rest of the FFB produced in Sulawesi, Maluku/Papua, and Java (3.33%). It means that two regions in Indonesia, Sumatera and Kalimantan are the most important FFB producing regions in the country. Distribution of smallholders is 79.56% in Sumatera, followed by 16.74% in Kalimantan, and the rest 3.7% are spread over Sulawesi, Maluku/Papua, and Java. In term of the number of smallholders, Sumatera and Kalimantan have also outnumbered the other regions in the country. Domination of Sumatera and Kalimantan in term of plantation area and number of smallholders indicates that better strategies to improve plantation management practices in those two regions must be a priority for decision makers to improve production efficiency and sustainability.

3.1 Fertilizer Use

Nutrients management will determine the level of efficiency and sustainability of FFB production. Knowledge level and access to fertilizers will affect practices implemented by oil palm producers in managing soil nutrient in soil in their plantation. Comparison between smallholders and companies in nutrient managements is shown in Figure 1.

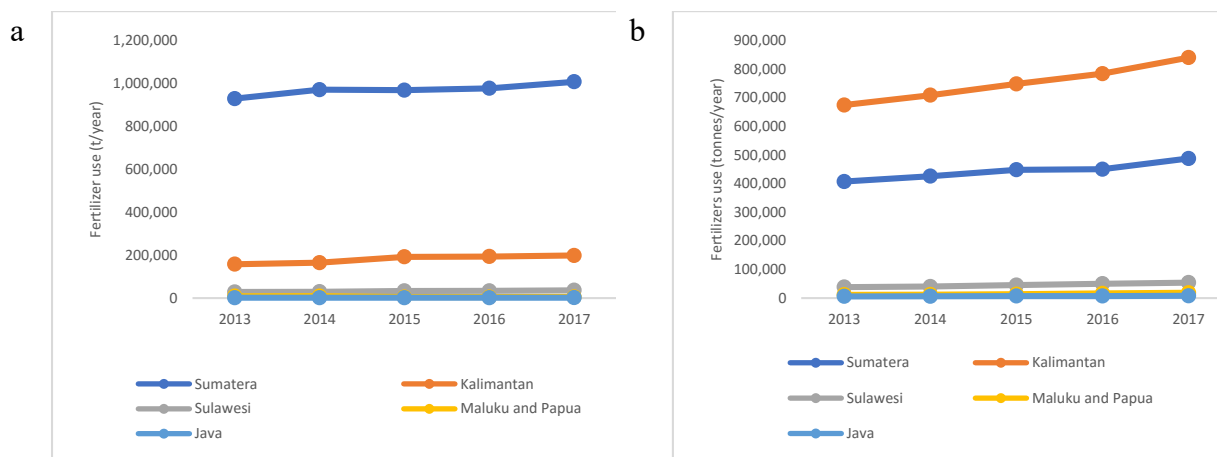


Figure 1. Fertilizers applied by smallholders (a) and companies (b) in FFB productions in Indonesia from 2013-2017

Nutrient management is different among smallholders and companies in each region. Figure 1 shows that the coefficient of variation of fertilizers rate applied by smallholders in Sumatera is 245% and in Kalimantan 229% comparing from the benchmark. Smallholders' knowledge about the appropriate nutrient rate and cash allocation to purchase fertilizers are contributing factors to those variations. In Kalimantan, smallholders have limited access to information about nutrient management in oil palm and FFB productivity in the region is lower than the one in Sumatera affecting the proportion of cash to be reinvested to purchase fertilizers leading to the slightly lower of the fertilizers rate. Although oil palm companies in Kalimantan have better knowledge on nutrient management, the coefficient of variation of the fertilizers rate is the highest (248%). Further works required to identify the reason, but capacity of the management unit to optimize FFB production and nutrient inputs in the sub-optimal land may be an underlying cause of this variation.

Two insights were generated from the practices implemented by smallholder and company plantations in nutrient management in each region. First, companies have better knowledge in nutrient management which was not disseminated to smallholders. This finding highlight the need to increase role of company plantation to disseminate knowledge and provide technical assistance to smallholders to increase fertilizers efficiency and sustainability of FFB production. Second, production efficiency and sustainability of FFB production in Kalimantan will be constrained by the land suitability.

3.2 FFB Production and Productivity

Distribution of FFB production by smallholders and company plantation is presented in Figure 2. The graphs reflect total amount of FFB production for each category of plantations in 5 regions in Indonesia.

