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CO_2 Emissions as the Effect of Land Use and Land-Use Change into Palm Oil Plantation

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Abstract

Identification of land use and land-use change is needed to see specific land change in the calculation of emissions caused by land-use change. The purpose of this study is to calculate the CO_2 emissions due to land use and land-use change for palm oil plantation. The method used is Quantum GIS to identify land-use change and the IPCC 2006 method for calculating CO_2 emissions. The results show that the conversion of land for palm oil plantations is still found in areas that have a high value of carbon stocks. Conversion of land into palm oil plantation results in a total value of emissions by 8.95 Mt CO_2e/year, a total sequestration of 1.78 Mt CO_2e/year, and net emissions by 7.17 Mt CO_2e/year.

Keywords: Land use; land use change; carbon stock; CO_2 emissions; carbon sequestration; palm oil

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1. Introduction

The world community's effort to prevent the increase of greenhouse gas emissions (GHG) is very welcomed by the Indonesian government. Indonesia is committed to reduce its emissions by 26% by 2020 with the efforts of unilateral and up to 41% with international supports. The follow-up toward this commitment is the publication of Presidential Decree Number 61 of the National Action Plan to Reduce Greenhouse Gas Emissions (RAN-GRK) and Presidential Decree Number 71 on the National Inventory of Greenhouse Gas Emissions. Other countries also provide environmental standards for palm oil to be changed into biodiesel. Biodiesel aims to overcome the scarcity of oil-based fossil energy and to reduce greenhouse gas emissions. Thus, minimum standards are required for GHG reduction, and the standard is the one by the European Union and the United States, the RSPO and ISPO.

Reference [4] has set the standard for sustainable bioenergy namely GHG emission reduction from the use of bioenergy of 35% to 50% from January 1, 2017. It also mentions that crude palm oil for biodiesel produced from peatlands or wetlands will not be accepted by the European market. Meanwhile, the United States Environmental Protection Agency [18] has issued a document on notice of data availability (NODA), namely the assessment of the amount of emissions from crude palm oil (CPO) as raw material for biodiesel based on LCA. US-EPA standard of 20% reduction in emissions starts in 2022. Calculation of US-EPA shows that for Indonesian palm oil by 17% and Malaysia palm oil by 11% has not met the requirements of raw material for biodiesel.

The standard of the Roundtable on Sustainable Palm Oil (RSPO) requires members to conduct an inventory of the amount and sources of emissions and provide an explanation of the ways to reduce emissions to meet market demand. Indonesian Sustainable Palm Oil (ISPO) standard sets guidelines for land clearing, seeding, and crop management to waste management as outlined in the Regulation of Agriculture Minister Number 19/2011.

Indonesia is one of the countries in Southeast Asia that produce palm oil along with Malaysia and Papua New Guinea. Palm oil production in Indonesia grows 7% annually for more than two decades, from an area of 3.5 million hectares in 1990 to approximately 13.1 million hectares in 2010 [5]. Palm oil is suspected as the main cause of deforestation in Indonesia [4] which contributes to carbon emissions by approximately 7-14% of the total global emissions [8]. Therefore, an accurate estimate of the potential emissions caused by land-use change for the purposes of expansion of palm oil plantation is essential, as to ensure the pattern of expansion of palm oil plantations with the number of carbon emissions resulted.

Estimates of palm oil expansion patterns and calculation on estimation of carbon emissions requires historical spatial map of land associated with the change of various types of land cover, including palm oil in an area [7]. Identification on the change of approximately 800,000 ha of peatlands into oil palm plantations in 2000 was done using moderate resolution satellite imagery [11]. To analyze land cover change from 1990 to 2010 and estimate changes in land use in 2020, high-resolution satellite imagery has been used [2]. From research conducted, it is known that the estimated carbon emissions generated during the process of expansion contributes 18-22% of carbon emissions produced in Indonesia in 2020. Several other studies have also noted that deforestation for the purposes of expanding palm oil in plantations Indonesia contribute to carbon emissions

[7, 13, 3], although to date there has been no specific research conducted to quantify changes in land use for palm oil plantations and especially biodiesel.

