Scenarios for withdrawal of oil palm plantations from peatlands in Jambi Province, Sumatra, Indonesia

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Abstract

In Indonesia, peatlands are still being converted into oil palm plantations. The associated fires and peat oxidation result in smoke and large carbon emissions. In the medium term, peatlands should be used for production systems that do not require (or require much less) drainage. In this context, this study aims to explore scenarios for the withdrawal of oil palm plantations from peatlands in Jambi province and the associated carbon emissions in the coming decades. We first analyzed past land-use change trends in Jambi peatlands. Then, we analyzed three scenarios for the future: (1) a baseline scenario, assuming further expansions by smallholders, but not by companies, (2) a scenario assuming withdrawal from peat by companies only, and (3) a scenario assuming withdrawal from peat by companies and smallholders. In both scenarios 1 and 2, it is assumed smallholders keep on expanding oil palm plantations in peatlands up to 2020 but not thereafter. To accommodate economic interests of growers, withdrawal of oil palm plantations is assumed to only take place when the palm trees are 25 years old and their productivity starts declining. Our study shows that there has been a rapid expansion of oil palm plantations in peatlands of Jambi from 30,000 ha in 1987 to 483,000 ha in 2014. In our baseline scenario, involving commitments from companies but not from smallholders, the area of oil palm further increases by 20% between 2014 and 2040; this implies that by 2040, almost all peatlands, including those in the buffer zone of Berbak National Park, will have been converted to plantations. The corresponding greenhouse gas emissions are 53 Mt CO₂-equivalent per year (from both peat decomposition and fires). In the scenario assuming withdrawal of company plantations from peatlands, the plantation area will be reduced to half that in the baseline scenario in 2040. This would decrease CO₂-equivalent emissions in 2040 to below 2010 levels (27.9 Mt per year). Our study shows that a substantial decrease in emissions is only possible in scenario 3 with an almost full withdrawal of plantations from peatlands by 2040. This reduces CO₂-equivalent emissions to the level of 2000 (4.3 Mt per year) and leads to safeguarding the remaining pristine peat swamp forest in Berbak National Park.

Keywords Withdrawal · Restore · Peatlands · Oil palm · Carbon emission · Mitigation

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Introduction

In Indonesia, peatlands cover around 21 million hectares (Mha) and store terrestrial carbon approximately 36.3 Tt (Wahyunto et al. 2006; Wahyunto and Subagjo 2003, 2004). Those peatlands are mostly located in the lowland areas of Sumatra (7.2 Mha), Kalimantan (5.8 Mha), and Papua (7.9 Mha), respectively store carbon 22 Tt (Wahyunto and Subagjo 2003), 11 Tt (Wahyunto and Subagjo 2004), and 3.6 Tt carbon (Wahyunto et al. 2006). The largest carbon storage is in Sumatra because most peatlands in Sumatra are relatively deep (> 3 m). In Papua, the areas of peatlands are as large as in Sumatra, but the peat is generally shallower (often < 1 m deep), and, they therefore, store less carbon.

Pristine peat swamp forest ecosystems are water-saturated peatlands, but oil palm plantations drains peatlands. Drainages decrease water levels to at least 60 cm below the surface (-60 cm) for oil palm plantations, and in practice, water levels are often much deeper, < -80 cm. In Sumatra, 69% of the converted peatlands are drained, much more than in Kalimantan and Papua (Miettinen et al. 2016). The drainages transform peatlands from carbon sinks to carbon emitters (Murdiyarso et al. 2010; Page et al. 2009). Drained peatlands become aerobic accelerating decomposition of peat material, leading to carbon dioxide (CO_2) emissions and susceptible to fires (Hooijer et al. 2006; Inubushi et al. 2003). Since 1997, fires have become an annual event in Indonesia, particularly in the dry months and in El-Nino years, like in 1997/1998 and 2015. Peat-fires release a large amount of carbon (Hooijer et al. 2006) including CO_2 , carbon monoxide, (CO), and methane (CH_4) (Heil et al. 2007). Smoke from fires causes a range of health effects (WB-Group 2016). Drainages cause subsidence by approximately 2–5 cm peat per year (following much faster subsidence in the first 3 years after draining starts) (Hooijer et al. 2012). Fires exacerbate the loss of peat surface. Subsidence and the loss of peat surface cause flood risk and decrease productivity of peatlands (Hooijer et al. 2015).

Peat restoration is the mitigation of the aforementioned environmental problems (Fairhurst and McLaughlin 2009; Hooijer et al. 2010). However, restoration measures, particularly rewetting and revegetation, requires stakeholder participation. Companies and smallholders generally resist to make land available for restoration, because of the lost income; although, some alternative crops can be grown in peatlands which potentially profitable (Houweling 2017; Tata and Susmianto 2016; Wibisono et al. 2005). Withdrawal of oil palm plantations requires integrated approaches of rewetting, revegetation, and revitalization because abandoned plantations are often subject to annual burning. Nevertheless, Indonesia can remain a leading palm oil producing country, even in scenarios assuming no deforestation and peat conversion (Afriyanti et al. 2016). Such scenarios assume increasing oil palm yields in mineral lands by applying best management

practices (BMP) doubling the current yields (Donough et al. 2009; Euler et al. 2016; Hoffmann et al. 2014; Horridge et al. 2015). To support policies aimed at restoring peatlands, it is essential that there is a reliable estimate of the areas of peatlands converted to oil palm plantations, how those plantations could be restored, and how much the potential CO_2 gains of such policies. Currently, such quantitative information is not available.

Therefore, this study aims to explore scenarios for the withdrawal of oil palm plantations from peatlands in Jambi province and the associated carbon emissions in the coming decades. In order to better understand the complexity and implications of such withdrawal, we first analyze the current peatland covered by oil palm in Jambi, based on a comparison of different sources of information. Then, we analyze a baseline scenario for land-use change based on current trends, two alternative scenarios assuming withdrawal of oil palm plantations from peatlands, as well as the associated CO_2 emissions. As far as we are aware, such an analysis has not been done for Indonesia. Yet, this is a crucial step in reducing CO_2 emissions, in particular, since some 58% of the world's CO_2 emission from peatlands come from drained and burnt peatlands in Indonesia (Hooijer et al. 2006). In wider context, peatlands in Indonesia have contributed to 171 Mt carbon emission from oxidation alone (Miettinen et al. 2017). Given the complexity of revealing the pattern of oil palm conversion and the potential for withdrawal, also because of limited data sources, we focus on Jambi province in Sumatra, a major palm oil producing region in Indonesia.

