

Trade-offs between ecological impact and economic efficiency of oil palm (*Elaeis guineensis* Jacq.) fresh fruit bunches production in Indonesia

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Abstract. Balancing efficiency and sustainability of fresh fruit bunches (FFB) production remains a critical issue facing by oil palm (*Elaeis guineensis* Jacq.) producing countries like Indonesia. To address those issue, we analyze trade-offs of those 2 variables in plantation managed by smallholders and compare the result to the one of the companies. The trade-offs are estimated by dividing the GHG emission to the partial factor productivity (PFP) of FFB production based on data from previous LCA assessment. Our study revealed that current practices implementing by smallholders are economically less efficient and ecologically unsustainable comparing from the FFB production practices implementing by companies. For smallholders, the trade-offs of ecological impact and economic efficiency reached 0.86 kg CO₂-eq/kg FFB or 2.6 times from the trade-offs of FFB production by companies (0.33 kg CO₂-eq/kg FFB). Several changes in nutrient management such as adjusting the fertilizers rate at smallholders in Sumatera, improving the OER from 0.20 to 0.22 for smallholders and from 0.21 to 0.22 for companies, and applying biochar technology are the most promising practices to minimize the trade-off up to 81%.

1 Introduction

Sustainability and efficiency are two main issues facing by oil palm producers in Indonesia. Although the country is positioned itself in the top level as the crude palm oil producers in the world since 2006, but the country capacity to manage the plantation in efficient and sustainable manners still need to be strengthened.

Oil palm plantation in Indonesia is managing by two categories of producers: smallholders and companies. Proportion of smallholders in 2017 is 41% [1]. The increase of the smallholder's involvement in oil palm production system increases the importance of inclusiveness in the debate around sustainability of oil palm productions.

Limited access of smallholders to knowledge and support system have been negatively affecting their capacity to manage their plantation in efficient and sustainable ways [2].

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However, there are limited study conducted to analyze efficiency and sustainability of fresh fruit bunches productions by smallholders to compare their performance in those two aspect with the ones in company plantation. Life Cycle Assessment (LCA) conducted by several authors [3, 4] is potential to be used as entry point to address this gap.

Prior LCA study [4] indicated that fertilizers uses are the most significant factors contributing to the ecological impacts and economic efficiency of FFB production. To reduce negative impacts of FFB production to the environment, [4] recommend increasing the FFB yield using high yielding oil palm seeds or seedlings, use of organic sources of N fertilizers instead of chemical, applying slurry from palm oil mill effluent (POME) as plant nutrient or applying combination of empty fruit bunches compost and POME as fertilizer. Advance works carried out by [5] to find solution to reduce N₂O and CO₂ emission from fertilizers in oil palm production found out that the use of Nitrification Inhibitor (NI) 3,4-dimethylpyrazol succinate (DMPSA) was able to reduce N₂O emissions by 50%. The finding contributes to our understanding about technological options to reduce the impacts.

Previous studies on ecological impacts of FFB production mainly focused on measuring the impacts to environments [6-8]and rarely analyze relationship between nutrient management practices implementing by smallholders to the ecological impacts. The previous studies were not considering spatiotemporal perspectives in their analysis. As a result, the study was difficult to be used as reference for decision makers at national and local levels to adjust their practices for addressing the challenges.

This study aims to estimate trade-offs between ecological impacts and efficiency of FFB production in Indonesia from 2013-2017 based on the results of LCA studies and used the estimate to develop options to minimize them.

2 Methods

Data for this simulation is based on the Tree Crop Estate Statistic of Indonesia Oil Palm 2013-2015 [9] and Tree Crop Estate Statistic of Indonesia Oil Palm 2015-2017 [10] published by the Indonesian Directorate of Plantation Ministry of Agriculture. Ecological impacts is estimated by multiplying fertilizer rate applied by smallholders and companies to the emission rate for each fertilizers. Result of the calculation is GHG emission in g CO₂-eq. Economic efficiency is measured by calculating Partial Factor Productivity (PFP) that reflect ratio between FFB yield to the total amount of fertilizers applied [11]. Comparison between GHG emission and PFP is the trade-offs. We implemented multi-criteria analysis (MCA) as a method to identify a preferred scenario to minimize the trade-offs. Criteria used to conduct scenario analysis is presented in Table 1.