Other studies also state that forest fires bring bad impact such as carbon emissions released into the air. Combustion products in the form of emission are one of the problems associated with global warming. Reference [16] Argues that the biggest emissions caused by fires are CO_2 and water vapor that amount to 80-90% of emissions. Fire accelerates the speed of the return of CO_2 to the atmosphere. The addition of CO_2 into the air is due to forest clearing, forest fires, and forest conversion to agriculture. Indonesia's greenhouse gas emissions is estimated at 3,000 Mt or 3 Giga tonnes (Gt) of CO_2-e per year, about 2000 Mt of total emissions come from peatlands. Current data on CO_2 emissions from decomposition of drained peat amounts to 632 metric ton / year (between 355 and 874 metric ton/year). Reference [9] states that these emissions will continue to increase if changes are not made in land management practices and peatland development plans. This study aims to calculate the CO_2 emissions from changes in land cover converted into palm oil.

2. Research method

This study consists of four stages, namely: 1) Identification on the type of land use in general in 2009 and in 2011, 2) identification on the conversion of land for palm oil, 3) the calculation of carbon stock changes due to land conversion for palm oil plantations, and 4) the calculation of CO_2 emission. Stages of research are shown in Figure 1.

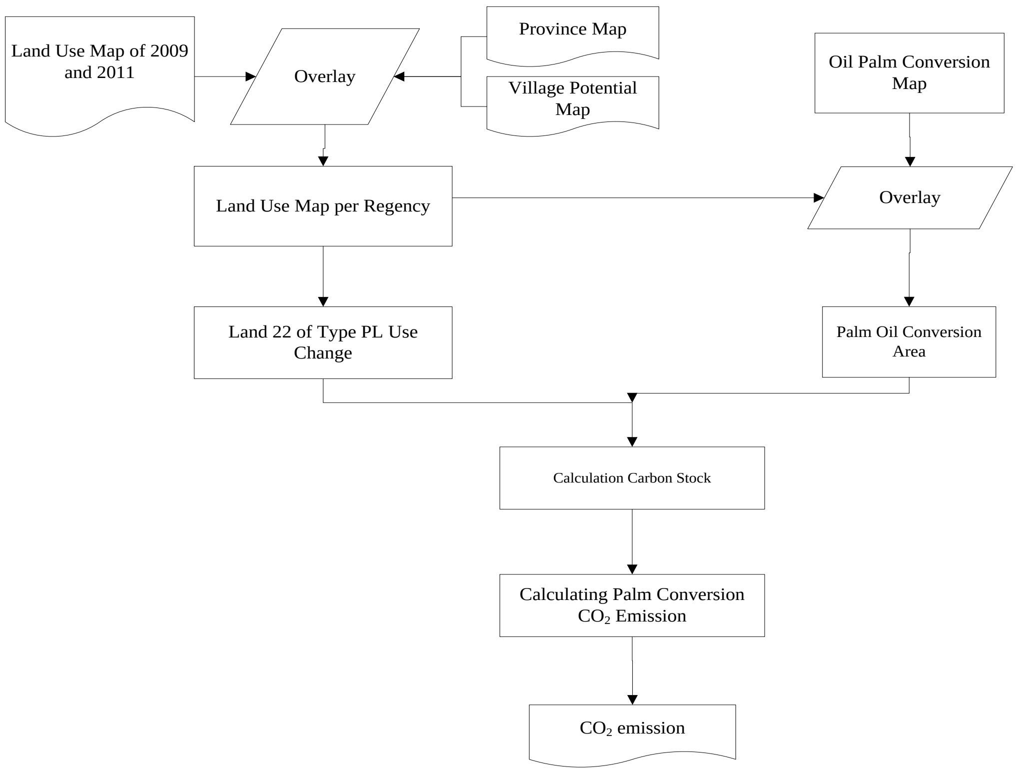

Figure 1: Stages of research.

