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EMISSION REDUCTION OPTIONS FOR PEATLANDS IN THE KUBU RAYA AND PONTIANAK DISTRICTS, WEST KALIMANTAN, INDONESIA

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ABSTRACT

The peatlands of Indonesia are an increasingly important land resource for the livelihood of the people and for economic development, but they turn rapidly into a carbon source when the peat forests are cleared and drained. Therefore, strategies are needed for the sustainable management of the peatlands and to reduce greenhouse gas emissions. This research was conducted on 464 642 ha of peatland varying in depth between 200 and 680 cm, in the districts of Kubu Raya and Pontianak, in the West Kalimantan province of Indonesia. It was aimed at: (i) evaluating land use changes in the peatland of the two districts and assessing the CO_2 emissions these entail; and (ii) recommending options for mitigation of the CO_2 emissions. Satellite images in the years 1986, 2002 and 2008 were used for the evaluation of land use changes. This was followed by ground-truthing of recent land cover in 2009. Interviews were conducted with stakeholders to develop emission reduction strategies. The results show that the peatlands were used for various purposes, including the traditional slash-and-burn agriculture for maize, pineapple plantations, intensive vegetable farming, and rubber and oil palm plantations. The peat forest area decreased by 16% from 393 000 ha in 1986 to 329 390 ha in 2008, while shrubland increased by 153% from 9427 ha to 23 814 ha over the same period of time. Oil palm plantations and paddy fields also increased rapidly in expansion. The main sources of emissions were from peat burning, especially for the slash-and-burn farming, peat decomposition due to drainage, and the loss of biomass depending on the land use trajectories. Emission reduction can be achieved through various scenarios. Scenario I, confining future agricultural land development to peatland with peat of <3 m thick, is expected to reduce by 6.8±2.9% the 2010 to 2035 cumulative CO_2 emissions from the 127 million tonnes 'business as usual' (BAU) level. Scenario II, providing fertiliser subsidy to replace the traditional burning technique in addition to Scenario I, is expected to reduce emissions by as much as 11.5±4.9%. Scenario III, switching future agricultural expansion to mineral soils, is expected to lower the cumulative emissions by as much as 20.5±8.8%. These scenarios form the basis for sustainable peatland management and for a state of preparedness to reduce emissions from peatland.

Keywords: land use change, peatland, CO_2 emission, burning, emission reduction.

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INTRODUCTION

With mineral soils for agricultural expansion becoming less available, the role of peatland is increasing in importance, especially in those provinces in Indonesia where the existence of peatland is dominant. In general, peatland development for agricultural production purposes poses relatively higher environmental and soil fertility problems, and entails lower economic returns. Higher capital is needed for its development, especially for drainage and infrastructural construction (Herman *et al*., 2009). From the environmental aspect, peatland has very important roles in water regulation, carbon storage and biodiversity conservation. These environmental functions rapidly decrease as the pristine peat forest is cut for timber and/or for agricultural use. Peat bulk density is very low, ranging from less than 0.1 to 0.4 g cm^{-3}; thus, the bearing capacity is also low for tree root anchorage (Agus and Subiksa, 2008). Under natural conditions, peatland is mostly water-saturated, except during long dry periods.

The carbon (C) reserve of peatland is very high, ranging from 30 to 70 kg C m^{-3} (Agus *et al*., 2009), or equivalent to 300 to 700 t C ha^{-1} m^{-1} of soil depth. An initial estimate (Wahyunto *et al*., 2004) shows that, on average, peat in Sumatra is around 6 m thick and, on average, has a C stock of approximately 3000 t ha^{-1}, while that of Kalimantan is about 4 m with a C stock of 2000 t ha^{-1}. By contrast, the C content of mineral soils is usually concentrated in several cm of the surface layer, and rarely exceeds 250 t ha^{-1}.

In the state of natural forest, peatland emits between 20 and 40 t CO_2-eq ha^{-1} yr^{-1} (Rieley *et al*., 2008), mostly resulting from CH_4 emission and the respiration of plant roots (autotrophic respiration) which is compensated for by the fixation of CO_2 via photosynthesis. Total CO_2 absorbed through photosynthesis is generally higher than the CO_2 released by root respiration, and the difference is manifested by increasing plant biomass. The addition of dead plants and leaf litter contributes to the growth of natural peat at a rate of 0 to 3 mm yr^{-1} (Parish *et al*., 2007).