Methodology

Study area

Jambi is a province in the central part of Sumatra, bordering with Riau in the North, South Sumatra in the South, West Sumatra in the West, and the South China Sea in the East. The province covers 51,000 km^2 consisting of 11 districts, ranging from mountainous to lowland areas. The wide range of ecosystems in Jambi is important for biodiversity and carbon reserves. Some areas are designated as national parks, including, from the mountainous to the lowland areas, Kerinci Seblat, Bukit Tiga Puluh, Bukit Dua Belas, and Berbak (a large Ramsar site). The parks are home for a group of indigenous people (*Suku Anak Dalam*), and also have a rich biodiversity including Sumatran tigers. Oil palm plantations have increasingly affected these areas. This has resulted in land conflicts with local and indigenous people. Since 2000, oil palm plantations have been increasing in peatlands because mineral lands were getting scarcer. In Jambi, peatlands are mostly located near the coastal areas of South China Sea, in the eastern part of the province, covering areas approximately

Fig. 1 The geographical location of Jambi province in Sumatra, the districts that we analysed in the study and areas of peatlands classified as non-protected (556,000 ha) and protected areas (98,000 ha) in East Tanjung Jabung, West Tanjung Jabung, and Muaro Jambi

700,000 ha (Wahyunto and Subagjo 2003). Currently, oil palm plantations in peatlands are mostly located in the districts of East Tanjung Jabung and West Tanjung Jabung (mostly smallholder plantations) and in Muaro Jambi (mostly private companies).

Our study concerns peat conversion and CO₂ emission from peatlands. Therefore, we focus on three districts with most peatlands. These are Muaro Jambi, West Tanjung Jabung, and East Tanjung Jabung (Fig. 1). In addition, areas cultivated for other crops are connected to these plantations through their drainage. There are also illegal activities such as illegal poaching, fishing, and logging, causing fires during El Niño years (Giesen 2004).

Analysis of past oil palm plantations

Developing a map of oil palm plantations in peatland of Jambi Province

The analysis of past oil palm plantations was aimed to gather a baseline spatial data for our projection of scenarios. This baseline spatial data were important because several data resources showed different areas of oil palm plantations. For instance, the national statistical data based on Deptan (2015) showed

that the areas of oil palm plantations were approximately 50% less than the data at the provincial statistical reports (Budidaya 2014, 2015). This was confirmed by stakeholders at the province due to unreported permits issued at districts and province level to the national database. Meanwhile, at districts and province level, a complete data series were not available. Therefore, we compiled several secondary data, ground surveys, and data gathered from the google earth; and this compilation was needed because one data-set was not able to provide information needed for scenario development requiring details for areas of plantations and planting years in order to estimate withdrawal years.

Firstly, we based our analysis a map of the oil palm plantations from the National Soil Agency of Jambi Province, a copy provided by the Agency for Environmental Monitoring and Protection of Jambi. This map was the most recent spatial data of oil palm plantations in Jambi Province. However, this map did not contain smallholder plantations, oil palm plantations operationalized since 2007, and plantations listed in the letter of Jambi Agricultural Office. These missing data were completed by utilizing a map resulted from a spatial interpretation of license letters in 2007 and 2012. Smallholder plantations were completed with a map from Miettinen et al. (2016). Beforehand, smallholder plantations indicated as oil palm

plantations of companies based on the map of licenses were excluded from the map of Miettinen et al. (2016). Up to this step, we resulted in a map of oil palm plantations containing company and smallholder plantations in both peatlands and mineral lands.

Next, our study requires oil palm plantations in peatlands; thus, exclusion of oil palm plantations in mineral lands was done. We overlaid the resulted map above with a peatland map providing by Wetlands International Indonesia Program (Wahyunto and Subagjo 2003). The resulted map was verified with 142 coordinates of oil palm plantations gathered from field surveys in smallholders and some company plantations in peatlands conducted through the project of assessment of oil palm plantations with Wetlands International Indonesia Program (described further in [Supplementary Material](#)). During the field survey, we interviewed communities (*masyarakat*) and companies at or nearby the surveyed oil palm plantations by asking; (i) what type of oil smallholder plantations (either plasma or independent smallholding); (ii) when the oil palm plants are planted; (iii) how much the production of FFB; and (iv) how stakeholders think about converting oil palm to paludiculture plants like Jelutung. At the district and province level, we interviewed some key informants for confirmation about the data-gap between province, national, and our study result as well as we asked the question point iv to confirm our scenario. The number of respondents were 1 company, 101 people at, and nearby the surveyed plantations. To note that the locations of surveyed were chosen purposively due to accessibility to areas regarding limited access to company plantations, some plasma plantations, and areas of peatlands. Then, we verified the resulted map with the historical imageries of Google Earth. The Google Earth confirmed that areas not indicated as oil palm plantations in the resulted maps are oil palm plantations, and mostly smallholder plantations. Smallholder plantations are patchy plantations spreading irregularly (1–2 ha) and of different ages in one area. Besides, expert knowledge about the areas assisted us to identify oil palm in the areas.

Interpretation of oil palm plantation ages and corresponding policies

The map resulted in “[Developing a map of oil palm plantations in peatland of Jambi Province](#)” section was interpreted for oil palm plantation ages. The interpretation was aimed to gather withdrawal years oil palm plantations following a qualitative approach. First, company plantations were assumed to be started 1 year after issuance years of permits. We understand that this estimation was rough due to some factors including that some plantations even started before permits were issued; while some plantations possibly started some later years than the permit years due social conflicts. Meanwhile, interpretation to high-resolution satellite imageries is not able

to sufficiently estimate oil palm ages, especially to oil palm plantations which are less than 5 or 7 years as conducted by Chemura (2012). Second, smallholder plantations were started 1 year after the assumed year of planting in company plantations (or 2 years after released permits) of nearby company oil palm plantations. Our assumption stands the situation that smallholders need mills and supply from companies, for example smallholders need drainages of companies to start their plantations. Then, the classified plantations were categorized for the stages of policy development and the dynamic of land-use changes. The result of this analysis was used for the basis of our baseline scenario.