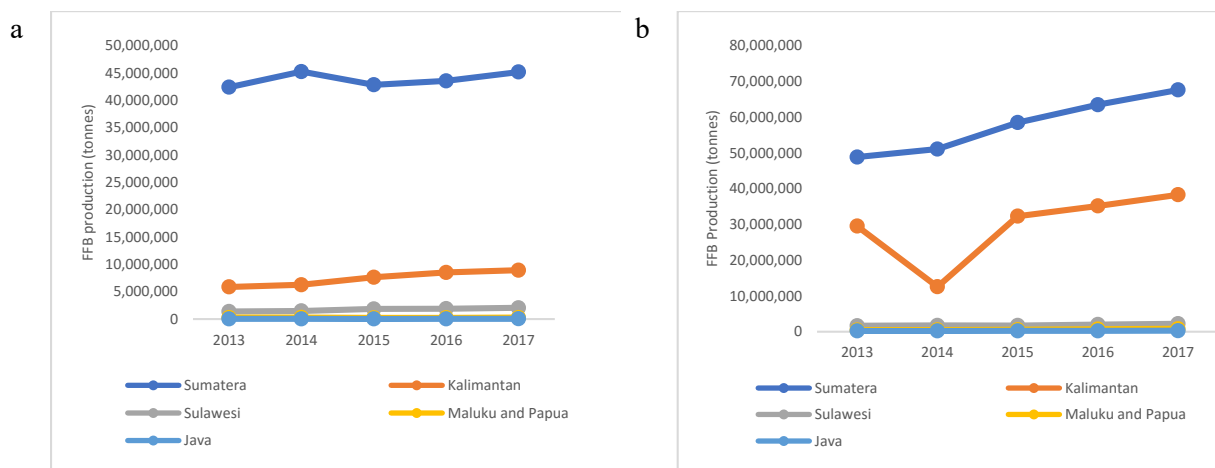


Figure 2. FFB Production by smallholder (a) and company (b) in Indonesia from 2013-2017

Based on the data, smallholders in Sumatera produced 42.42 ton FFB in 2013 and 45.20 ton FFB in 2017. Smallholders in Sumatera region contributed 79.91% of the FFB production followed by 15.83% of smallholders in Kalimantan, and 4.26% by smallholders in Sulawesi, Maluku/Papua, and Java. In total, smallholders contributed 34% of FFB production in Indonesia in 2017 and the rest (64%) was from company plantation. For the company plantations, the highest FFB production was the one in Sumatera which reported a total production of 48.85 ton in 2013 and an increase to 67.65 ton in 2017. Companies in Sumatera region contributed to FFB production among the companies by 61.89% following by companies in Kalimantan, 35.06%. Based on FFB production in Indonesia from 2013 to 2017, smallholders share to FFB production was 38.96% while company plantations contributed 61.04% of the production.

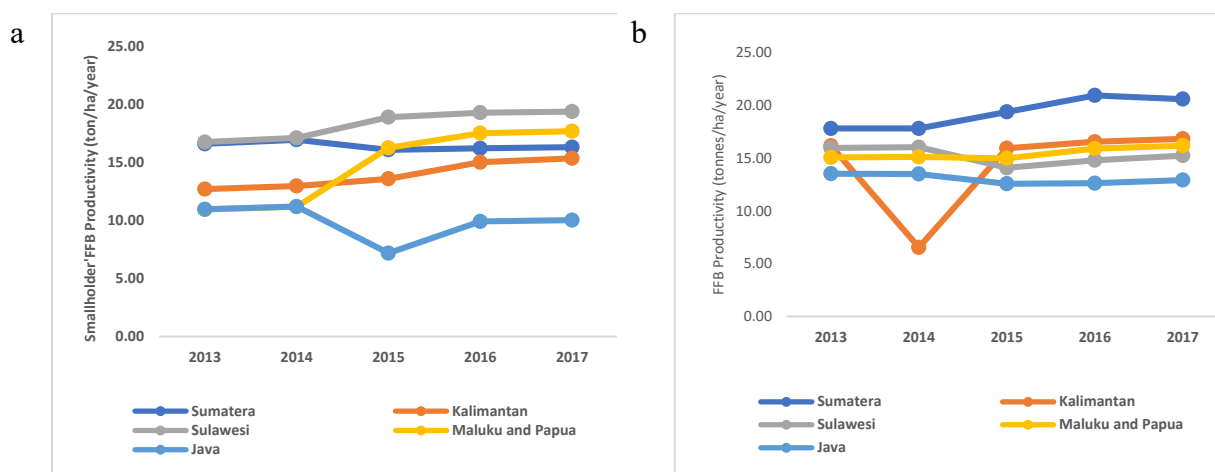


Figure 3. Productivity of FFB production for smallholders (a) and company (b) in Indonesia from 2013-2017