Identification of land use is carried out through a spatial analysis employing a base map of Combined Map of Riau Province and Village Potential Map at the Regency level and is overlaid each with a map of 2009 and 2011 Land Use Map. The 2009 Map is chosen based on the Act No. 32 of 2009 and the 2011 Map is chosen based on the enactment of the Regulation of Agriculture Minister No. 19/Permentan/ OT.140/3/2011 on Guidelines for Indonesian Sustainable Palm Oil (ISPO). As for the conversion of land into palm oil plantations, Palm Oil Plantation Map of the Province of Riau is employed.

Emissions calculations for land-based sector are obtained from the calculation of carbon stock changes. The value of carbon stocks of palm oil based on several previous studies is, on the average, 49.36 $tCha^{-1}$[6] amounted to 30.96 Mg ha; [15] by 68.84 $tCha^{-1}$; [14] by 60 $tCha^{-1}$; [17] by 47 $tCha^{-1}$; ([19] by 40 $tCha^{-1}$). As for the other use, the default rate content of carbon stocks and historical emissions is used [1]. Calculation of carbon stock uses the International Panel for Climate Change [10]. Carbon stock is calculated using the following equation:

$$\begin{aligned}\Delta C_t = {} & A.C_{Br} + A.C_{Hp} + A.\Delta C_{Hs} + A.C_{Hmp} + A.C_{Hms} + A.C_{Hrp} + A.C_{Br} + A.C_{Hrs} + A.C_{Ht} + A.C_{Plb} + A.C_{Pk} \\ & + A.C_{Pm} + A.C_{Pt} + A.C_{Pc} + A.C_{Rw} + A.C_{Sw} + A.C_{B} + A.C_{S} + A.C_{Tm} + A.C_{T} + A.C_{Tr} + A.C_{A}\end{aligned} \quad (1)$$

Calculation of changes in carbon due to conversion of land use to palm oil plantations uses the “Stock difference” method. The carbon stock change is the difference between carbon stocks at time 1 and time 2, calculated by the following equation [10]:

$$\Delta C_{konversi} = \frac{\left\{(Ct_2 - C_{po_{t_2}}) - (Ct_1 - C_{po_{t_1}})\right\}}{(t_2 - t_1)} \quad (2)$$

In which:

$C_{konversi}$: Carbon stock change in the conversion into palm oil plantation

C_{t1} : Total carbon stock in year 1

C_{t2} : Total carbon stock in year 2

C_{pot1} : Total carbon stock of palm oil plantation in year 1

C_{pot2} : Total carbon stock of palm oil plantation in year 2

The change of carbon stock into CO2 emissions is obtained by multiplying the comparison of the weight of CO_2 molecule and C molecule.

$$\text{Emisson } CO_2 = 0.367 \text{ x } \Delta C \quad (3)$$

3. Result and discussions

3.1 Identifying land use and land-use conversion into palm oil plantations

Changes in land cover types and land use for the conversion of palm oil plantations in 2009 and 2011 are shown in Table 1. The total area of palm oil plantations in Riau in 2009 amounted to 1498932 ha and in 2011 covered an area of 1680759 ha or there has been an addition of 181827 ha.

Table 1: Land-use conversion into palm oil plantation in 2009 and 2011.