When peat forests are cut and drained, there is a drastic increase in CO_2 emissions due to the change in the peat environment, from anaerobic to aerobic conditions that accelerate microbial (heterotrophic) decomposition. Total emissions from peat decomposition are largely determined by the depth of drainage, although there are many other influencing factors such as soil pH, temperature, C/N ratio and peat maturity. Provisional emission estimates, for land use systems with a drainage depth of 60 cm, are around 55 t CO_2 ha^{-1} yr^{-1} (Hooijier *et al*., 2010), based on a linear relationship between drainage depth and emissions. However, Jauhiainen *et al*. (2008) found an indication that the relationship is not linear and that the highest emissions occurred when the depth of the water-table is about 60 cm. With a shallower water-table the soil is highly saturated, while when the water-table is very deep, the soil becomes very dry; both conditions are not ideal for microbial activities (Husen and Agus, 2011). Carbon is also lost because of decomposition and/or burning of the plant materials as well as burning of the peat.

CO_2 emissions from peatlands are considered a serious global problem because the amounts can be several times higher than emissions from mineral soils. It is also a local problem because it causes peat subsidence that, in turn, affects the hydrology of the area. Therefore, appropriate measures must be taken to sustain the peatland.

This study was aimed at: (i) analysing changes in the use of peatlands; (ii) analysing the magnitude of CO_2 emissions under different farming systems on peatland; and (iii) developing scenarios for reducing CO_2 emissions.

MATERIALS AND METHODS

Intensive observations of land use, carbon stock and CO_2 emissions were conducted in the Kubu Raya and Pontianak districts, West Kalimantan province, in 2009. The main land uses observed include secondary forests, smallholder rubber (*Hevea brasiliensis* Muell. Arg.) plantations, oil palm (*Elaeis guineensis* Jacq.) plantations, pineapple [*Ananas comosus* (L.) Merr.] plantations, vegetables, rice (*Oryza sativa* L.) fields, and the traditional slash-and-burn system for maize (*Zea mays* L.) farms. For each land use type, the following items were observed.

Land Use Changes and Land Management Systems

Land use changes were analysed through interpretation of satellite imagery and interviews with the local communities and government officials. The images used in this study included the Landsat Multi Spectral Scanner (MSS) of 1986, Landsat Thematic Mapper (TM)-7 taken in 2008 and ALOS taken in 2007 and 2008. Other maps used include topographic maps of 2002 at a scale of 1:250 000, land system and physiographic unit maps of West Kalimantan at 1:250 000 (REPPPROT, 1989), a geological map of Pontianak at a scale of 1:250 000 (Cameron *et al.,* 1983), forest and land status maps at a scale of 1:500 000 (Dinas Kehutanan Kalbar, 2008) and a provincial land use planning map (Bappeda Kalbar, 2008).

The land use and vegetation cover map developed by the National Land Agency of West Kalimantan in 2002 was used as the basis for exploring land use and land cover changes. Time series land use and land cover changes over the period of 1986-2008 were generated using remote sensing techniques, *i.e.* the Earth Resources (ER) Mapper software. The most recent images were validated by ground-truthing conducted from May to June 2009, to gather geo-referenced information on existing land use.

Sampling points were selected randomly to represent land use or land cover types, peat maturity and peat depth. Using all the ground references as the training sets – *i.e.* land use, land cover, peat depth, peat maturity and soil drainage – the spectral signatures of each class category were extracted from the Landsat TM and ALOS scenes for classifying the types of land use and land cover of the study areas. For the classification process, the maximum likelihood supervised classifier was used and refined by a hybrid knowledge-based approach (Abkar *et al*., 2000; Singh *et al*., 2001; Wahyunto *et al*., 2010) to reach at least 80% assessment accuracy.

Forty-nine peat observation points were selected by cross-sectional transects stretching from a river bank or canal towards the centre of the peat dome, and by random observations at representative land uses for the points further away from the river. The potential uses of the peatland for agriculture (annual food crops, tree crops and plantations) were evaluated according to Djaenudin *et al*. (2003). To some extent, high economic value and environmental quality impact to reduce carbon emissions were also considered. Peatland having >3 m peat thickness was recommended for conservation and environmental protection because of very low fertility and its high potential for emissions as outlined by the Minister of Agriculture's Regulation (*Peraturan Menteri Pertanian, Permentan No. 14/2009*).