Productivity or area-based efficiency of FFB production by smallholders and companies is shown in Figure 3. Average productivity of FFB production for smallholder in the last 5 years was 14.64 ton FFB/ha or 60.90% of the potential productivity and the productivity of

the company was 15.49 ton FFB/ha or 64.43% of the potential productivity. This finding confirmed the result of study conducted by Tao et al. (2018) that the increase of fertilizer rate had no effect to the yield but had effect on the nutrient use efficiency. High discrepancy between actual and potential productivity between smallholder and company plantations showed that both smallholder and company plantations can be interpreted in 2 ways. First, it reflects that management practices for oil palm production need to be improved as the current management capacity of smallholder and company was not able to meet the potential yield standard. Secondly, the higher contribution of company to oil palm production in Indonesia is caused by the higher area managed by the companies and better access to good quality planting material and fertilizers.

3.3 Decoupling Rates

In average, smallholders resource decoupling rate from 2013 to 2017 was 0.86 kg fertilizer/kg FFB. This rate is 93.48% of the average of the companies (0.92 kg fertilizer/kg FFB) for the same period. However, the average impact decoupling rate of the smallholders was higher than the one of the companies. The average impact decoupling rate for smallholders was 3.06 g CO₂e/kg FFB, which is 188% of the rate of the companies (1.62 g CO₂e/kg FFB). This finding revealed that smallholders were using less fertilizers or were slightly efficient than companies but the level of emission were higher than that of the companies. As there are no differences between the type of fertilizers use by smallholders and the type used by the companies, the high emission rate for each unit FFB produced by smallholders is mainly caused by the use of low quality planting materials. Low *tenera* ratio (only 24.6% to 35.9% in the smallholders' plots) (Jelsma et al., 2017) and the overdose of fertilizer at smallholders' level as indicated by Harsono et al. (2012) are the two main reasons. Based on these findings, we estimate the impact of changes of fertilizer rates and oil extraction ratio (as a proxy of access to certified planting material) to the decoupling rates. Impacts of the changes of fertilizers rate (Scenario 1) to the decoupling rates are shown in Figure 4.

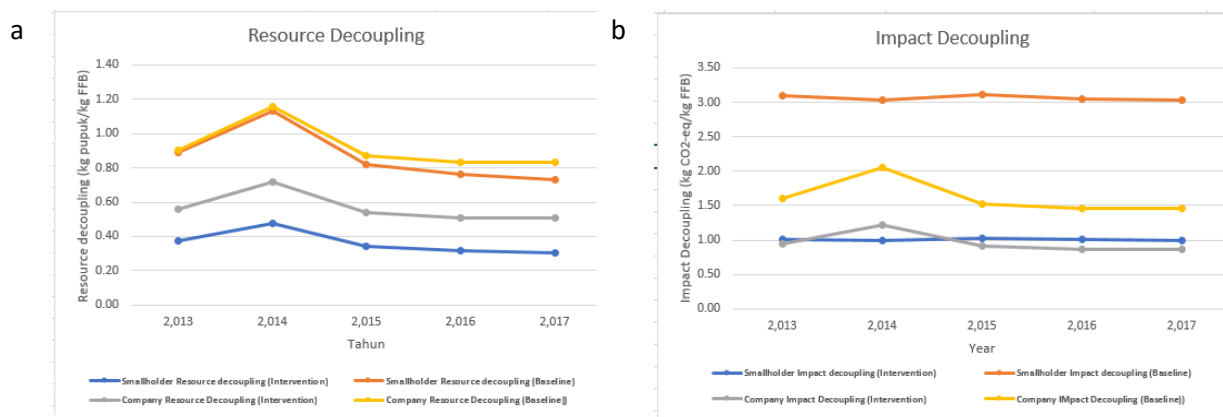


Figure 4. Impact of adjustment of fertilizers rate to the resources decoupling rate (a) and impact decoupling rate (b) of FFB production 2013-2017

Changes in fertilizers rates without changing the OER, have reduced both resources and impact decoupling rates. Changing fertilizers rates applied by smallholders and companies reduced the resource decoupling rate, in average, by 58.14% (from 0.86 to 0.36 kg fertilizer/kg FFB) at the smallholder level and 38.56% (from 0.92 to 0.57 kg fertilizer/kg FFB) at company levels. Impact decoupling rate is also decreased by 67.32% (from 3.06 to 1.10 g CO₂e/kg FFB) for smallholder and by 40.84% (from 1.62 to 0.96 g CO₂e/kg FFB) for companies. This finding suggest that the reduction of fertilizers rate will make FFB production more efficient and with less emission. The impact is higher for the smallholder due to the higher fertilizer rate applied by them to maintain nutrient availability in the oil palm plots from 2013 to 2017.

