Carbon emission reduction scenario in palm oil production

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Abstract. The palm oil industry has an excellent opportunity to contribute to achieving the emission reduction targets set in the Nationally Determined Contribution (NDC). This research offers a Greenhouse Gas (GHG) emission mitigation scenario model that can be used for oil palm companies. The study was conducted from November 2023 to July 2024 in oil palm plantations in Siak Regency, Riau Province. Carbon emissions were calculated using the RSPO GHG Calculator, focusing on operational activities. The carbon reduction scenario is developed based on several factors, such as carbon emission structure, cost of reduction initiative, and its effect on productivity. The total of GHG emissions generated from palm oil production was recorded to be 111,780 tCO_2-eq/year, in which the biggest source of emissions comes from peatland cultivation, followed by Palm Oil Mill Effluent (POME), agronomic activities such as fertiliser application, and fossil fuel combustion. The establishment of Methane Capture plays a key role in the carbon reduction scenario. Mitigation scenario by establishing a methane capture (MC), combined with peatland rewetting, and application of B30 is expected to significantly reduce GHG emissions up to 37.12%, while still maintaining crop productivity.

1 Introduction

The palm oil industry is an agricultural commodity that plays a strategic role in Indonesia's economic development, with an area reaching 16.83 million ha [1]. Besides producing processed products for food and household use, palm oil is also processed into renewable energy, such as biodiesel. Indonesia applied for B35, a fuel that blends 35% of palm oil, from 2023 to 2024, and is planning to launch B40 by 2025 [2]. This program enhances domestic palm oil consumption by using palm oil for biodiesel blending in Indonesia and contributes to reducing carbon emissions as it reduces the use of fossil fuel.

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In Indonesia, the agricultural sector is targeted to contribute to reducing Greenhouse Gas (GHG) emissions by 0.3% of the 31.89% NDC (Nationally Determined Contribution) target [3] **by 2030**. As part of the agricultural sector, the palm oil industry can contribute by applying green technology in the production process, increased energy efficiency, and good waste management [4]. Methane Capture (MC) is an example of green technology that can be applied to capture methane emissions from Palm Oil Mill Effluent (POME) [5] and convert them into biogas energy.

To develop a comprehensive low-carbon palm oil production strategy while maintaining high productivity, it is essential to understand properly the sources of emissions and the methods for reducing carbon emissions in the palm oil industry. Some emission sources from palm oil production include land clearing, the oil palm cultivation process, palm oil extraction that produces POME as waste, peat decomposition, transportation, and others [5, 6, 7]. Moreover, the amount of carbon emissions is influenced by several factors, including the size of the operation [6], the type of land [5], and the calculation technique [7].

This research is focused on identifying the sources and calculating the carbon emissions in the palm oil industry. In addition, this study also formulates a catalogue of carbon emission reduction methods based on previous studies used to develop emission reduction scenarios.

2 Methods

This research was conducted from November 2023 to July 2024 in an oil palm plantation in Siak Regency, Riau Province. Activity data collected from the palm oil production process is summarised Table 1.

Table 1. Activity data of the palm oil production process in the study area as of 2022. The activity data was summarized following [5, 8]

Activities	Sources Emission/Sequestration
Plantation	a. Peat land b. Mineral c. HCV Area d. Fossil fuels e. Fertiliser use f. Herbicides g. Pesticides
Mill	a. Fossil fuels b. Chemicals c. Electricity used d. Palm Oil Mill Effluent (POME)

The GHG emissions were calculated using a basic formula as described in the IPCC report [9]:

$$\text{GHG Emissions} = \text{Emission Factor (EF)} \times \text{Activity Data} \tag{1}$$

This calculation prioritises Emission Factors (EF) according to EF Tier 2. When EF Tier 2 is unavailable, EF Tier 1 will be applied. The calculation platform used in this study was the PalmGHG calculator from RSPO, and the discussion is focused on operational activities. The assumptions and default values applied in the PalmGHG calculator are described in the RSPO GHG Assessment Procedure for New Plantings, updated in December 2014 [10]. The mitigation option was designed as a carbon emission reduction catalogue. Using the data provided in the catalogue and considering several factors, such as carbon emission structure, the cost of the reduction initiative, and the effect on productivity, three carbon reduction scenarios were developed.

3 Results and discussion

3.1 Greenhouse Gas (GHG) Emissions

The oil palm plantation of this study operates on an area of about 6,408.8 ha, with a mineral area of around 4,183 ha, a peatland area of around 2,178 ha, and an HCV area of around 45.8 ha. The initial planting was started in 1993, and the plantation was equipped with a palm oil mill (processing capacity is 45 tons FFB (Fresh Fruit Bunch)/hour. In 2022, the total FFB (Fresh Fruit Bunch) processed was around 260 thousand tons/year, coming from nucleus, plasma, and independent smallholders. Details of production activity in the oil palm plantation are presented in Table 2.