From the information on the pattern of land use changes and land management systems, and the C stock and/or emission level, we estimated the amounts of CO_2 emissions under the business-as-usual (BAU) and alternative scenarios. From the difference in CO_2 emissions under BAU and the alternative scenarios, we calculated the amount of emissions that could be mitigated.

Above-ground Carbon Stock

Above-ground C stock (C in plant biomass and necromass) was gauged from a 5 m x 40 m plot for each land use type. If trees with a diameter at breast height (DBH) of >30 cm existed in the 5 m x 40 m plot, then the plot size was increased to 20 m x 100 m for measuring DBH of those large trees. Branched tree biomass (BK) was estimated from measurements of diameter (D) larger than 5 cm and wood density (ρ), based on an allometric equation by Ketterings *et al*. (2001):

$$BK = 0.11\rho\ D^{2.62}$$

If the wood density was not known, other allometric equations as listed by Hairiah and Rahayu (2007) were used.

For smaller plants and plant litter (dead plants with diameter <5 cm), oven-dried weights of samples from a defined area were determined. Larger (>5 cm diameter necromass) assessments of volume were based on diameter and length measurements, and estimates of the decomposition level were made from the 200 m^2 plot. The content of plant carbon was calculated as 46% of the biomass (Hairiah and Rahayu, 2007).

CO_2 Emission Calculation

Net CO_2 emission can be calculated (Agus *et al*., 2009) as:

$$E = \frac{(E_a + E_{bb} + E_{bo} - S_a)}{\Delta t}$$

where:

E_a is the emission associated with biomass decomposition and/or burning, which is equivalent to plant C stock of the initial land use x 44/12, while 44/12 is the conversion factor from C to CO_2.

E_{bb} is the emission from peat burning, which is applicable if the land use or land use change involves peat burning.

$$E_{bb} = d * A * D_b * C_{org} * 44/12$$

where d is the average depth of the burnt peat, A = area burned, D_b = peat bulk density, $C_{org(w)}$ = the weight fraction of organic C relative to the dry mass of the soil. The default value of the volume-based organic carbon, $C_{Org(v)}$, which is D_b*$C_{org(w)}$, ranges from 0.03 to 0.07 t m^{-3} with an average of 0.05 t m^{-3} (Agus and Subiksa, 2008).

E_{bo} is the emission from peat decomposition, which, in this case, was assessed using the modified relationship by Hooijer *et al*. (2010). They proposed that CO_2 emission increases by as much as 0.91 t ha^{-1} yr^{-1} with every cm increase in drainage depth. We multiplied this rate by 0.7 to exclude about 30% CO_2 from root-related respiration (Handayani, 2009) which confounds most of the CO_2 flux measurements normally taken in closed chambers (Agus *et al*., 2010).

S_a is the sequestration component by the successive plants which is equal to the time average C stock of the plant biomass x 44/12 t CO_2 ha^{-1} within the time period, t.

Several assumptions about the depth of drainage and plant biomass C stock used for the calculations are given in *Table 1* (adapted from Agus *et al*., 2010). We also assumed that if the peat forest or shrub is burned during land clearing, then the depth of the burnt peat is expected to be as deep as 15 or 5 cm, resulting in C emissions of 75 or 25 t C ha^{-1} (25 yr)$^{-1}$, respectively. Furthermore, under the traditional maize farming system, in which peat burning is a regular practice to generate

TABLE 1. ASSUMPTIONS OF DRAINAGE DEPTH, ABOVE-GROUND CARBON (C) STOCK, EMISSIONS FROM PEAT DECOMPOSITION AND PEAT BURNING ASSOCIATED WITH LAND USE AND LAND USE CHANGE IN PEATLAND