Table 1. Multi-criteria used to identify trade-offs 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	0.20	0.22	0.22	0.22
Biochar amendment	No	No	Yes	Yes
Biomass Fertilizer Ratio [12]	0	0	0	50:50

3 Results and discussions

3.1 Partial factor productivity of FFB production

Economic efficiency of FFB production is estimated by calculating the partial factor productivity (FPF). FPF of FFB production in plantations managed by smallholders and companies in 5 regions in Indonesia is shown in Fig. 1.

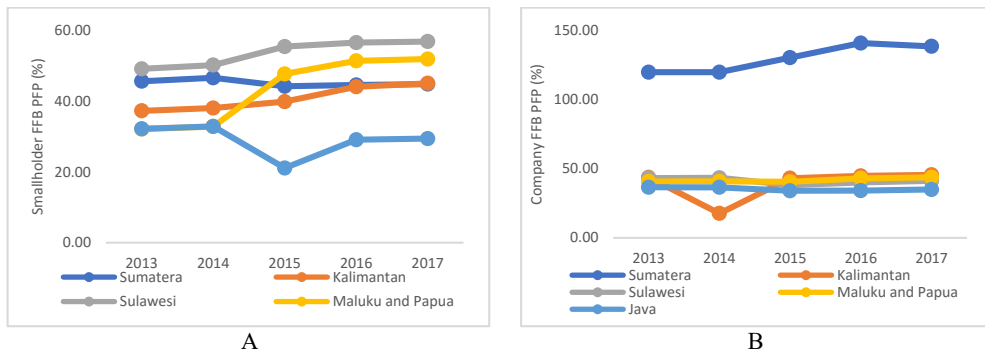


Fig. 1. FPF of FFB production in oil palm plantation managed by smallholder (A) and company (B) in Indonesia from 2013-2017.

For smallholders, the highest FPF was achieved by smallholders in Sulawesi (53.69%), followed by smallholder in Sumatera (45.20%), Maluku/Papua (43.22%), Kalimantan (40.89%) and Java (28.94%). From 2013-2017, the average of smallholders' FPF increased by 16.16% from 39.30% in 2013 to 45.65% in 2017. For companies, the highest FPF was achieved by the ones in Sumatera (130.05%), followed by companies in Maluku/Papua (41.88%), Sulawesi (41.27%), Kalimantan (39.06%), and Java (35.32%). From 2013-2017, the average of companies' FPF increased by 7.01% from 56.92% in 2013 to 60.91%.

Based on the FPF data, it can be concluded that companies in Sumatera is the only FFB producers that have a high FPF. The long history of oil palm plantation development by companies in Sumatera contributes to the high company capacity to manage production and inputs supported by better access to planting materials and fertilizers. High discrepancy of FPF between companies in Sumatera to companies in other region and smallholders in all regions reflected a problem in knowledge transfers and uneven distribution of inputs (planting materials and fertilizers).

3.2 Greenhouse gases emission

Calculation of greenhouse gasses emission from fertilizers applied by smallholders and company plantations in FFB production reflects ecological impacts of the plantation management. Nitrogen, phosphorus, and potassium are the three-main compound in chemical fertilizers contributing to GHG emission. Comparison of the emission in plantation managed by smallholders and companies is shown in **Fig. 2**.

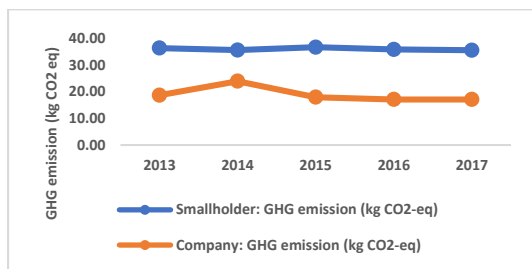


Fig. 2. GHG emission in oil palm plantation managed by smallholders and companies in Indonesia from 2013-2017.