Scenario analysis

Oil palm plantations up to 2040

We developed three scenarios for the period 2015–2040. The scenario analysis was aimed to explore plausible future oil palm development considering a shift towards sustainable peatland management. General assumption is described in Table 1. The first scenario is a baseline scenario assuming that companies do not further expand their plantations in peatlands from 2015, while smallholders expand oil palm plantations in peatlands between 2015 and 2020 but not thereafter. It is called baseline scenario because we consider the impact of recent governmental regulations including the governmental regulation No. 71/2014 jo No. 57/2016 about the protection and peatland management. The regulation restricts the oil palm development, by which plantations located in deep peatlands (> 3 m) will be banned after the plant reaching one cycle of harvesting; and allows utilization of shallow to moderate depths of peatlands (<3 m), by maintaining water level at a maximum level of 40 cm below peat surface. The baseline scenario assumes the least enforcement of this regulation, restricting only further expansion of oil palm plantations by companies, while maintaining water level at 40 cm below peat surface is not feasible due to technical problems including the difficulty to have effective dams to increase water level as such. There will be enforcement of governmental regulations stopping oil palm plantations of companies in peatland; however, we assume that the regulation will not have an impact to the behavior of stakeholders to land clearing and claim land, and they usually plant oil palm as observed by Schwarze et al. (2015). Nevertheless, the smallholder expansion stops due to unavailability of peatlands. The baseline scenario was interpreted spatially applying the assumption that company plantations will be maintained and smallholder keep expanding into available peatlands.

The second scenario assumes that company plantations will be withdrawn from peatlands as soon as oil palm trees reach 25 years; while smallholders follow the assumption in the baseline scenario above. Our assumption for company

Table 1 Description scenarios: Baseline, Companies Withdrawal, and Companies and Smallholders Withdrawal

Scenario	Basis for assumptions
<p>Scenario 1: Baseline</p> <p>No expansion in peatland by companies after 2015, while increasing expansion by smallholders up to 2020.</p>	<ul style="list-style-type: none"> • Moratorium on issuing new licenses to companies in peatlands • Smallholders prefer oil palm as in Euler et al. (2016) • Recent observations of agricultural activities and new oil palm plantations in the buffer zone of Berbak National Park in 2013–2014
<p>Scenario 2: Companies withdrawal</p> <p>Companies gradually withdraw oil palm plantations from peatlands when trees reach 25 years. The areas are used for <i>paludiculture</i> and/or wet-peat-adaptive local commodities. In the withdrawn areas the water level is kept at 40 cm below surface.</p>	<ul style="list-style-type: none"> • Ongoing concerns about peat fires and ratification of the ASEAN Agreement on Transboundary Haze Pollution (AATHP) by the government of Indonesia (ASEAN 2017) • Failure of companies to keep the water level at 40 cm below surface causes the government to set up peat restoration plans and regulations • Smallholders prefer oil palm as in Euler et al. (2016) • Withdrawn areas of companies are managed by the government
<p>Scenario 3: Companies and smallholders withdrawal</p> <p>Companies and smallholders gradually withdraw oil palm plantations from peatlands when trees reach 25 years, and the areas are used for <i>paludiculture</i> and/or wet-peat-adaptive local commodities.</p>	<ul style="list-style-type: none"> • Companies withdrawal is enforced by more stringent policies • Smallholders prefer to plant peat-indigenous species • The markets for the products of peat indigenous plantations will develop following the measure to restore peatlands • The risk for fires is higher when peatlands are drained, and this is realized by both companies and smallholders

plantations is based on the enforcement of aforementioned governmental regulation and the regulation about transboundary haze problems in South East Asia. Plantations located in deep peatlands (> 3 m) will be banned after the plant reaching one cycle of harvesting. Although, the regulation allows utilization of shallow to moderate depths of peatlands (< 3 m), by maintaining a water level at maximum level of 40 cm below surface, we assumed that such minimum water level will not be suitable for productive oil palm plantations. Therefore, withdrawal of oil plantations shall be followed by planting indigenous species through *paludiculture* system. Our assumption for smallholder expansion follows the assumption in the baseline scenario as the regulations cannot be enforced to smallholders, and alternative livelihood from *paludiculture* is not fully developed. The company withdrawal scenario was interpreted spatially by applying the assumption that company plantations will be withdrawn and converted to *paludiculture*, while smallholders expand oil palm plantations into available peatlands.

The third scenario assumes that both companies and smallholders withdraw their oil palm plantations from peatlands as soon as trees reach 25 years. Rewetting and *paludiculture* are increasingly adopted by companies and smallholders. This assumption follows the enforcement of the aforementioned regulation combined with more developed *paludiculture* and adaptive commodities to wet-peatland. The development of *paludiculture* also coupled by the development of its market. Our assumption stands because the government of Indonesia has established the Peat Restoration Agency, by which restoration of peatland is more organized. Action research on *paludiculture* and local commodities has developed several possibilities to change towards more responsible peatland management. The possibilities include sago plantations,

liberica coffee production, areca nut production, honey bee, jelutung plantation, duck production, and fish production and so forth (personal communication, 2017, by reviewing 61 research projects of the peat restoration agency). The company and smallholder withdrawal was interpreted spatially by applying the assumption that both companies and smallholders withdraw from peatlands and convert to *paludiculture*.

Estimation of CO₂ emissions from peat oxidation and fires

Peat oxidation We calculated carbon emissions caused by oxidation of drained peatlands. Drained peatlands emit CO₂ as a result of decomposition of organic matter following reduced water levels after drainage (Blain et al. 2006; Hooijer et al. 2006; Inubushi et al. 2003; Wösten et al. 2006). Therefore, we considered water level as a factor determining CO₂ emission from the oxidation process in plantation areas. Water levels and CO₂ emission were assumed to be linearly related, although it is argued that the function could be non-linear (Couwenberg and Hooijer 2013; Murdiyarso et al. 2010). CO₂ emissions from oxidation were calculated following Tier 2 of the IPCC Guidelines (Blain et al. 2006), using national emission factors (EFs) and drained areas. The EFs in this study depend on water levels assumed in the scenarios.