Land use type	Drainage depth	Above-ground C stock	Emission from peat decomposition	Emission from burnt peat during forest conversion	Emission from burnt peat during peat shrub conversion	Emission from burnt peat under crop cultivation
	cm	t C ha^{-1} (25 yr)$^{-1}$				
Natural forest	0	157	0	0	0	0
Shrubland	40	15	172	75	0	0
Oil palm	60	40	257	75	25	0
Rubber/agro forestry	30	60	129	75	25	0
Paddies	10	2	43	75	25	0
Maize	30	2	129	75	25	250
Pineapple	35	7	150	75	25	0
Vegetables	30	2	129	75	25	0

TABLE 2. ESTIMATED ANNUAL CO_2 EMISSIONS FROM LAND USE AND LAND USE CHANGE, BASED ON A 25-YEAR AVERAGE

Land use	Peat forest	Shrubland	Oil palm	Rubber/AF	Paddy fields	Maize	Pineapple	Vegetables
	t CO_2 ha^{-1} yr^{-1}							
Peat forest	0	57	66	44	40	89	55	53
Shrubland		25	38	16	12	61	27	24
Oil palm			38	x	x	x	x	x
Rubber				19	x	x	x	x
Paddies					6	x	x	x
Maize						56	x	x
Pineapple							22	x
Vegetables								19

Note: x - no such trajectory of land use change exists in the research area.
AF - Agro forestry.

ash for improving the peat fertility, an annual combustion thickness of about 2 cm was assumed. This assumption was based on findings from a survey of the local farmers. Emissions from peat burning although uncertain may be higher compared with emissions from peat and plant biomass decompositions.

Carbon balance was calculated based on the net emissions for each land use and land use change for the period of 25 years, multiplied by the area under the respective land use and land use change. Land under primary forest was assumed to have zero emission (IPCC, 2006). Other land use types were assumed to constantly emit CO_2 from peat decomposition during the 25-year period due to drainage. For the traditional maize farming system, emissions resulted from annual burning and peat decomposition.

If the peat forest was changed into agricultural land, the amount of emission was determined by the initial forest biomass C stock, time average C stock in the plant biomass of the succeeding crop, carbon loss from peat burning, and emissions from peat decomposition in the agricultural systems.

Data in *Table 2* show the calculated amounts of CO_2 emissions from land use and land use change based on the 25-year (one cycle of plantation crop) average. Emissions from biomass and peat combustion usually happen during land clearing. In this calculation, we spread out the value into annual averages within the 25-year period. For example, for shrubland remaining as shrubland, and with an average water-table/drainage depth of 40 cm, 25 t CO_2 ha^{-1} yr^{-1} was expected to be released from peat oxidation. On the other hand, if peat shrubland was converted into an oil palm plantation, the annual emission would likely increase to about 38 t CO_2 ha^{-1} yr^{-1}, mainly because of the increase in CO_2 emission from peat oxidation due to different drainage depths between the two land use types. Carbon sequestration into the oil palm biomass, emissions from the peat shrub biomass clearing and peat fire during the conversion were also accounted for.

Scenarios of Emission Reduction

Table 2 shows that peat oxidation was mainly associated with peat drainage, peat burning, and above-ground biomass removal, all of which were among the major means of potential emission reduction. Therefore, the opportunities for reducing emissions are high if proper policy and management systems to reverse the processes can be implemented. The descriptions of BAU and each of the emission reduction scenarios are elaborated in *Table 3*.

RESULTS AND DISCUSSION

Land Use Change and Management Systems of the Studied Peatland

Data in *Figure 1* show land use changes from 1986 until 2008, and the linear extrapolation under the BAU scenario in the year 2035. The area of peat forests is shown to decline significantly. At the same time, paddy fields, oil palm plantations and peat shrub areas increased. This indicates that the majority of forest land that have been cleared (as represented by shrubland) was not transformed into plantations or other agricultural use. The area of rubber plantations, which is mostly under smallholders, also decreased, presumably due to higher incentives to switch to other agricultural systems. Interviews with residents, government officials and growers in the area revealed that most plantations, including oil palm (as was also shown by the spatial data analysis), were developed from shrubland and, to a lesser extent, from secondary forests. Smallholder rubber plantations and mixed cropping systems (agro forestry) decreased, while the land used for traditional system of maize cultivation is almost unchanged.