Land cover types		2009 (ha)			% KS	2011 (ha)			% KS	Δ LC KS
		PL	KS	Total		PL	KS	Total		
Thicket swamp	Br	713 863	140 872	854 735	9.38	815 478	166 425	981 903	9.93	25 553
Primary dryland forest	Hp	165 788	184	165 972	0.01	164 101	184	164 285	0.01	0
Secondary dryland forest	Hs	501 271	8 892	510 163	0.59	482 757	10 607	493 364	0.63	1 715
Primary mangrove forests	Hmp	4 952	454	5 406	0.03	4 706	454	5 160	0.03	0
Secondary mangrove forests	Hms	153 255	7 791	161 046	0.52	152 478	7 812	160 290	0.47	21
Primary swamp forest	Hrp	321 187	8 019	329 206	0.53	190 844	8 019	198 863	0.48	0
Secondary swamp forest	Hrs	1 177 531	72 585	1 250 116	4.83	1 115 896	103 557	1 219 453	6.18	30 972
Plantation forest	Ht	382 300	18 030	400 330	1.20	409 772	24 593	434 365	1.47	6 563
Airport / harbor	Plb	868	0	868	0	868	0	868	0	0
Plantation	Pk	1 526 511	870 796	2 397 307	57.99	1 386 495	966 886	2 353 381	57.68	96 090
Settlement	Pm	108 402	0	108 402	0	108 402	0	108 402	0	0
Mining	Tb	31 741	4 085	35 826	0.27	30 178	4 085	34 263	0.24	0
Dryland agriculture	Pt	339 432	63 791	403 223	4.25	319 726	63 791	383 517	3.81	0
Mixed dryland agriculture	Pc	674 593	112 758	787 351	7.51	698 322	126 535	824 857	7.55	13 777
Swamp	R	27 261	419	27 680	0.03	27 304	419	27 723		0

	w								0.02	
Field	S	213 697	26 458	240 155	1.76	213 697	26 458	240 155		0
	w								1.58	
Shrubs	B	683 881	83 880	767 761	5.59	681 200	88 389	765 080		4 509
									5.27	
Savana	S	578	0	578	0	578	0	578		0
									0	
Fishpond	T	2 327	554	2 881	0.04	2 327	554	2 881		0
	m								0.03	
Clearing	T	368 754	73 818	442 572	4.92	418 364	76 445	492 182		2 627
									4.56	
Transmigration	Tr	3 064	5 546	8 610	0.37	3 064	5 546	8 610		0
									0.33	
A body of water	A	71 985	0	71 985	0	71 993	0	71 993		
									0	
Total		7470 614	1 498 932	8 972	100	7 298	1 680	8 972		181 827
				173		550	759	173	100	

Based on the results in Table 1 on the area of oil palm plantations in 2009, the largest area is to be found in land cover type of plantations of 57.99%, followed by thicket swamp of 9.38%, mixed dryland agriculture of 7.51%, shrubs of 5.59%, clearing of 4.92%, secondary swamp forest of 4.83%, and dryland agriculture of 4.25%. Whereas in 2011, the largest area of oil palm plantations are in areas with land cover type of plantations of 57.68%, then thicket swamp of 9.93%, mixed dryland agriculture of 7.55%, secondary swamp forest of 6.18%, shrubs of 5.27%, clearing of 4:56%, and dry land agriculture of 3.81%. Table 1 also shows that in 2009 palm is also planted on primary dryland forest (Hp) covering 184 ha or 0.01%. However, in 2011, the addition of palm oil plantations on primary dryland forest is not found anymore.

The addition of palm plantation area in 2011 equals to 181,827 ha. The addition comes from the thicket swamp cover type by 25,553 ha, mangrove forests by 21 ha, secondary swamp forest by 30,972 ha plantations of 6563 hectares, plantations by 96,090 ha, mixed dryland agriculture by 13,777 ha, and clearng by 2,627 ha. Such changes are shown in Figure 2.

Figure 2 shows that the type of land used for the cultivation of palm oil is plantations. Identification results show that palm oil trees are also grown on thicket swamp, secondary swamp forest, dryland agriculture, mixed dryland agriculture mixture, shrubs, and clering. Other areas are relatively smaller, except for savanna, on which there are no visible palm oil plantations.

3.2 Comparison of carbon stock of land use and conversion of palm oil

Calculation on carbon stock changes for palm oil conversion is obtained by comparing the value of carbon stock in initial land area and palm oil plantations. Changes in the value of the carbon stock of land cover and of palm oil plantations in 2009 are shown in Table 2 and in 2011 are shown in Table 3.