Ecological impact of FFB production in oil palm plantation managed by smallholders is 189.95% comparing from the emission of FFB production in plantation managed by companies. High fertilizers rate applied by smallholders to meet plan nutrient requirements increased the level of the emission. GHG emission in 2017 in smallholder’s plantation is decreasing by 2.20% comparing from the emission in 2013. For company, plantation the decrease is 8.43% in 2017 comparing from the level of emission in 2013. These findings highlighted the fact that the ecological impact of FFB production from nutrient management is higher than the ones in company plantation. The GHG emission in FFB production tend to decrease with the decrement rate at companies higher than the rate in plantation managed by smallholders. Lack of knowledge, awareness, and access to technologies and input to reduce GHG emission at smallholders’ level are the main reason the GHG emission at the latter higher.

3.3 Trade-offs

Trade-offs of ecological impacts (GHG emission) and economic efficiency(PFP) between smallholders and company plantations are shown in **Fig. 3**.

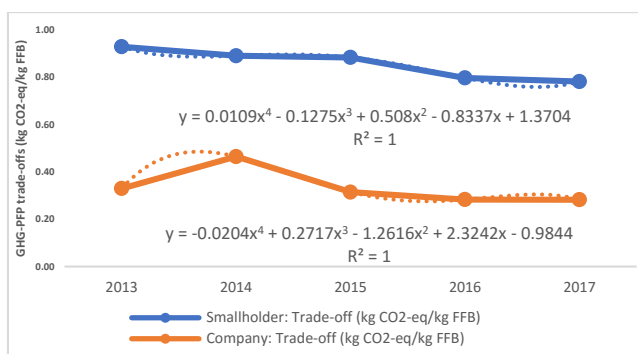


Fig. 3. GHG emission and PFP trade-offs in oil palm plantation managed by smallholders and companies in Indonesia from 2013-2017.

In general, GHG to PFP trade-offs in oil palm plantation managed by smallholders is higher than the ones in plantation managed by companies. Both trade-offs tend to decrease. In 2017, the trade-offs for smallholders decreased from 0.93 in 2013 to 0.78 in 2017 or decreasing by 16.13%. For companies, the trade-off decreased from 0.33 in 2013 to 0.28 in 2017 or decreasing by 15.15%. FFB production at smallholders was economically

inefficient (lower PFP) and ecologically unsustainable (higher GHG emission). To address these challenges, we develop scenario based on some criteria to reduce the trade-offs. Results of scenario analysis based on the criteria as presented in Table 1. are presenting in Fig. 4.

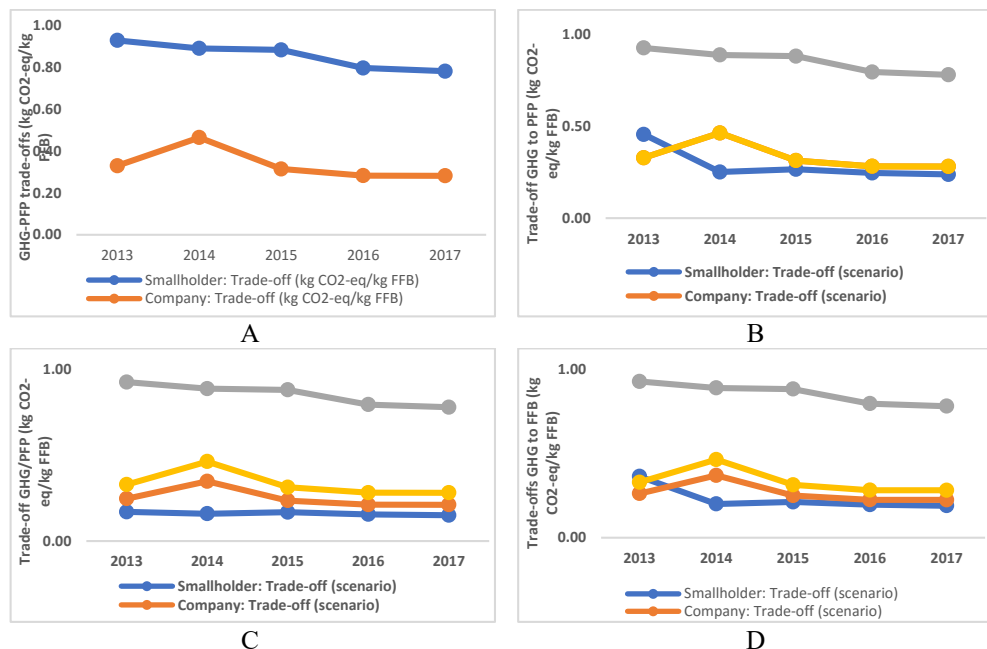


Fig. 4. Trade-offs GHG emission – PFP for FFB production in plantation managed by smallholders and companies based on Scenario 1 (B), Scenario 2 (C), and Scenario 3 (D) comparing from the baseline (A).