Emission Reduction

Land use and land status. Owing to the high potential for CO_2 emissions from peatlands following peat

TABLE 3. DESCRIPTION OF THE BUSINESS-AS-USUAL (BAU) AND A FEW EMISSION REDUCTION SCENARIOS OF THE PEATLANDS OF THE KUBU RAYA AND PONTIANAK DISTRICTS, WEST KALIMANTAN

Scenario	Description
BAU	• Areas of secondary forest, shrub and farm land increase as a linear extrapolation of the historical 1985-2010 trends relative to peatland at all thicknesses. • Most traditional farmers (mainly maize farmers) improve the peat soil fertility by burning weeds, causing the burning of a peat layer as thick as 2 ± 1 cm annually.
I	No future agricultural development on peatland of >3 m peat thickness. The peat must be relatively mature (sapric or hemic maturity), without quartz or acid sulphate sub-stratum [legal compliance to the Minister of Agriculture's Regulation (*Permentan 14/2009*)].
II	As Scenario I plus no burning under the traditional agricultural systems. The farmers are provided with fertiliser subsidy to manage soil fertility.
III	Scenario II plus switching future agricultural expansion to the low carbon mineral soils that have been allocated for agriculture (APL areas).

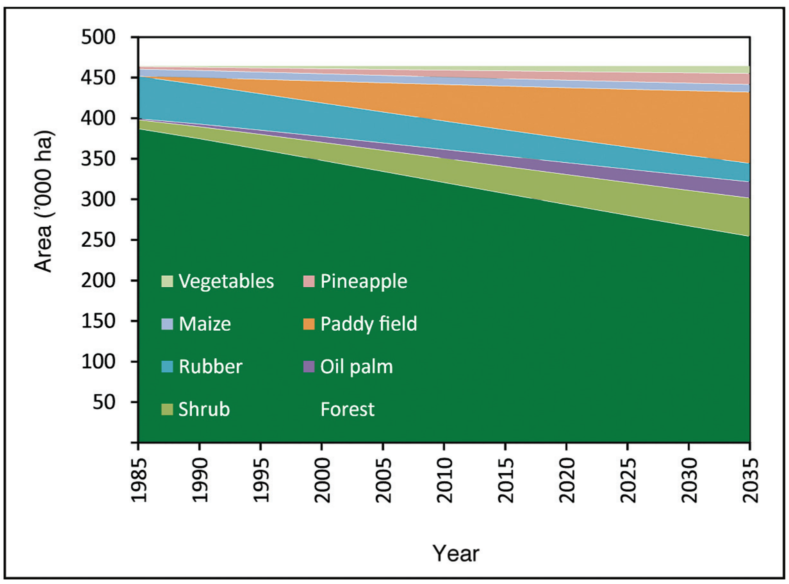

Figure 1. Historical and linear extrapolation of areas under different land use systems in the Kubu Raya and Pontianak districts of West Kalimantan.

forest conversion, one of the efforts to limit the use of peatland was the issuance of the Minister of Agriculture's Regulation (*Permentan No. 14, 2009*) which prohibits the opening of peatlands with a peat thickness of >3 m, having fibric maturity, and those with quartz and acid sulphate substrata. Of all these criteria, the easiest one to measure and map is peat thickness, and this criterion was adopted in the emission reduction scenario. *Table 4* shows that only about a quarter of all the peatland in the research area met the criterion of being <3 m thick. Of the existing peat forests, only about 35 000 ha (12%) and, of the peat shrub, only about 6000 ha (approximately 30%) meet the criterion of the peat being <3 m thick. In addition to the criterion of peat thickness, agricultural expansion is also limited by the land status (*Table 5*). Land with the status of protected forest (HL) cannot be converted while the land allocated for production (APL) with <3 m peat thickness has the potential to be used for agriculture. It can be noted from *Table 5* that the forest area within APL which is suitable for annual

TABLE 4. AREAS (ha) OF DIFFERENT LAND USES ON PEATLAND WITH PEAT THICKNESS OF <3 m AND >3 m, BASED ON SATELLITE IMAGERY (Wahyunto *et al.*, 2004) AND FIELD VERIFICATION

Land use/ land cover	Peat depth		Total	%
	<3 m	>3 m		
Forest	35 307	294 083	329 390	69
Shrubland	6 172	17 642	23 814	5
Mixed gardens (tree crops)	9 845	22 328	32 173	7
Oil palm	3 022	5 682	8 704	2
Rubber	6 792	6 394	13 186	3
Pineapple	6 915	4 829	11 744	2
Annual crops – vegetables	313	4 640	4 953	1
Annual crops – maize	3 406	6 676	10 082	2
Paddy fields	40 082	1 671	41 753	9
Total	111 854	363 945	475 799	100
% of total	24	76	100	