Table 2. Palm Oil Production Activities as of 2022

	Activity	Detail	Total	Unit	Emission Factor*
Plantation		FFB Nucleus	130,998	ton/year	-
		FFB Plasma	45,949	ton/year	-
		FFB smallholders	83,711	ton/year	-
		Total FFB processed	260,658	ton/year	-
	Single Fertilizer Usage	Borate/boron	53,900	kg	B_2O_3 : 1.97
		CU EDTA	8,925	kg	CuO : 0.815
		Dolomite	109,470	kg	MgO : 1.18 CaO : 0.13
		Kieserite	38,440	kg	Mg : 1.18
		Muriate Of Potash (MOP)	8,700	kg	K_2O : 0.58 CaO : 0.13
		Agricultural Lime (KAPTAN)	330,550	kg	$CaCO_3$: 0.43
		Triple Super Phosphate (TSP)	2,600	kg	P_2O_5 : 1.01 CaO : 0.13
		Zn EDTA	7,325	kg	N : 5.88
		Urea	7,000	kg	1.92
	Compound Fertilizer Usage	NPK 13.6.26	1,599,710	kg	N : 5.88 P_2O_5 : 1.01 K : 0.80
		NPK 15.6.24	2,768,950	kg	N : 5.88 P_2O_5 : 1.01 K : 0.80
	Herbicide Usage	Ally	274	kg	10.97
		Emulan	1,235	kg	10.97
		Garlon	17	kg	10.97
		Gempur	6,812	kg	10.97
		Gramoxon	2,117	kg	10.97
		Starane	10	kg	10.97
	Pesticide Usage	Matador	734	kg	10.97
	Fossil Fuel Usage	Gasoline	27,758	1	CH_4 : 0.007 NO_3 : 0.006 CO_2 : 2.74

	Activity	Detail	Total	Unit	Emission Factor*
		Lubricants	16,141	l	CH_4 : 0.0001 N_2O : 0.00002
		Diesel	295,878	l	CO_2 : 0.70 CH_4 : 0.16 N_2O : 0.05
Mill		Crude Palm Oil Shell Kernel Fibre	50,957 10,740 13,396 29,773	ton/year ton/year ton/year ton/year	- - - -
	Chemical Usage	Sodium Hydroxide Alum	200 94,850	kg kg	1.1 1.7
	Fossil Fuel Usage	Diesel	285,317	l	CO_2 : 0.70 CH_4 : 0.16 N_2O : 0.05
	Waste	POME	135,420	m^3	0.51

*) emission factors from [9, 11, 12, 13], the emission factor for peatland is 41.45 tCO_2-eq

Total GHG emissions from all operational activities in 2022 amounted to 111,780 tCO_2eq/year (see Table 3). The most significant emission contributor was from the estate sector, accounting for 86,439 tCO_2eq. The significant source of emissions from the estate sector is peatland, which generates 81,261 tCO_2eq. From agronomic activities, the amount of CO_2 emission from used fertilizer is 3,712 tCO_2eq. The palm oil mill generated 25,341 tCO_2eq, with the most significant contributor coming from POME (24,628 tCO_2eq), which released methane during anaerobic decomposition.

Table 3. Greenhouse Gas (GHG) Emissions generated from data activity as of 2022

Sources of Emission	Amount of Emission (tCO_2eq/year)
Plantation	*86,439*
Fertiliser	3,712
Fuel	1,466
Peat	81,261
Mill	*25,341*
POME	24,628
Fuel	713
Total of Emission	111,780

3.2 GHG Emission Reduction Catalogue

Considering the emission levels and structure presented in Table 3, it is crucial to develop methods to mitigate these emissions and promote low-carbon palm oil production. Many studies have reported methods to reduce emissions from agricultural activities, some of which are summarised in Table 4. This catalogue will be useful as a basis for developing the GHG reduction scenario for the palm oil industry.

Table 4. GHG Emission Reduction Catalogue

Countermeasure Area	Alternative Reduction	Activity
Peat	Peat Rewetting	Peatland rewetting in oil palm plantations reduced total soil respiration by 20% [14]
Agronomic	Land Application	Sludge application to replace chemical fertiliser could reduce 65.5% of CO_2 emissions [15]
	Integrated Pest Management	The application of integrated pest management can be enforced to reduce emissions from pesticide applications [16].
Fossil Fuel	Fuel reduction	Application of Biosolar (B30) is able to reduce up to 28.19% CO_2 compared to Diesel [17]
POME	Methane capture	Carbon reduction by Methane Capture (MC) can reduce 0.65 tCO_2 e/t CPO compared to non-Methane Capture (MC) [5]

3.3 GHG Emission Reduction Scenario

Following the problems faced by the palm oil industry in the context of GHG emission reduction, where an increasing amount of GHG emissions follows production growth, it is crucial to develop appropriate mitigation scenarios that consider productivity, carbon reduction objectives, and emission reduction costs. Based on the data provided in the catalogue (see Table 4), the GHG emissions reduction scenario model was developed, and the result is presented in Table 5.