In the baseline scenario, the water level was based on observation from August to November 2012. Our observation confirmed that water levels were between – 80 and – 110 cm, and in order to be conservative with our estimate, we used the lower end of this range (– 80 cm). By this water level, the EF is 80 ton annually per ha (Jauhiainen et al. 2012). To note, the water level is lower than as required by regulations of the agriculture ministry (– 60 cm) and water levels fluctuate over the year as a function of rainfall (BPPT and Midori-

Engineering 2015). The plantation areas were obtained from the analysis of past developments in oil palm plantations in peatlands in “Analysis of past oil palm plantations” section for the baseline scenario.

In the withdrawal scenario, both for company withdrawal as well as company and smallholder withdrawal, we assumed that water levels will be managed to -30 cm within the first 5 years of withdrawal to allow alternative crops to grow and survive (Wibisono et al. 2005). For instance, alternative crops include *Jelutung* rubber, adaptable coffee species (like *liberica* grown by traditional farmers in the West Tanjung Jabung, Jambi Province) and bamboo, but the seedlings of these plants are intolerant for waterlogged conditions. The EF for withdrawn areas with water level approximately -30 cm is 27 ton annually per ha based on Jyrki Jauhiainen et al. (2008). In unwithdrawn oil palm plantations, the water level is -80 cm and CO_2 emissions are quantified as in the baseline scenario (Jauhiainen et al. 2012).

CO_2 emissions from peatlands were calculated based on an equation adapted from the IPCC Guidelines (Blain et al. 2006):

$$\text{CO}_2 \text{ drained peat} = A_{\text{drained peat}} * \text{EF}_{\text{CO}_2 \text{ drained-peat}}$$

where

$\text{CO}_2 \text{ drained peat}$ = CO_2 emissions from drained peatland (tons year $^{-1}$).

$A_{\text{drained-peat}}$ = Area of drained peatland (ha).

$\text{EF}_{\text{CO}_2 \text{ drained-peat}}$ = Emission factors for CO_2 from drained peat per hectares (ton ha $^{-1}$ year $^{-1}$).

Peat fires Drained peatlands are susceptible to fires resulting in various greenhouse gas emissions (Akagi et al. 2011). We calculated CO_2 -equivalent emissions of CO_2 and CH_4 , using global warming potentials (GWP) (Forster et al. 2007). Emissions were calculated using EFs for CO_2 and CH_4 per unit of dry mass combusted ($M_{\text{combusted}}$). $\text{EF-}\text{CO}_2$ and $\text{EF-}\text{CH}_4$ were based on Akagi et al. (2011). The $M_{\text{combusted}}$ was calculated from the burnt areas (A_{burnt}), fire depths, and bulk density of peatlands. A_{burnt} was calculated based on the number of hotspots and the areas of individual hotspots, estimated based on Tansey et al. (2008), observing that one hotspot represents 15–16 ha. For future carbon emissions (up to 2040) due to fires, we estimated the areas which may be burnt as a result of the assumed expansion of oil palm plantations ($A_{\text{oil palm}}$). We first related observed fires during the period 2001–2015 to the observed expansion of oil palm plantations. MODIS Active Fire provided data since November 2000; thus, the first complete start year is 2001. For future years, we estimated burnt areas in line with our scenario assumptions. An important assumption is that there are no fires in the restored area, in line with the increased water table leading to more humid conditions during the dry season. We

acknowledge that this is a crucial assumption that depends upon the implementation of the blocking of canals draining the peat and providing incentives for local people, smallholders, and plantation companies to combat fires related to the use of peat for paludiculture and/or wet-peat adaptive commodities. This assumption is the rationale we plan for a very gradual conversion of oil palm plantations to other land uses in our scenarios. We come back to this assumption in the “Discussion” section. The following equations were applied:

$$\text{CO}_2\text{-emission (ton.year}^{-1}) = \text{EF-}\text{CO}_2 * M_{\text{combusted}}$$

where $\text{EF-}\text{CO}_2 = 1563$ g/kg $M_{\text{combusted}}$ (Akagi et al. 2011)

$$\text{CH}_4\text{-emission (ton.year}^{-1}) = \text{EF-}\text{CH}_4 * M_{\text{combusted}}$$

where $\text{EF-}\text{CH}_4 = 12$ g/kg $M_{\text{combusted}}$ (Akagi et al. 2011).

$$\text{CO}_2\text{-equivalent (ton.year}^{-1}) = \text{GWP} * [(\text{CO}_2) + (\text{CH}_4)]$$

where $\text{CO}_2\text{-equivalent-}\text{CO}_2 = 1$, $\text{CO}_2\text{-equivalent-}\text{CH}_4 = 25$ (Forster et al. 2007)

$$M_{\text{combusted}} (\text{kg}) = A_{\text{burnt}} * \text{fire depth} * \text{bulk density}$$

where A_{burnt} is area burnt (ha) fire depth = assumed to be on average 35 cm. (Hirano et al. 2014) and average bulk density = 0.134 g/cm 3 (Couwenberg and Hooijer 2013).

$$A_{\text{burnt}} (\text{ha}) = n\text{-fire hotspots} * 16$$

where n -fire hotspots are the number of fire hotspots in a particular year, and A_{burnt} per fire hotspots is 16 ha (Tansey et al. 2008)

$$n\text{-hotspots of oil palm plantations} = 0.003 * A_{\text{oil palm}}$$

where 0.003 is number of fire hotspots per hectares oil palm plantations ($A_{\text{oil palm}}$) gathered from dividing hotspots between 2001 and 2015 with $A_{\text{oil palm}}$ from the same period; or 0.003 hotspot/ha oil palm plantations, or 0.048 ha burnt areas/ha oil palm plantations.

Sensitivity analysis of CO_2 emission The source of uncertainty is the estimation of CO_2 emission associating with the effectiveness of rewetting. Restoration of peatland is conducted by building rewetting infrastructures, mostly by blocking canals. Although, canal blockings have been developed following hydrological analysis; the effectiveness of those canal blockings to restore peatlands hydrologically is still limited. Therefore, we assume that the rewetting is the source of the uncertainty of peat restoration, and to gather a sensitivity of CO_2 emission, we assumed a water table of 60 cm after hydrological restoration following withdrawal of oil palm plantations. The water table as such will cause emission 43 Mg CO_2 /ha/year (Agus et al. 2013).