TABLE 5. SUITABILITY AND STATUS OF PEATLAND IN KUBU RAYA, WEST KALIMANTAN (evaluation was conducted only on peatland of <3 m peat thickness)

Current land use/land cover	Area (ha)	Land status	Potential for agriculture
Forests	26 773	APL	Annual crops, horticulture crops
	6 787	HPK	Annual crops, horticulture crops
	1 747	HL	Protected forests (for conservation)
Bush and shrubland	688	APL	Annual crops, horticulture crops
	214	HPK	Annual crops, horticulture crops
	5 270	HL	Protected forests (for conservation)
Mangroves	1 273	HL	Protected forests (for conservation)
Annual crops – maize	430	APL	Annual crops – maize
	362	HL	Annual crops with conservation practices
Oil palm plantations	691	APL	Oil palm plantations
	3 022	HPK	Oil palm plantations
	2 331	HL	Sustainable peatland management for oil palm
Pineapple	1 700	APL	Annual crops – pineapple
	4 022	HPK	Annual crops – pineapple
	2 322	HL	Sustainable pineapple crop management
Annual crops –vegetables	190	APL	Annual crops – vegetables
	123	HL	Sustainable annual crop management
Rubber	5 342	APL	Rubber

Note: APL - land allocated for agriculture.
HPK - production forests that may be converted for production under certain circumstances.
HL - protection forest.

and horticultural crop development is quite large (26 773 ha), while the bush and shrubland available for agricultural development is quite small (688 ha). Therefore, the chance for not cutting down the peat forest is very small because of the pressing need for development under the BAU scenario.

Emission reduction under several scenarios. Under the BAU scenario, annual emission from all peatland in the Kubu Raya and Pontianak districts increased by as much as 73 919 t yr^{-1} (*Figures 2* and *3*). Enforcing scenarios of emission reduction starting in 2010 will potentially decrease the emissions significantly. Scenario I (legal compliance), for example, is estimated to reduce the cumulative emission between 2010 and 2035 by as much as 12.4 million tonnes, or equivalent to a 10% relative to the BAU scenario (*Table 6*). Scenario II, imposing no burning on the traditional maize farms, which account for only about 2% of all the peatland area of the two districts, will potentially reduce emission by up to an additional 7%.

The prospect of success for each scenario varies depending on cost and ease of implementation.

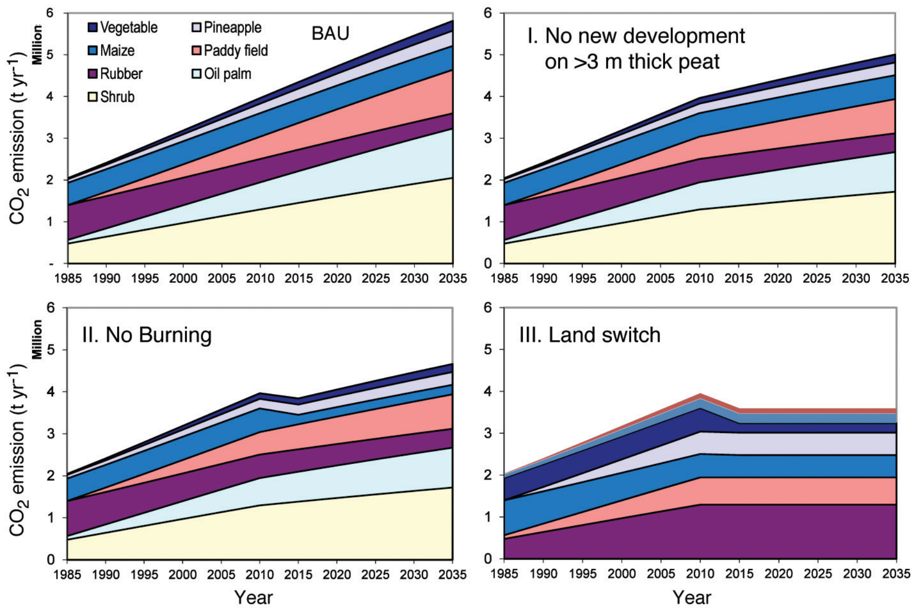

Figure 2. Estimated historical annual emissions (from 1985 to 2010) and potential emissions (from 2010 to 2035) under the business-as-usual and selected emission reduction scenarios, showing the contribution from each land use type.

