Sustainable Peatland Management in Indonesia:

Towards better understanding of socio-ecological dynamics in tropical peatland management




Saritha Kittie Uda

Propositions

1. To move towards sustainability, peatland development should involve a gradual phasing out of drained crops on peat and replacing them by crops that do not require drainage. (This thesis)

2. Knowing the fit between the regulators and adopters on peatlands' use is essential for sustainable peatland management. (This thesis)

3. The key challenge for paludiculture is finding markets for its products.

4. Land is increasingly scarce and therefore informed trade-off analysis is more important than ever before.

5. The best solution for society is often not the best solution for the individual decision-makers.

6. For indigenous people, losing their land will affect their cultural identity and economy, but the loss of cultural identity may be most damaging to their well-being.

7. A healthy community always requires a healthy environment.

Propositions belonging to the thesis, entitled:

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Thesis

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Contents

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CHAPTER 1

Introduction

1.1 Background

1.1.1 Global importance of tropical peatlands

Peatlands occur in about 180 countries of the world but we have recently started to understand their important roles in the global environment as well as build up our efforts to manage them appropriately. Peatland is an area covered by peat layers at the surface, in which under natural conditions peat accumulates when the rate of organic matter production exceeds its decomposition rate, within a minimum peat depth of 30 cm (Hooijer 2013; Joosten 2010; Rieley et al. 2008). Peat is formed through the long-term accumulation of organic matter in a waterlogged environment. In its natural state, peat comprises ninety percent water and ten percent decayed plants. It is also acidic (pH 3–5), anaerobic and generally has nutrient-deficient conditions (Jaenicke et al. 2011; Yule 2010; Joosten 2010).

Covering ~3% of the global terrestrial surface, peatlands can exist in different continents with different climate conditions, from the temperate (Arctic) to the boreal and tropical zones, and from sea level to high-alpine conditions (Joosten and Clarke 2002; Xu et al. 2018). Their crucial roles in the global climate are particularly related to the global carbon cycle and the regional water cycle. Peatlands may hold ~644 Gton C or 21% of the global total soil organic carbon stock of ~3000 Gton C, persisting as the largest carbon sink among other terrestrial ecosystems. Their important role in the regional water cycle is as the water retention over the wet season and the water supplier to local watercourses during the dry season (Leng et al. 2017; Leifeld and Menichetti 2018). Undisturbed peatlands can prevent flooding during the high intensity of rainfall, while gradually release their moisture back into the air during the dry season (Leng et al. 2017; Biancalani and Avagyan 2014).

The tropical peatlands were originally covered by tropical rainforest (Dohong et al. 2017). The tropical peatlands cover ~12% of the global peatlands that may store 40 to 90 Gton C (Page et al. 2011; Leifeld and Menichetti 2018). Large portions of natural tropical peatlands have been converted to lands with other usages e.g. agriculture areas and industrial plantations. Furthermore, some peatland areas have been opened for the trees and land claiming-then-abandoned which then lead to large areas of grasslands and degraded peatlands (Law et al. 2015; Urak et al. 2017).

According to Leifeld and Menichetti (2018), it is estimated that around 41% (24.1 Mha) of the global tropical peatlands have been drained and converted into non-forested peatland areas (Figure 1.1), contributing ~1.48 (0.04–2.79) Gton CO_{2eq} emissions. Meanwhile, the largest proportion of tropical peatland is in South-East-Asia with around 57% (24 Mha) of the global tropical peatland, and almost half of this area (47%) is located in Indonesia which holds 57.4 Gton C or ~65% of the global tropical peatland carbon resource (Page et al. 2011).