Results

Past development of oil palm plantations in peatlands

Policies

Policies on oil palm development largely influenced the development of oil palm plantations in Jambi (Table 2). Oil palm development passed several phases in Indonesia. In Jambi, the decentralization phase (2002–2006) resulted in the largest expansion of oil palm plantations. During this phase, permits were given by local government (district heads or a governor). Two hundred sixty-seven thousand hectares of peatlands were converted to oil palm plantations, much larger than the previous phases. During the transition time of the moratorium on deforestation and peat conversion (2007–2009), 181,000 ha of peatlands were converted to oil palm. The moratorium decreased the areas permitted for oil palm plantations in peatlands.

Past land-use changes

Based on our surveys, there was an area of peatlands which was not included in the map of Wahyunto and Subagjo (2003). This area is approximately 65,000 ha of peatland, adding to the 668,000 ha. Thus, total peatlands in our study become 733,000 ha. Table 3 shows that up to 2014, 66% of the observed peatlands (483,000 ha) have been converted to oil palm plantations, 57% and 43% of which have been owned by companies (275,000 ha) and smallholders (209,000 ha), respectively. In addition, 195,000 ha of peatlands are peat swamp forest (in the buffer zone and inside Berbak National

Park), 30,000 ha peatlands are acacia plantations, 24,000 ha peatlands are other agricultural uses (coconut plantations, rice fields, and mix cropping plantations owned by farmers).

Furthermore, up to 2014, the 483,000 ha of oil palm plantations in peatlands corresponded with direct land use changes (deforestation of peatlands) (49%) at least since 2000 (the earliest land use data available), and indirect land use changes (51%). Fifty-nine percent of the oil palm plantations associated with direct land use change (140,000 ha) have been assigned as company plantations. Similarly, 55% of oil palm plantations associated with indirect land use changes (136,000 ha) have been owned by companies. Nevertheless, smallholders also played important roles in increasing oil palm plantations in peatlands. Smallholder plantations have accounted for 41% of oil palm associated with the direct land-use change (96,000 ha) and 45% of the oil palm associated with the indirect land use changes (113,000 ha).

Current situation

In Jambi, there have been oil palm plantations in mineral lands since the 1980s. This is earlier than in peatlands (1987). The planning of oil palm started in Muaro Jambi on 500 ha of mineral soil. Thereafter, rapid expansions took place on mineral soils (mostly in Merangin, Bangko, Bungo, Tebo, Batanghari and Muaro Jambi). But most expansions took place in peat since 2000.

Both smallholders and companies were involved in the expansion. Companies typically start with a proposal to regents. Based on this, regents allocate areas in principal licenses. Holding principal licenses, companies then propose location permits. After that, an assessment follows to decide whether the

Table 2 Oil palm plantations in Jambi peatlands in association with the phases of the policies on palm oil development in Indonesia. Based on WRM (2017)

Phases	Definition	Years of planting	Area planted (*1000 hectares)
PIR-TRANS (Until October 1993)	Centralized permits caused deforestation outside Java for State-owned plantation companies (nucleus) and smallholding (<i>plasma</i>) by Transmigration program, and regional forestry offices authorized permits up to 100 ha.	1987	6
Deregulation (1993–1996)	Governor authorized permits for the conversion of forest areas up to 200 ha, while larger scale permits were authorized by Directorate General of Estate Crops in Jakarta. This phase promoted regional (provincial) development and ensured a long-term commitment of private companies.	1995	4
Privatization (1996–1998)	Encourage private sector initiatives and facilitate foreign direct investment.	1997	11
Cooperatives (1998–2002)	Governors are allowed to issue permits of plantations for areas up to 1000 ha, while the Ministry of Forests and Estate Crops issued permits for areas up to 20,000 ha.	1998&2002	28
Decentralization (2002–2006)	Permits up to 1000 ha were issued by the District head (within one district) and by governors (within two or more districts). The Ministry of Agriculture issued permits of over 1000 ha.	2003–2006	267
Transition towards 2010-moratorium	Decentralization phase continues until 2010 when the moratorium by the Letter of Intent (LOI) with Norwegian Government	2007–2009	181
Moratorium 2010	Limited permits	2014	17

Table 3 Conversion of peatland to oil palm plantations in the past (from before 2000 to 2014), and the areas of peatlands not converted to oil palm plantations in 2014, which are assumed to be converted to oil palm plantations by smallholders in the baseline scenario

Types of land use based on and unidentified by Wahyunto, Ritung et al. (2003)		Land use change based on years of permits and assumption for smallholders (area in*1000 ha) ²										Area (*1000 ha) of Peatlands not converted to oil palm plantations in 2014 ⁶		
Type of land use ¹	Area (*1000 ha)	<2000-2000		2001-2005		2006-2010		2011-2014		The total area of oil palm plantations in 2014 (*1000 ha)				
		C ³	S ⁴	C ³	S ⁴	C ³	S ⁴	C ³	S ⁴	C ³	S ⁴	T ⁵	%	
A. Direct Land Use Changes														
Peat Swamp Forest ¹	310	6	0	35	26	22	24	2	0.05	65	50	114	37	195
Unidentified in Wahyunto, Ritung, and Subagio (2003) ²	65	5	0	15	11	13	6	14	0.04	47	18	65	100	
Oil palm (of peat swamp forest) ¹	56	12	1	16	14	10	13	7	0	28	28	56	100	0
Total oil palm plantations associated with direct land use changes from peat swamp forest										140	96	235		
B. Indirect Land Use Changes														
Coconut (and rice fields) ¹	51	0	0	7	0	28	12	0	0	34	14	48	94	3
Industrial plantations (HTI) (<i>Acacia</i>) ¹	40	2	0	3	0.012	6	0	0	0.4	10	0.012	10	25	30
Logging concession (HPH) ¹	3	1	210	1	0.012	0.3	0	0	0	3	0.2	3	100	0
Mix cropping ¹	7	3	0	0	2	1	0	0	0	4	2	6	89	0.7
Oil palm (of rice fields) ¹	0.2	0	222	0	0	0	0	0	0	0	0.2	0.2	100	0
Rice fields ¹	119	7	0	12	19	31	48	0	0	50	67	117	98	2
Rubber plantations ¹	37	3	6	12	2	6	0	0	0	22	2	23	63	13
Shrubby swamp ¹	45	2	0	6	14	6	14	0	0	13	28	41	90	4
Total oil palm plantations associated with indirect land use changes from peat swamp forest										136	113	248		
Total areas	734 ⁷	31	2	105	89	123	117	16	0.5	275	209	483	66	249