The second scenario examined was increasing access of smallholder to better quality planting material; we tested this scenario to find the impacts of the change to decoupling. Changes in the proxy indicator, oil extraction rate (OER) without changing the fertilizer rate had unexpected impacts. For smallholders, the increase of OER increased the resource decoupling rate by 105.22% (from 0.86 to 0.90 kg fertilizer/kg FFB) and the impact decoupling rate by 115.82% (from 3.06 to 3.55 g CO₂e/kg FFB) respectively. For companies, the increase was 104.37% (0.92 to 0.96 kg fertilizer/kg FFB for resource decoupling rate) and 104.83% (1.62 to 1.70 g CO₂e/kg FFB for impact decoupling rate). This finding suggests that increasing access to better quality planting material will be inadequate to reduce either resources or impact decoupling rates. Our finding suggests that increasing access to planting material without adjusting nutrient management practices is not an option either for smallholders or for companies.

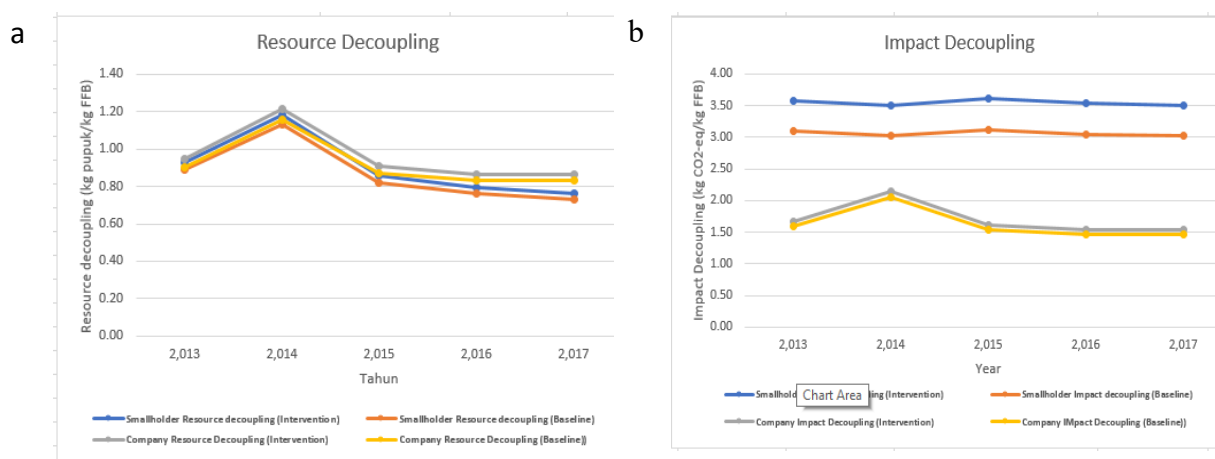


Figure 5. Impact of changes in OER to the resources decoupling rate (a) and impact decoupling rate (b) of FFB production 2013-2017

A combination of the adjustment of fertilizer usage rate and better access to quality planting material was the third scenario we tested to find their impacts on decoupling rates. Using this scenario, the average resource decoupling rate for smallholder will be reduced by 55.80% (from 0.86 to 0.38 kg fertilizer/kg FFB), while the impact decoupling rate reduced by 61.95% (from 3.06 to 1.17 g CO₂e/kg FFB). For companies, the reduction will be 35.63% (0.92 to 0.59 kg fertilizer/kg FFB for resource decoupling rate) and 38.03% (1.62 to 1.00 g

CO₂e/kg FFB for impact decoupling rate). This finding suggests that increasing access to better quality planting material will be inadequate to reduce either resources or the impact decoupling rates. Our finding suggests that increasing access to planting material without adjusting nutrient management practices is not an option either for smallholders or for companies.