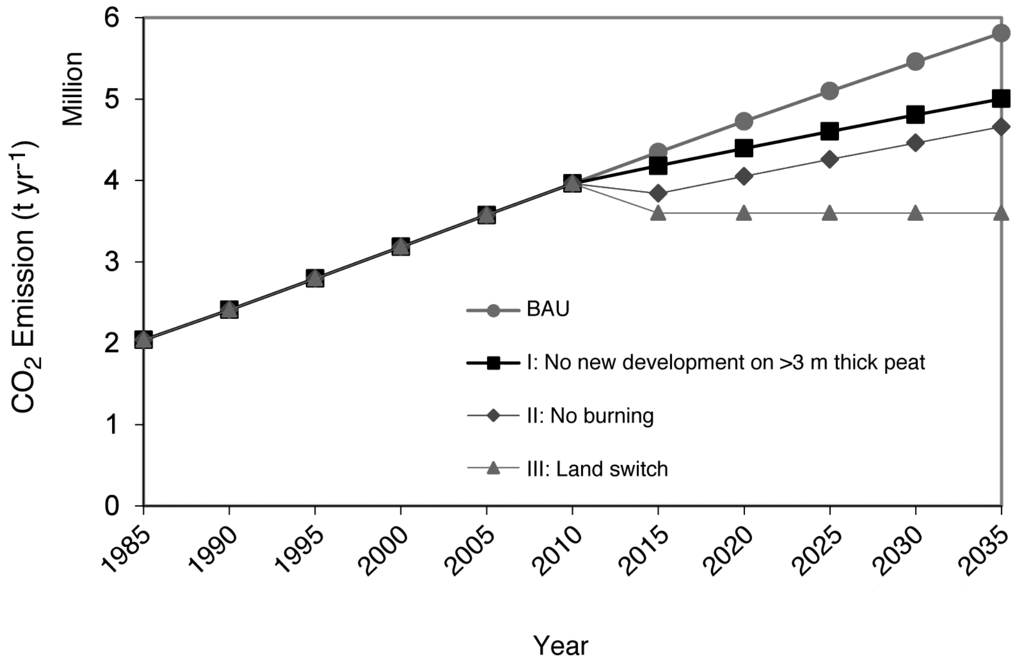

Figure 3. Estimated historical (1985 to 2010) and projected (2010 to 2035) annual CO_2 emissions under the business-as-usual and alternative scenarios.

TABLE 6. ESTIMATED CO_2 EMISSIONS UNDER DIFFERENT SCENARIOS, CUMULATIVE REDUCTION RELATIVE TO THE BUSINESS-AS-USUAL (BAU) SCENARIO AND INCREMENTAL DIFFERENCE IN THE EMISSIONS AS CONTRIBUTED BY EACH SCENARIO FROM THE BAU EMISSION LEVEL

Scenario	Cumulative emission	Cumulative difference from BAU		Incremental difference from BAU	
		Million tonnes CO_2	%	Million tonnes CO_2	%
BAU	127.2	n.a.	n.a.	n.a.	n.a.
I: No future development on >3 m thick peat	114.8	12.4	10	12.4	10
II: No burning in maize cropping system	106.2	21.0	16	8.6	7
III: Land switch	90.0	37.2	29	16.2	13

Note: n.a. = not applicable.

TABLE 7. ADJUSTED ESTIMATES OF CUMULATIVE EMISSION REDUCTION UNDER THE DIFFERENT SCENARIOS

Scenario	Adjusted cumulative emission reduction	
	Million tonnes CO_2/25 years	% of BAU
I. No future development on >3 m thick peat	8.7±3.7	6.8±2.9
II. No burning	14.7±6.3	11.5±4.9
III. Land switch	26.0±11.2	20.5±8.8

Note: BAU – business-as-usual.