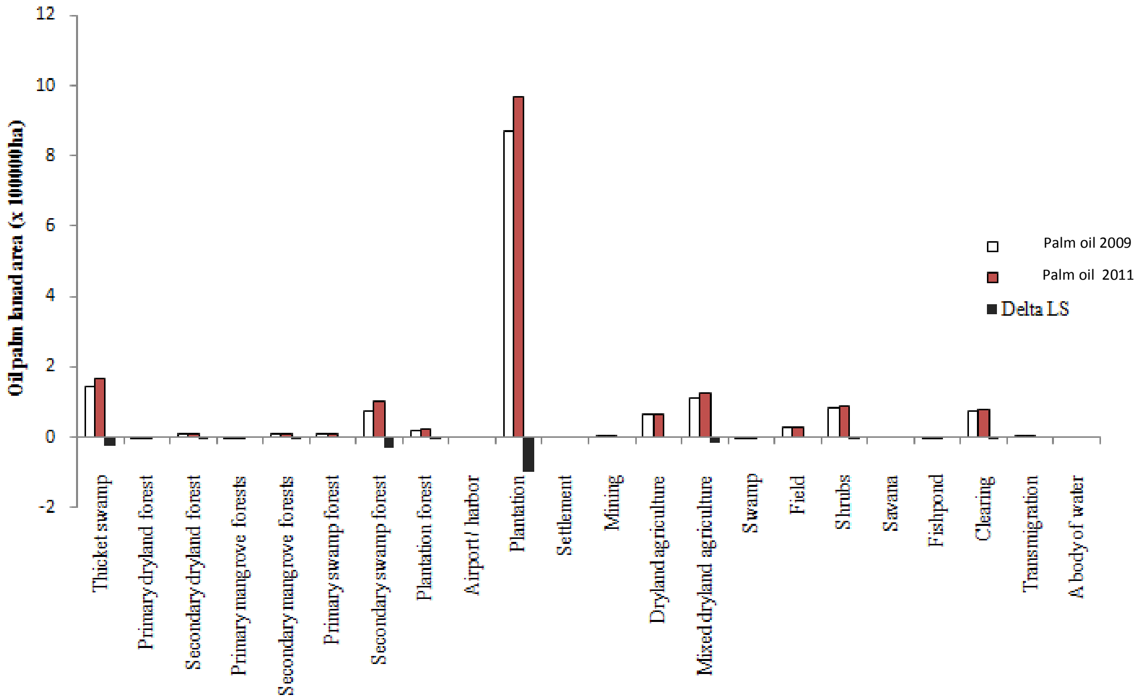

Figure 2: Palm Oil Plantation Area in 2009 and 2011.

The results in Table 2 indicate that the total carbon stocks for land cover types are 82.45 million tons/ha/year, while for palm oil plantation are 73.98 million tons C/ha/year. Due to the conversion of land into palm plantations oil, carbon stock changes in the value of 8.46 million tons C/ha/year. The total value of changes obtained is positive which indicates that the release of carbon or emissions occurs. From the data, there are also areas, due to conversion into palm oil, result in carbon sequestration, referring to changes in carbon stocks to be negative as in the types of land of thicket swamp, dryland agriculture, mixed dryland agriculture, fields, shrubs, fishponds, and clearing. Changes in land cover marked in positive value mean that those changes emit carbon, such as in primary dryland forest, secondary dryland forest, primary mangrove forest, secondary mangrove forest, secondary swamp forest, plantations, and settlement.