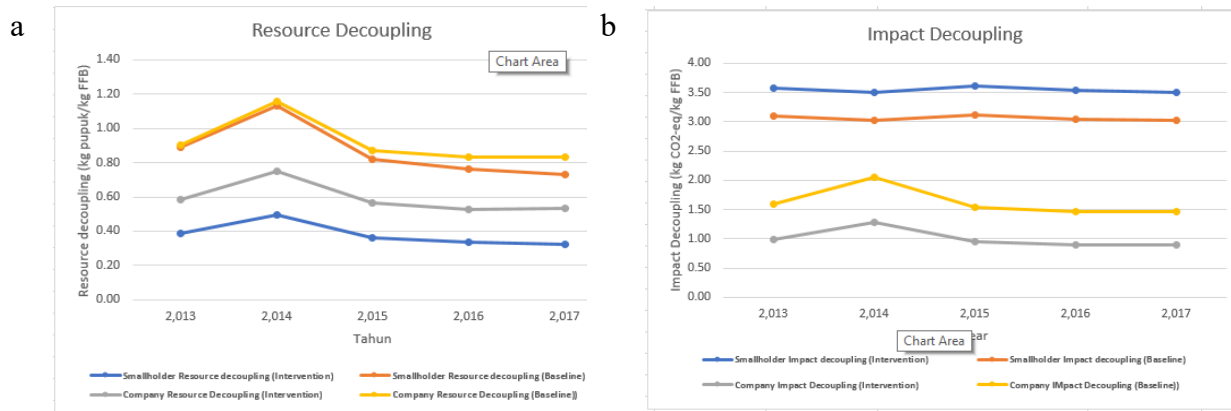


Figure 6. Impact of adjustment of fertilizers rate and OER to resources decoupling rate (a) and impact decoupling rate (b) 2013-2017

Comparison of the influence of the scenario to the changes of decoupling rates is shown in Table 3.

Table 3. Summary of decoupling rates for smallholders and companies based on relevant scenario*

Scenario	Baseline		Scenario 1		Scenario 2		Scenario 3	
	S	C	S	C	S	C	S	C
Resource decoupling rate (kg fertilizer/kg FFB)	0.86	0.92	0.36	0.57	0.90	0.96	0.38	0.59
Impact decoupling rate (g CO ₂ e/kg FFB)	3.06	1.62	1.10	0.96	3.55	1.70	1.17	1.00

*S = smallholder; C = company

Table 3 shows that adjusting the fertilizers rate (Scenario 1) provides the highest impact either to both resources and impact decoupling rates. It means that rationalizing fertilizer rate to the rates implemented by the companies in Sumatera (as a benchmark) will increase resource use efficiency for smallholders as well as reduce the impacts to the environment in the form of GHG emission. In practice, factors influence FFB productivity and GHG emission are complex. Water surplus or deficit 3 years before bunch maturity time (Cock et al., 2016) affects FFB productivity. Soil loam content, percentages of water-filled pores space (WFPS) (Sakata et al., 2015; Volpi et al., 2017) type of N sources in fertilizers (ammonium or nitrate) (Volpi et al., 2017) affect the emission rate. The increased of the resource and

impact decoupling rates in our study were in line to the study conducted by Tao et al. (2018) that adjustment of the fertilizers rate significantly affected the nutrient use efficiency as shown by the increased of the resource decoupling rate in every scenario in which the fertilizer rate been adjusted to the rate of the benchmark.

Further studies required to access the impact of those factors to the resource and impact decoupling rate. However, our study shows that smallholders in Indonesia can afford sustainable practices in FFB production by reducing fertilizers rate – as a consequence, reducing the amount -- to the benchmark (144% reduction for smallholders in Sumatera and 129% reduction for smallholder in Kalimantan) and increasing access to certified planting materials to improve *tenera* ratio (Jelsma et al., 2017) to improve OER and productivity. Technical assistance from government and plantations to promote fertilizers adjustment and to provide access to the certified planting materials are steps required to realize this in practice.

4. Conclusion

Current smallholders' practices in FFB production are less efficient and less friendly to the environment in comparison to the practices implemented by oil palm companies. The smallholders reported used more fertilizers to produce each unit of FFB compared to the companies. The smallholder contribution to GHG emission per unit FFB is higher compared to the benchmark company. Lack of knowledge in nutrient managements and access to good quality planting materials are the two main factors contributing to the lower performances among farmers. The smallholders require assistance to increase their fertilizer use efficiency and reduce their emission. Our simulation to improve the performance by implementing 3 scenarios is able to find the best option to improve the smallholders' performance. Adjustment of nutrient management practices by reducing the dose of fertilizer by the smallholders considered to be the most appropriate scenario to increase FFB production efficiency and to reduce the environmental impacts. We conclude that smallholders are able to produce FFB sustainably by changing their practices in nutrient management and increasing their access to certified planting materials. Further works required to test the robustness and to validate the result of this simulation and to assess contribution of another factors to the decoupling rate.

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