Scenario I will require the delineation of peat thickness into at least two classes (<3 m and >3 m) in maps which have to be detailed enough to be implementable. Scenario II, depending on the government or other C buyers' willingness to provide fertiliser subsidies, promises highest success because application of fertilisers will not only stop burning, but will also increase crop yield significantly. The use of nitrogen fertiliser in lieu of the burning practice is expected to contribute to N_2O emission, but the additional emission will be more than compensated for by the reduction of emission from no burning. Scenario III will require an assurance of the availability of and accessibility to land with mineral soils in the same district to replace the peatland that will be conserved. This may require a legal reform to change the status of the peatland from a production to a conservation area. We estimated the prospect of success of implementation for each scenario to be about 70%, and adjusted the estimate of emission reduction as shown in *Table 7*. The details of the current management level and proposed mitigation option for each land use type in the area are presented in *Table 8*.

CONCLUSION AND RECOMMENDATION

Peatland is becoming more important for the livelihood of the populace in many areas of Indonesia, such as the Kubu Raya and Pontianak districts where it is the dominant land resource. However, the carbon stock in peat is fragile and can easily transform into CO_2, the main form of greenhouse gas. Agricultural land, except for rubber plantations, is expanding, but shrubland is also increasing at the expense of forested areas. This indicates that forest clearing is not only driven by agricultural expansion, but also by the harvesting of timber.

From the various land uses, the slash-and-burn maize system emits the highest CO_2 per unit area because of high emissions from the annual burning and from peat decomposition. A few scenarios have been proposed including legal compliance, banning of peat burning and land switch to mineral soils. Each of the scenarios prompts different levels of difficulties and costs, and thus has a different level of success. The option dealing with on-farm treatment, such as no burning, is likely have a better chance of success while those dealing with land tenure, land status and legal system are likely to be more complicated and require regulatory reforms.

The scenarios developed under this study will form the basis for sustainable peatland management as well as emission reduction from peatland. A follow-up stringent test of local acceptance will be necessary in preparation for the Locally Appropriate Mitigation Actions (LAMA). Measurement, verification and reporting of the effects of each scenario should follow.

TABLE 8. LAND USE TYPE, CURRENT MANAGEMENT SYSTEM AND RANGE OF CO_2 EMISSION MITIGATION OPTIONS

Land use type	Description	Possible mitigation technologies
Forests	About 60% of the total forested area is logged forests (especially along the main rivers) with a C stock of about 40-60 t ha^{-1}, while about 40% is natural peat forests with a C stock of 100-200 t ha^{-1}. This land area is decreasing and turning into shrubland and plantations.	Maintain as forest and allow natural regrowth to happen. In case of pressing need for development, prioritise the use of secondary or logged-over forests.
Shrubland	Having bushes about ±2 m tall with stem diameter <5 cm. This area stocks C at about ±15 t ha^{-1}.	May be used for plantations by taking into consideration a peat thickness of <3 m as stipulated in the Minister of Agriculture's Regulation (*Permentan No. 14/2009*).
Rubber plantations	In the traditional management system, planting uses seedlings rather than clones; no fertiliser application; drainage depth of 20-50 cm.	Adjustment of drainage system to ≤ 30 cm.
Oil palm plantations	Drainage depth of 50-80 cm, and in general involving intensive fertiliser applications (300 kg of urea ha^{-1} yr^{-1}).	Adjustment of drainage canal depth to maintain water level at 50 cm.
Dragon fruit and vegetables	Continuous cropping; intensive fertiliser application; heavy use of barnyard manure and ash.	Limit new development only to peat shrubland.
Pineapple plantations	Replanting every 3 years; drainage depth of about 70 cm; fertiliser application through plant residue recycling; no use of fertilisers.	Adjustment of drainage depth to 30-50 cm, improvement of management systems to slow down expansion.
Pineapple, traditional system	Water-table level at 25-45 cm; no application of fertiliser; wide plant spacing.	Increase plant population and improve management.
Traditional maize farming with short fallow rotation	About 8 months' fallow and one maize crop per year. During fallow period, vegetation is burned to generate ash and this often burns about 2 cm peat layer per year. The smoke from burning also disrupts the flight schedules of the nearby Supadio airport.	Transformation into a more intensive system by providing fertiliser subsidy to eliminate burning.

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