Carbon sequestration that occurs due to conversion of land into oil palm indicates that the presence of palm oil plantations can increase carbon stocks compared to initial land types. The sequestration value is as follows: clearing at 3.46 million tons C/year, thicket swamp at 2.73 tons C/year, dryland agriculture at 2.51 million tons C/year, mixed dryland agriculture at 2.18 million tons C/year, shrub at 1.62 million tons C/year, fields at 1.25 million tons C/year, transmigration and mining respectively at 0.22 million tons C/year and 0.20 million tons C/year. Emission due to carbon stock is higher in initial lands compared to palm oil plantations, meaning that the presence of palm oil cannot replace the amount of carbon stocks on previous land types. Emission values are as follows: plantations at 11.88 million tons C/year, secondary swamp forest at 7.67 million tons C/year, primary swamp forest at 1.18 million tons C/year, secondary dryland forest at 1.07 million tons C/year, secondary mangrove forest at 0.55 million tons C/year, plantation forest at 0.26 million tons C/year, primary mangrove forest and primary dryland forest each at 0.05 million tons C/year and 0.03 million tons C/year.

Table 2: The total value of carbon stock of land use and conversion of palm oil in Rau Province in 2009.

Types of Land Cover		CS Value (ton/ha)	2009 (x1000 ha)		
			CS PL	CS Palm Oil	ΔCS
Thicket swamp	Br	30	4 226	6 953	-2 727
Primary dryland forest	Hp	195.4	36	9	27
Secondary dryland forest	Hs	169.7	1 509	439	1 070
Primary mangrove forests	Hmp	170	77	22	55
Secondary mangrove forests	Hms	120	935	385	550
Primary swamp forest	Hrp	196	1 572	396	1 176
Secondary swamp forest	Hrs	155	11 251	3 583	7 668
Plantation forest	Ht	64	1 154	890	264
Airport / harbor	Plb	0	-	-	-
Plantation	Pk	63	54 860	42 982	11 878
Settlement	Pm	5	-	-	-
Mining	Tb	0	-	202	-202
Dryland agriculture	Pt	10	638	3 149	-2 511
Mixed dryland agriculture	Pc	30	3 383	5 566	-2 183
Swamp	Rw	0	1	21	-20
Field	Sw	2	53	1 306	-1 253
Shrubs	B	30	2 516	4 140	-1 624
Savana	S	4.5	-	-	-
Fishpond	Tm	0	-	27	-27
Clearing	T	2.5	185	3 644	-3 459
Transmigration	Tr	10	55	274	-218
A body of water		0	-	-	-
Total			82 450	73 987	8 463

Note: CS= carbon stock, negative mark: sequestration and positive mark: emission.

The results in Table 3 show that the total carbon stocks for land cover types are 95.34 million tons C/year, while for palm oil plantations are 82.96 million tons C/year. Due to the conversion of land into palm oil plantations, the carbon stock changes in value of 12.38 million tons C/year. The total value of the changes obtained is positive which indicates that the release of carbon or emission occurs.

Sequestration value in 2011 is as follows: clearing of 3.58 million tons C/year, thicket swamp at 3.22 tons C/year, dryland agriculture at 2.51 million tons C/year, mixed dryland agriculture at 2.45 million tons C/year, shrub at 1.71 million tons C/year, fields at 1.71 C/year, transmigration and mining respectively at 0.22 million tons C/year and 0.20 million tons C/year. The emission values are as follows: plantations at 13.18 million tons C/year, secondary swamp forest at 10.94 million tons C/year, primary swamp forest at 1.18 million tons C/year, secondary dryland forest at 1.27 million tons C/year, secondary mangrove forest at 0.55 million tons C/year, plantation forest at 0.26 million tons C/year, primary mangrove forest and primary dryland forest each at 0.05 million tons C/year, and 0.03 million tons C/year.

Table 3: The total value of carbon stock of land use and conversion of palm oil in Riau Province in 2011.