¹ Land use on peatland maps of Jambi Province (Wahyunto, Ritung et al. 2003)

² Resulted from overlays of oil palm maps from several maps and field observation as mentioned on section 2.2

³ C is companies

⁴ S is smallholders

⁵ T is total conversion up to 2014

⁶ The remaining peatlands (not converted to oil palm in 2015), of which is assumed to be used by smallholders to expand oil palm plantations in the baseline scenario

⁷ Total areas of peatlands in study areas (Muaro Jambi, East Tanjung Jabung, and West Tanjung Jabung).

proposed area is located in a forest or non-forest zone. If the areas are not in a forest zone, location permits are released. Location permits covering areas within a district or two districts are released by a district head or a governor, respectively. After receiving location permits, companies are responsible to conduct a social assessment for social readiness (following the pre prior and inform concern to local communities and a physical assessment). Next, business permits are proposed. These include business plantation permits (IUB) and/or business plantation and mill (IUP). Permits are given based on the Agriculture Ministry Decree (*Permentan*), No.98/OT.140/9/2013.

In this study, we used information from the Agriculture Office of Jambi, including location permits and IUP/IUB. IUP is the permit to manage lands for both plantations and processing. IUB is the permit to manage lands for plantations. The data of *Dinas Perkebunan Jambi* were received by letter No. S_772/Disbun-2.2/XII/2015, consisting location permits

and IUP from 1981 to 2014. Permits in peatlands have been given since 1986, and most are released between 2000 and 2010, just before the moratorium policy commenced. However, we observed differences in the information on oil palm plantations among sources (Table 4). The information from the National Office of Agriculture Department covers a 50% smaller area than from provincial reports. The map of location permits in 2012 represents some of the oil palm plantations in 2015.

Scenarios for the development of oil palm plantations in peatlands

Baseline scenario

Based on our assumption in “Oil palm plantations up to 2040” section, in the baseline scenario, in 2020, there will be

Table 4 Oil palm plantation areas in 2012, 2014, and 2015

Districts	Oil palm plantations up to 2014 (*1000 ha)		Location permits	
	The National data of Agriculture Department (2015)	The annual reports provincial Agriculture Office (2015)	Map of location permits (2012)	Letter from Jambi Agriculture office (2015)
Kerinci	0.1	-	-	-
Merangin	68	220	183	108
Sarolangun	77	245	173	190
Bungo	83	172	149	97
Tebo	57	107	185	114
Batanghari	94	230	182	146
Muaro Jambi	149	192	164	167
East Tanjung Jabung	38	58	72	46
West Tanjung Jabung	127	126	70	138
Total areas of oil palm plantation in Jambi	693	1,349	1,178	1,005

618,000 ha oil palm plantations in peatlands. Likewise, company plantations remained 275,000 ha and smallholder plantation increase to 343,000 ha. The expansion will mostly occur in Muaro Jambi (120,000 ha). Furthermore, it will use 90% of peatlands in Jambi and threaten Berbak National Park (see Fig. 2, part a and b).

Company withdrawal scenario

In this scenario, by 2040, companies are assumed to withdraw from peatlands. This will decrease the area of oil palm plantations 343,000 ha in 2040. Muaro Jambi will have the largest withdrawal oil palm plantations (109,000 ha), followed by East Tanjung Jabung (87,000 ha) and then West Tanjung Jabung, which will be 39% and 25% larger than those in East Tanjung Jabung and West Tanjung Jabung (78,000 ha). The largest withdrawal will be between 2026 and 2035 (Table 5). However, the company withdrawal scenario will not safeguard the peat swamp forest near Berbak National Park (see Fig. 2 part c).

Company and smallholder withdrawal scenario

This scenario assumes that by 2040, companies and smallholders will withdraw from peatlands and expansion of smallholders plantations do not exist. This will decrease the areas of oil palm plantations by 453,000 ha from 483,000 ha of existing oil palm plantations in peatlands up to 2014. The largest withdrawal period is 2026–2030 (43%) of the total withdrawal areas, followed by the period 2031–2035 when oil palm plantations will be withdrawn by another 40% of the total withdrawal areas. In Muaro, Jambi is the largest areas for companies to withdraw, and. In West Tanjung, Jabung will be the largest areas of smallholders withdrawal (49% of the total

areas of smallholder plantations) (Table 6). This scenario will contribute to safeguarding to the Berbak National Park as well.

CO₂ emission

Under the baseline scenario, CO₂-equivalent emission increases from 2.61 Mt in 2000 to 42.4 Mt in 2015 and to 53.3 Mt in 2020. Company's withdrawal still increases CO₂-e emission by 16% by 2020, and decrease by 43% by 2040 from the level of emission in 2020. Company's and smallholder's withdrawal decreases CO₂e emission by 2020 to 91% CO₂-e by 2040. Peatlands converted to OP plantations are susceptible to fires. More fires are observed in OP plantations managed by companies. Up to 2015, we gathered that 1-ha-oil palm plantation has a risk of fires 0.003 fire-hotspot. Therefore, we assume that under the baseline scenario, expansion causes 0.003 hotspot/ha from 2016 to 2040 and repetitive fires take place in oil plantations from 1987 to 2015. Fire contribute to maximum 0.4 Mt in the baseline scenario (Table 7).