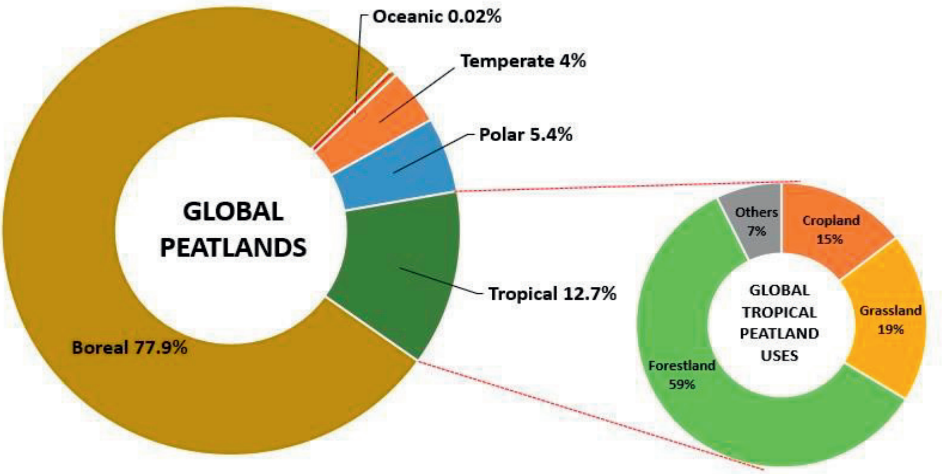

Figure 1.1 The proportion of global tropical peatland in the global peatlands and their distribution based on land uses (adapted from Leifeld and Menichetti 2018).

1.1.2 The state of the Indonesian tropical peatlands

1.1.2.1 The national distribution

Indonesian peatlands probably cover about 4% of the global peatlands and are the fourth-largest peatland area in the world after the peatlands in Russian, Canada, and the United States (Xu et al. 2018). In Indonesia, peatlands cover between 6–14% of the total Indonesia's land area, ranging from 12 to 26.4 million hectares (depending upon the sources of the peatland distribution map, Wahyunto and Suryadiputra 2008; Ritung et al. 2011; MoEFRI 2015). Based on the current official government map of peatlands in Indonesia, Indonesian peatlands are predominantly distributed in the islands of Sumatra (~43%), Kalimantan (~32%) and Papua (~24%), comprising seventeen provinces of in total thirty-three provinces in Indonesia (Ritung et al. 2011). Most of the Indonesian peatlands are located on the low-altitude coastal and sub-coastal areas and also on several hundred kilometres (50–300 km) inland along river valleys and watersheds (Dohong et al. 2017). Among the provinces with peatlands, Riau province has the largest peatland cover which is about ~26% of the total Indonesian peatland area and shares ~60% of the total Sumatra peatland areas. Moreover, Central Kalimantan province includes ~18% of the total Indonesian peatland area and ~55% of the total Kalimantan peatland areas. Also, Papua province has ~18% of the total Indonesian peatland area, covering ~70% of the total Papua peatland areas (Ritung et al. 2011).

1.1.2.2 The characteristics

In Indonesia, peatland is defined as an area with a surface peat layer greater than half a meter thick and composed of organic matter with more than 12% carbon organic (by dry weight) and less than 35% ash content (BSN 2013; ICCC–DNPI 2016; INCAS 2016). This definition differs from the previous scientific definitions on the peat characteristics, peat depth, and material contents of peat (see ICCC–DNPI 2016; Joosten 2010). However, this peatland definition is officially used to define peatland particularly related to management and policy interventions in Indonesian peatlands (ICCC–DNPI 2016).

Large peatlands in Indonesia are classified as ombrotrophic having a rain–fed source of nutrients, while few peatland areas are shown to be minerotrophic with nutrients supplied from rainfall and surface run–off and/or groundwater (Rieley et al. 2008). The Indonesian peatlands were established under high temperature with the average temperature around 23–29º C and high rainfall at 900–4824 mm/year (BPS 2018). Besides shrubs and swampy grasses, the swamp forest trees are the major vegetation cover in Indonesian peatlands. The swamp forests largely have provided the woody materials to form the peat. The Indonesian peatlands have various peat depth up to 20–m with the average peat thickness of 5.5 m and the estimated peatland volume of 1138 Gm^3 (Page et al. 2011; ICCC–DNPI 2012). The Indonesian swamp forests and peatlands have been formed during the past 14,000 years (Dommain et al. 2011). In Kalimantan, the lowland peat swamp forests are mostly aged < 5000 years but some are aged >11,000 years, formed above sea mud and sand formations (MoEF 2014).