Types of Land Cover		CS Value (ton/ha)	Year 2011 (x1000 ha)		
			CS PL	CS Palm Oil	Total
Thicket swamp	Br	30	4 993	8 215	-3 222
Primary dryland forest	Hp	195.4	36	9	27
Primary dryland forest	Hs	169.7	1 800	524	1 276
Primary mangrove forests	Hmp	170	77	22	55
Secondary mangrove forests	Hms	120	937	386	552
Primary swamp forest	Hrp	196	1 572	396	1 176
Secondary swamp forest	Hrs	155	16 051	5 112	10 940
Plantation forest	Ht	64	1 574	1 214	360
Airport / harbor	Plb	0	-	-	-
Plantation	Pk	63	60 914	47 725	13 188
Settlement	Pm	5	-	-	-
Mining	Tb	0	-	202	-202
Dryland agriculture	Pt	10	638	3 149	-2 511
Mixed dryland agriculture	Pc	30	3 796	6 246	-2 450
Swamp	Rw	0	1	21	-20
Field	Sw	2	53	1 306	-1 253
Shrubs	B	30	2 652	4 363	-1 711
Savana	S	4.5	-	-	-
Fishpond	Tm	0	-	27	-27
Clearing	T	2.5	191	3 773	-3 582
Transmigration	Tr	10	55	274	-218
A body of water		0	-	-	-
Total			95 340	82 962	12 378

Note: CS= carbon stock, negative mark: sequestration and positive mark: emission.

Changes in the value of carbon stocks in 2009 and 2011 as well as the value of CO_2 emissions due to land conversion to oil palm are shown in Table 4. The CO_2 emission value is obtained by multiplying carbon stock changes with the value of 3.67, as displayed in Figure 3.

Table 4 shows that the value of the carbon stock change in 2009 is 8.46 Mt C/year and in 2011 increases to 12.38 Mt C/year. Thus, the difference in carbon stocks in 2009 and carbon stocks in 2011 is 3.92 Mt C/year or 1.96 Mt C/year and if converted to CO_2/ year equals to 7.18 Mt CO_2e/year. Changes in land cover on secondary swamp forest into palm oil contribute the biggest emission equals to 4 Mt CO_2e/year and plantation contributes 1.6 Mt CO_2e/year. The largest sequestration happens in thicket swamp converted into the palm oil of 0.6 Mt CO_2e/year and mixed dryland agriculture of 0.3 Mt CO_2e//year.

Table 4: Changes in carbon stock in 2009 and 2011.

Types of Land Cover		ΔCS Palm Oil 2009	ΔCS Palm Oil 2011	Emission of C/2 year	Emission of C/year	Emission of CO_2
Thicket swamp	Br	-2 727	-3 222	-495	-247	-908
Primary dryland forest	Hp	27	27	0	0	0
Primary dryland forest	Hs	1 070	1 276	206	103	379
Primary mangrove forests	Hmp	55	55	-	-	-
Secondary mangrove forests	Hms	550	552	1	1	3
Primary swamp forest	Hrp	1 176	1 176	-	-	-
Secondary swamp forest	Hrs	7 668	10 940	3 272	1 636	6 004
Plantation forest	Ht	264	360	96	48	176
Airport / harbor	Plb	-	-	-	-	-
Plantation	Pk	11 878	13 188	1 311	655	2 405
Settlement	Pm	-	-	-	-	-
Mining	Tb	-202	-202	-	-	-
Dryland agriculture	Pt	-2 511	-2 511	-	-	-
Mixed dryland agriculture	Pc	-2 183	-2 450	-267	-133	-489
Swamp	Rw	-20	-20	-	-	-
Field	Sw	-1 253	-1 253	-	-	-
Shrubs	B	-1 624	-1 711	-87	-44	-160
Savana	S	-	-	-	-	-
Fishpond	Tm	-27	-27	-	-	-
Clearing	T	-3 459	-3 582	-123	-62	-226
Transmigration	Tr	-218	-218	-	-	-
A body of water	A	-	-	-	-	-
Total		8 463	12 378	3 915	1 957	7 183

Note negative mark: sequestration and positive mark: emission.

Figure 4 shows the CO_2 emissions from changes in land use to oil palm plantations. From the figure, it negative emission values are found in thicket swamps, dryland agriculture mixture, shrubs, and clering. This shows that if palm oil plantations are to be developed on land cover areas which have low reserve of C, there will be a reduction in emissions and an increase in sequestration of CO_2. [12] states that to pass the EU criteria of crude oil, palm oil trees must be planted on land that previously had low carbon stocks such as grasslands, shrubs, and on mineral lands not swamp.