Discussion

Our study confirms that analyzing oil palm areas at local scales unravel larger oil palm areas and land-use changes. Substantial areas of peat swamp forest have been converted to oil palm plantations since 1987, which may associate with some areas had been converted to logged-over forests between 1986 and 1992 confirmed by Murdiyarso and Wasrin (1995). In 2015, oil palm areas in peatlands were 12% larger than both smallholders and industrial plantations of Miettinen et al. (2016) as some degraded peat swamp forest areas are smallholder plantations in our study. If acacia plantations are excluded from industrial plantations of Miettinen et al. (2016),

Fig. 2 **a** Areas of oil palm plantations in 2015, and for three scenarios to 2040 **b** baseline scenario, assuming the expansion by smallholders, **c** scenario assuming withdrawal from peatlands by companies, and **d** scenario assuming withdrawal areas of companies and smallholders from peatlands

oil palm areas will become 23% larger than the aforementioned smallholders and industrial plantations. Our study observed that oil palm areas are recorded differently in different registration systems. Importantly, the area covered by oil palm

plantations in peat in Jambi according to national data is half of that according to provincial data.

In the baseline scenario, we assumed that there will be no expansion of oil palm plantations in peatlands by companies

Table 5 Withdrawal areas (1000 ha) in the company withdrawal scenario in the Muaro Jambi, East Tanjung Jabung, and West Tanjung Jabung District, Jambi Province

Period	Muaro Jambi	East Tanjung Jabung	West Tanjung Jabung	Total
2020-2025	11	13	0	25
2026-2030	61	20	24	105
2031-2035	31	45	48	123
2036-2040	6	0	16	<1
Total up to 2040	109	78	87	275

Table 6 Withdrawal areas (1000 ha) in the company and smallholders withdrawal scenario on five year-periods in the three districts

Period	Muaro Jambi		East Tanjung Jabung		West Tanjung Jabung		Total areas are withdrawn	
	C	S	C	S	C	S	C	S
2020-2025	11	0	13	0	0	0	25	0
2026-2030	61	23	20	24	24	43	105	90
2031-2035	31	8	45	15	48	37	123	60
2036-2040	6	14	0	8	16	8	22	29
Total withdrawal per type of plantations	109	44	78	47	87	87	275	178
Total withdrawal per districts	153		125		175		453	

and no withdrawal. This assumption is made based on the recent moratorium of oil palm plantations in peatlands. As a result, oil palm companies continue the plantations up to the permits to use of peatlands for oil palm plantations ended. The permit can be extended if the oil palm plantations are managed in such a way to prevent fires in plantations, including increasing water level in canals to reach water table 40 cm or less (as stipulated in the governmental regulation No. 14/2014 jo No. 57/2016 about the protection and management of peat ecosystems. This means that the water level in canals is less than 40 cm. However, smallholders are likely to expand because the policies do not address the problems concerning expansions by smallholders and high motivation of smallholders to plant oil palm such as large market of oil palm fresh fruits bunches, low price of rubbers, lack of markets for other products (Schwarze et al. 2015) and the tradition to grab lands in forested areas. Consequently, it is assumed that there will be still fires in plantations due to improper water management and prolonged dry season. The water table decreases to a lower level than 40 cm below peat surface causing it loses

moisture to prevent fires (J. H. M. Wösten et al. 2008). These conditions have made peatlands become susceptible to fires even if there are small fires like from people smoking and throwing their cigarettes to dry peatlands. If the areas are outside but bordered with oil palm plantations inside one hydrological unit, fire risks are high.

In scenarios assuming withdrawal, it is assumed rewetting take places and paludiculture and/or adaptive wet peat commodities-management is practiced. This assumption stands because the government of Indonesia has regulated Peat Restoration Agency in 2016 to restore at least 2 Mha peatlands (Presidential Decree No. 1/2016) in community cultivation zones, or entirely 5.7 Mha industrially managed peatlands would be restored. Restoration has been done by rewetting, revegetation, and revitalization of the local economy. The areas are targeted in cultivation areas of smallholders (and/or communities). There are some examples of wet-plantations (if not paludiculture as such) like sago plantations in Riau. However, this assumption is very optimistic if it relies on the measure taken by Peat Restoration Agency because as

Table 7 Oil palm plantation areas, annual emission, and emission reduction in three scenarios Jambi Province, Sumatra, Indonesia

In the year	Baseline		Company withdrawal				Company& smallholder withdrawal			
	Areas (*1000 ha)	CO ₂ e from oxidation and fires (Mt)	Withdrawn areas (*1000 ha)	Remaining OP (*1000 ha)	CO ₂ e from oxidation and fires (Mt)		Withdrawn areas (*1000 ha)	Remaining OP (*1000 ha)	CO ₂ e from oxidation and fires (Mt)	
					A	B			A	B
2000	31	2.61	-	31	2.61	2.61	-	31	2.61	2.61
2005	226	19.2	-	226	19.2	19.2	-	226	19.2	19.2
2010	466	39.6	-	466	39.6	39.6	-	466	39.6	39.6
2015	483	42.4	-	483	42.4	42.4	-	483	42.4	42.4
2020	618	53.3	4	614	49.2	49.3	4	614	49.2	49.3
2025	618	53.3	13	604	48.0	48.9	25	593	47.4	48.5
2030	618	53.3	119	499	41.8	51.6	220	398	37.0	41.3
2035	618	53.3	242	376	32.4	40.5	460	158	18.5	32.4
2040	618	53.3	258	360	27.9	39.9	618	0.1	4.3	26.6

• Emission A is calculated based on emission factors of fire, oxidation after successful hydrological restoration

• Emission B is calculated based on emission factors of successful withdrawal but limited impact of hydrological restoration

aforementioned that the management of peatlands shall be considered at a landscape approach (a hydrological unit) comprising some land uses and multiple stakeholders (small-holders/local communities, companies, the government for *Tahura* and some protected areas); meanwhile, the Peat Restoration Agency manages only one part of this land use, namely cultivation zone belong to communities. The withdrawal of oil palm plantations by companies is somehow unrealistic unless the regulation of the ministry of agriculture and the ministry of environment and forestry are aligned with the stringent examples of restoration measures by the Peat Restoration Agency by providing for instance by improved paludiculture management in all aspects including wet peatlands, developing markets (or marketable products), and increasing carbon sequestration.

In terms of land cover changes, the uncertainties accrue in our analysis include the age of oil palm tree. We assumed that planting starts 1 year after the license have been issued and companies finish planting in 1 year. This assumption could be relevant if companies comply with the regulation. In some cases, oil palm plantations start earlier or later than the issued permit year due to some conflicts with communities which is beyond the scope of the current study. This depends on some factors including overlapping license like observed between oil palm and acacia, as well as conflicts with communities. Our assumption to some extent is qualitative, but it remains relevant high-resolution imageries are only able to distinguish oil palm ages up to 13 years (Chemura 2012), while we needed to estimate oil palm up to 25 years. This implies that it is important to communicate with oil palm plantation managers at district levels to the development oil palm database.