1.1.2.3 The biodiversity

The unique characteristics of the Indonesian peatland ecosystems are also attributed to their biodiversity. The peat swamp forests in Indonesia serve as habitats for numerous flora, fauna and microbes including endemic and endangered animals and plants species such as orang–utan

(*Pongo pygmaeus*, declared as critical endangered species in 2016), proboscis monkey (*Nasalis larvatus*), Sumatran tiger (*Panthera tigris*), dragonfish/arowana (*Scleropages formosus*, a popular aquarium fish from black-water rivers in peatlands), meranti hardwood/ illipenut (*Shorea* spp., being endemic and critically endangered) and iron–wood/ulin (*Exiderottykon zwager*) (Yule 2010; Posa et al. 2011). It is marked to see that the largest population of orangutans in the world is found in Central Kalimantan which contains most of the peatland areas in the Kalimantan island (Ancrenaz et al. 2016). Moreover, about 927 flora species have been recorded in Kalimantan peat swamp forests, while about 300 plant species have been recorded in Sumatra peatlands (MoEF 2014). This ecosystem also provide refuge areas for various birds, primates, and mammals including e.g. rhinocerou horbills/*Buceros rhinoceros*, Bornean white-bearded gibbon (*Hylobates albibarbis*), owa (*Hylobates agils*) and tapir (*Tapirus indicus*), etc., also habitat for about 200–300 fish species including helicopter catfish/tapah fish/*Wallago leeri*, climbing gourami fish (*Anabas testudineus*), giant mudfish/ toman fish (*Ophiocephalus micropeltes*), striped snakehead fish (*Channa striata*), etc. (Yule 2010, Posa et al. 2011). Remarkably, the Black Water Ecosystems (BWE) can be found in the Indonesian peatland ecosystems which exhibit a unique characteristic of clear black-red watercolour (due to the presence of acids in plant material which have leached into the rivers or lakes) and valuable biodiversity including phytoplankton and at least 40 species of traditional pharmacological plants (Adinugroho et al. 2005).

1.1.2.4 The hydrological conditions and peatsoil subsidence

The hydrological status of peatland can be monitored by the fluctuations of its groundwater levels, of which many studies show that the groundwater levels play a key role in controlling the greenhouse gas emissions from the peatlands and soil subsidence (Jaenicke et al. 2010; Hooijer et al. 2012; Jauhiainen et al. 2016). The water level in Indonesian natural peat swamp forests can increase to one meter above the peat surface during the rainy season and can drop up to one meter below the peat surface in the dry season (Wösten et al. 2008). Canals and ditches have been constructed to manage water (mainly to decrease the groundwater levels of the peatlands for agriculture and plantation purposes) and also act as a mode of transportation for both people and goods (Page et al. 2002). Maintaining the groundwater level at $<$ 10 cm below peat surface will minimise the surface and deep peat fires (Putra et al. 2018; Wösten et al. 2008). The construction of dams across the drainage canals (canal blocking) has been applied to control the water levels and restore the hydrological status of the peatland ecosystems (Joosten et al. 2012). The water management involving 40–60 cm of drainage levels has been promoted as best practice for plantations in Indonesian peatlands (Lim et al. 2012), however in practice the drainage is often deeper and even drainage between 40 and 60 cm is not sustainable since it still leads to large CO_2 emissions and soil subsidence.

The soil subsidence occurs when peatlands are drained. The subsidence is a consequence of both the physical drainage of the water from the peats (in particular in the first 5–year after the drainage) as well as the chemical oxidation of dry peat. The soil subsidence leads to flood risks because many Indonesian peatlands are situated in the coastal lowlands which on the other hand will also be affected by sea-level rise due to climate change (Dommain et al. 2011; Hooijer and Vernimmen 2013). Based on observations in the drained peatlands for acacia and oil palm plantation in Sumatra, the peatsoil subsidence rates can be as high as 1.5–m in the first 5–year after the drainage and 3–5 cm in the subsequent years with a typical water table depth of about 70 to 90 cm below the peat surface (Hooijer et al. 2012). This soil subsidence will negatively affect the opportunity to use peat for crop production and other uses (Sumarga et al. 2016) and carbon loss (CO_2 emissions). However, peatland uses that do not require drainage (e.g. paludiculture crops) substantially lower the risk of subsidence (Joosten et al. 2012).