Several factors need to be considered in developing GHG reduction scenarios to ensure their effectiveness and sustaining productivity. Some of them are described below:

1. The availability of methods proven effective in reducing carbon emissions means that the selected methods must be demonstrated to effectively reduce GHG emissions and be accessible to palm oil companies.
2. The economic feasibility of the available methods. Some methods, such as carbon removal technology, effectively reduce emissions, but they might not be economically viable for some companies.
3. The impact of the applied methods on crop productivity. For instance, chemical fertilizer is vital to agronomy activity. Hence, reducing the quantity of fertilizer applied would affect the yield.
4. Considering the scale of the company, the investment cost must be assessed to determine its affordability.

Considering these factors, this study offers three emission reduction scenarios while still maintaining oil palm productivity. It is important to note that each scenario affects oil palm productivity since it involves fertilizer modification. Since POME is a significant contributor to total GHG emissions and technology to capture methane emissions is widely available, Methane Capture (MC) is considered as an option in all scenarios.

Emission reduction practices in each scenario where MC is always provided as an alternative option are described below:

1. Scenario 1: The plantation operates normally (Business as Usual /BAU).

2. Scenario 2: The GHG reduction program is developed and applied while maintaining productivity, with significant investment. The efforts include peatland rewetting, Methane Capture (MC), and the utilization of B30 to reduce fossil fuel consumption. However, Methane Capture (MC) requires a significant investment and differs depending on the expected product. Building Methane Capture (MC) to process methane into gas for boiler fuel requires an investment of around IDR 30-35 billion, while it will need a higher investment to process methane into electricity or bio-CNG.
3. Scenario 3: In this scenario, several emission reductions are conducted by the reduction of chemical fertilizer application in agronomy activities, utilisation of Methane Capture (MC), and peat rewetting.

GHG Calculations for these three scenarios are presented in Table 5. Methane capture plays the most significant role in all GHG emission reduction scenarios by contributing the main reduction portion. This is particularly true since the application of methane capture is able to remove emissions amounting to 24,628 tCO_2 -eq/year or about 22.03% of total carbon emission (CO_2-eq) in a business-as-usual scenario. Scenario 1 with methane capture is expected to result in 22.03% emission reduction. In comparison, the highest reduction of 38.78% is achieved if the company applies Scenario 3 with the establishment of MC as the main carbon reduction contributor, in combination with peat rewetting and chemical fertilizer reduction. This scenario involves a huge amount of investment for MC and peat rewetting. Unfortunately, the reduction of chemical fertilizers may have an impact on crop productivity due to fewer available nutrients. If we compare Scenario 2 and Scenario 3, Scenario 2 produces reductions of around 37.12%, which is slightly lower compared to Scenario 3, but has less impact on the crop productivity since there was no chemical fertilizer reduction.

Table 5. Projected GHG emissions by the Reduction Scenario

Sources of Emission	Emission as of 2022	Scenario 1		Scenario 2		Scenario 3	
		With MC	Without MC	With MC	Without MC	With MC	Without MC
	.... (t CO_2eq)….						
Agronomy	3,712	3,712	3,712	3,712	3,712	1,856*	1,856*
Peat	81,261	81,261	81,261	65,008.80**	65,008.80**	65,008.80**	65,008.8**
POME	24,628	0,00	24,628	0,00	24,628	0,00	24,628.0
Fossil fuel	2,179	2,179	2,179	1,564.74***	1,564.74***	1,564.74***	1,564.74***
Total emission	111,780	87,152	111,780	70,285.54	94,913.54	68,429.54	93,057.54
Reduction (%)	0.00	22.03	0.00	37.12	15.09	38.78	16.75

* : reduction by reducing chemical fertilizer dosage by 50%
** : reduction by peat rewetting
*** : reduction by B30 usage

4 Conclusion

The most significant sources of GHG emissions from the palm oil industry are peatland and POME generated from the palm oil mill. Methane Capture (MC) is the key to achieving a significant carbon reduction option in the palm oil industry. A mitigation scenario establishing Methane Capture (MC), peatland rewetting, and B30 as fuel can significantly reduce GHG emissions by up to 37.12% while maintaining crop productivity. The scenario can be a promising option for palm oil companies to be part of the global carbon mitigation agenda.

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