In terms of CO₂ emission, the uncertainties are related to the water level, soil properties, and seasons (climatic variabilities). In one aspect, our study may overestimate CO₂ emission. Water levels may vary by locations and time, while we assume they are homogenous. CO₂ emission from the decomposition of peat materials is affected by bulk density, moisture, and temperature, which beyond the scope of our analysis. We tried to limit the uncertainties by applying emission factors of CO₂ emissions from J Jauhiainen et al. (2012); a study was conducted in a relatively long period of measurement, in nearby areas with our study, considered some soil properties (bulk density and peat temperatures). Nevertheless, considering soil properties also will not decrease uncertainties, since it is argued that lower CO₂ emission (66 ton ha⁻¹ year⁻¹) can be caused by a higher precipitation (Couwenberg and Hooijer 2013). We did not include the effect of soil nutrient to CO₂ emission as suggested by Murdiyarso et al. (2010), but they found suggested a lower CO₂ emission (59.4 ± 10.2 ton ha⁻¹, 25% of which, even then, was contributed by land clearing). The lower emission is likely due to the higher water table considered in their study. In addition, CO₂ emission from oxidation in ex-burnt areas shows lower value (42.2 ton/

CO₂-e/ha/year) (Hirano et al. 2014), which is also out the scope of this study. In another aspect, CO₂ emission in our study is conservative as climatic variabilities are not included. Lestari et al. (2014) suggested that more frequent El-Nino increases the susceptibility of peatlands to fires. CO₂ emission measurement has been more extensive after the El-Nino in 1997/1998 causing fire outbreaks in Jambi. Our calculation for CO₂ emission in 2000 may be overestimated, as Taylor and Ali (2001) suggested much lower CO₂ emission (30-ton ha⁻¹ year⁻¹) in transmigration areas managed with water table 90 cm (as the first measurement in Jambi). Nevertheless, later studies show higher emission as mentioned above (Couwenberg and Hooijer 2013; Hooijer et al. 2006, 2010).

Our study shows that the withdrawal of oil palm plantations from peatlands is important for the mitigation of carbon emission. An alternative management to oil palm plantation is highly diverse paludiculture practices. Assisting the practices requires policy enforcement like the government regulation No. 71/2014 jo No. 57/2016. Several efforts are practiced in some areas; however, it is very difficult and costly to restore peatlands once they have been drained. Hence, a major effort the GoI should do is to protect peatlands that are currently not drained and prevent draining here. It is also important that a long-term perspective is needed in restoring peatlands. Simply abandoning oil palm plantations is not helpful because replacement with paludiculture is needed while the paludiculture is not well assisted. This also implies the large investment in canal blocking and effectiveness of canal blockings are complex and site-specific. Nevertheless, yet paludiculture crops such as jelutung, sago, coffee liberica, and honey bee and plants for feeding the bee are well understood but the market needs to be further developed. Some other plants are potential but the correlation of ecological (biophysical factors of wet peatlands) requires further studies. In addition, the payment for ecosystem services, like carbon storage, potentially undermines the benefit from palm oil production (Buttler et al. 2009) or the cost for withdrawals.

Conclusion

Our study confirms that the data of oil palm plantations in Jambi Province (both in mineral and peatlands) vary by sources, and the data published by provincial offices are doubled than those at the national statistical data. Our compilation and analysis on some oil palm license maps are approaching the provincial oil palm plantation areas. Our study shows that in the past, there was a rapid expansion of oil palm plantations in Jambi from 30 to 483,000 ha (between 1987 and 2014). Up to 2014, oil palm plantations in peatlands of Jambi have associated with direct land-use change (49%) and indirect land-use changes (51%), mostly for company plantations, while

smallholders also play important roles. This oil palm development in Jambi was stimulated by decentralized policies to develop oil palm. As the moratorium of oil palm plantations in peatlands have caused substantial decrease in oil palm plantations in peatlands since 2010, in the future, smallholders take over the roles of companies in the expansion of oil palm plantations in peatlands either by encroachment in the areas surrounding of Berbak National park (the buffer zone areas) or the existing coconut, mix cropping, or rice field areas.

Our study indicates that carbon emission mitigation requires substantial restoration of peatlands being used for oil palm plantations (483,000 ha in 2014). Otherwise, oil palm plantations will increase to 617,000 ha (in our baseline scenario up to 2040), particularly done by smallholders. Such increases will result in large CO₂-equivalent emissions of 53 Mt year⁻¹ (from peat decomposition and fires) in 2040. If substantial changes in palm oil development will be taken place, including a new regulation and participation of smallholders for the withdrawal of oil palm plantations from peatlands, large areas of oil palm plantations can be restored and rewet. The restoration and rewetting will mitigate a large amount of CO₂ emissions. In the scenario assuming withdrawal of company plantations from peatlands, the oil palm plantations will be reduced to 360,000 ha in 2040 (25% reduction of oil palm plantations in 2015). This would decrease CO₂-equivalent emissions to below 2010 level. The most substantial decrease in oil palm plantations in peatlands is projected for the scenario assuming an almost full withdrawal of plantations from peatlands, resulting in a reduction of CO₂-equivalent emissions to the level of close to 2000 (4.3 MT CO₂ emission in 2040, with further decrease to zero after 2040 is possible after restoration is fully established). Otherwise, the remaining pristine peat swamp forest in Berbak National Park will be further degraded and may disappear. The degradation in Berbak National park will correspond with drainages for oil palm plantations in peatland surrounding it. Fires will be a major threat to the park as uncontrolled activities possibly conducted inside the park. This fire will associate with drainages surrounding the park, which have an impact to decrease the water level inside the park as well. Summarizing, we foresee a large potential for withdrawal of oil palm plantations between 2026 and 2035. If policies to realize withdrawals fail, oil palm plantations may continue to be developed in peatlands, and in a few decades cover about 90% of peatlands in Jambi Province (as in our baseline scenario). Nevertheless, peat restoration is a complex approach comprising multiple stakeholders and several license years.

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