The calculations of emission, sequestration, and net emissions of CO_2 due to conversion of land covers into palm oil plantations in 2009-2011 are presented in Table 5.

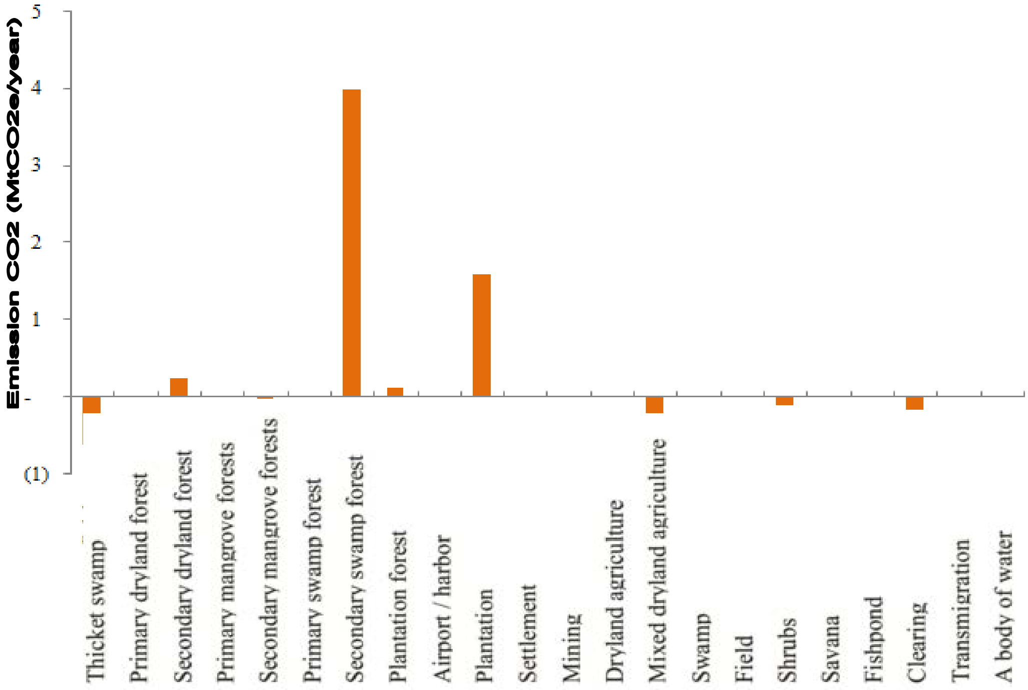

Figure 4: CO_2 emissions from the conversion of land covers into palm oil plantations.

Table 5: Emission, sequestration, and net emissions of CO_2 due to conversion of land covers into palm oil plantations in 2009-2011.

No	Source	Unit	Total
1	Emission per ha	tons CO_2e/(ha.year)	5.33
2	Sequestration per-ha	tons CO_2e/(ha.year)	1.06
3	Net emission per ha	tons CO_2e/(ha.year)	4.27
4	Total emission	tons CO_2e/year	8 959 581
5	Total sequestration	tons CO_2e/year	1 781 678
6	Net emission	tons CO_2e/year	7 176 903

Table 5 shows that the change in land use to palm oil plantations leads to sequestration of approximately 1.78 $MtCO_2$e/year or 19.89% of the total emissions. Meanwhile, net emissions generated are around 7.17 $MtCO_2$e/year or 80.11% of the total emissions. The low percentage of sequestration is due to land conversion for oil palm mostly conducted on lands that have relatively high reserve of C.

4. Conclusion

Conversion of land into palm oil plantations results in a total value of emissions by 8.95 Mt CO_2e/year, total sequestration by 1.78 Mt CO_2e/year and net emissions by 7.17 Mt CO_2e/year.

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