Implementation of Scenario 1 (Fig. 4.B) reduced the trade-offs of FFB production by 66% from 0.86 kg CO₂-eq/kg FFB (baseline) to 0.29 kg CO₂-eq/kg FFB (scenario 1). Results of this simulation showed reduction of fertilizers rates applied by smallholders in Sumatera following by increasing the Oil Extraction Rate (OER) to 0.22 will decrease the trade-offs. This strategy can be effective with the assumption that local governments able to facilitate knowledge exchanges from companies to the smallholders in Sumatera and smallholders access to good quality planting materials can be improved.

Implementation of Scenario 2 (Fig. 4.C) reduced the trade-off by 81% from 0.86 kg CO₂-eq/kg FFB (baseline) to 0.16 kg CO₂-eq/kg FFB (scenario 2) for smallholders. Implementation of Scenario 2 by company plantation is potentially reduce the trade-off by 25% from 0.33 kg CO₂-eq/kg FFB (baseline) to 0.25 kg CO₂-eq/kg FFB (Scenario 2). The decrease of the trade-offs in Scenario 2 revealed that the use of biochar as soil amendment will positively contribute to the FFB production and reduction of GHG emission. This strategy can be effective if government able to introduce biochar technology for smallholders and companies.

Implementation of Scenario 3 (Fig. 4.D) reduced the trade-off by 73% from 0.86 kg CO₂-eq/kg FFB (baseline) to 0.23 kg CO₂-eq/kg FFB (scenario 2) for smallholders. Implementation of Scenario 3 by company plantation is potentially reduce the trade-off by 20% from 0.33 kg CO₂-eq/kg FFB (baseline) to 0.27 kg CO₂-eq/kg FFB (Scenario 2). The decrease of the trade-offs in Scenario 3 revealed that the use of mix between biomass and chemical fertilizers is a potential strategy to reduce ecological impacts while maintaining

economic efficiency. The increase of biomass-fertilizer ratio (BFR) will reduce production costs, improving soil condition, and reduce GHG emission as the amount of chemical fertilizers amended to the soil is decreased. To be effective, government must facilitate transfer of technology to increase smallholder's capacity to produce biomass to substitute the chemical fertilizers.

Combination of adjustment of fertilizers rate by smallholders in Sumatera, increasing of OER from 0.20 to 0.22 for smallholders and from 0.21 to 0.22 for company, and implementation of biochar technology are the most promising strategy to minimize the tradeoffs between ecological impact and economic efficiency of FFB productions in Indonesia.

4 Conclusion

Current FFB production practices implementing by smallholders is economically less efficient and ecologically unsustainable comparing from the FFB production practices implementing by companies. For smallholders, trade-offs ecological impact and economic efficiency 0.86 kg CO₂-eq/kg FFB or 2.6 times of the trade-offs of FFB production by companies (0.33 kg CO₂-eq/kg FFB). Higher fertilizers rate applied by the smallholders in Sumatera, limited knowledge about best management practices in FFP production, and lack of access to technologies are three main factors contributing to the trade-offs.

Implementation of Scenario 1 (adjustment of fertilizer rate used by smallholders in Sumatera + increasing of OER to 0.22), Scenario 2 (Scenario 1 + biochar amendment), and Scenario 3 (Scenario 2 + improvement of biomass to fertilizer ratio) potentially reduced the trade-offs by 66% (Scenario 1); 81%(Scenario 2), and 73% (Scenario 3) comparing from the baseline. This study revealed that combination of adjustment of fertilizers rate by smallholders in Sumatera, increasing of OER from 0.20 to 0.22 for smallholders and from 0.21 to 0.22 for company, and implementation of biochar technology are the most promising strategy to minimize the tradeoffs between ecological impact and economic efficiency of FFB productions in Indonesia.

Acknowledgements

We acknowledge the financial support from Universitas Indonesia through PITTA Grant Number: 2582/UN2.R3.1/HKP.05.00/2018 to support data collecting, analysis, and dissemination of the results of this study.

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