1.1.2.5 Peatland management regimes

Local management practices in Indonesian peatlands have often been adopted from the traditional agriculture practices by the indigenous people. Using the traditional approaches, the local peatland farmers select the proper locations (usually only shallow peatlands), then build non-continuous canals and cultivate selective crops or commodities alongside livestock or aquaculture farms. For instance, Dayak farmers in Central Kalimantan have only used shallow peats with thickness ≤ 50 cm (locally named *petak luwau*) for their cultivated areas which located near the river banks. They construct dams (locally named *tabat*) and water fish ponds (locally named *tatah* and *beje*) by wood constructions to maintain the water tables in their peatland farming. In this traditional shifting cultivation system in order to obtain peatlands fertile and feasible for cultivation, they also implement the traditional canal system (locally called *handil system*) to construct water management system from the river banks to up to 3–km inlands and slash–burn practices to prepare their lands. Also, they still apply schedules to manage their farms, including, for instance, burning activities for clearing lands that will be done at the end of the dry season (middle to end of August) by taking into account the weather and peat dryness conditions (Limin et al. 2007; Carmenta et al. 2017).

Some Indonesian peatlands are managed according to the community-based systems. Peatland farmers often combine their annual crops (woody crops) with some seasonal crops (e.g. vegetable crops) and/or raising livestock or fish farming in order to increase their incomes. Beside several "fancy" species planted in the drained-peatland based peatland management (e.g. oil palm, paddy, rubber and acacia), various endemic peatland plants and animals with high potential economic values are also popular be developed in the peatland areas including ramin hardwood (*Gonysstylus bancanus Kurtz*), illipenut (*Shorea* spp.), gemor tree bark (*Alseodaphne umbeliflora*), jelutung latex (*Dyera costulaca*), nyatoh latex (*Palaquium scholaris*), cajuputs oil (*Melaleuca cajuputi*), sago starch (*Metroxylon sagu*), rattan (*Calamus* spp.), some edible fruits trees (e.g. rambutan (*Nephelium* spp.), mangosteen (*Garcinia mangostana*), durian (*Durio* spp.), etc.), vegetables (e.g. kelakai edible swamp ferns (*Stenochlaena palustris*), water spinach (*Ipomoea aquatica*), bitter gourd (*Momordica charantia*), etc.), medicinal plants (e.g. bintangor latex (*Calophyllum teysmanni var. inophylloide*), contains anti-HIV properties), fish species (e.g. striped snakehead fish (*Channa striata*), climbing gourami fish (*Anabas testudineus*), gourami fish (*Osphronemus gourami*), etc.), birds (e.g. Borneo domestic duck (*Anas platyrhynchos Borneo*), muscovy duck (*Carina moschata*), etc.), and mammalia (e.g. swamp buffalo (*Bubalus bubalis carabensis*)) (Giesen 2013; Noor et al. 2014).

However, the large majority of peatlands in Indonesia are used for agriculture perennial crops (e.g. oil palm and rubber), and plantation–forestry crops (e.g. acacia for pulp and paper production). While the smallholder farmers' focus on rice, soybean, corn, fruit, vegetables, and oil palm, the large plantations (both state–owned and privately-owned) tend to focus on the commodities with products for export (e.g. palm oil, rubber, and pulp/paper). The smallholders have land < 2 ha with a mix of annual and seasonal crops or rotating farming system and manage their lands using manual farming tools (manually seedling, maintaining, and harvesting). On the other hand, plantations are managed with the monoculture system that usually involve large areas (usually several thousands of hectares), number of labourers and plasma farmers, monitoring quality of the products and certainly access to markets (Giesen & Nirmala 2018; Noor et al. 2014).

1.1.3 Social, demographic and economic aspects

1.1.3.1 Population and inhabitants

By population, Indonesia is the fourth–largest country in the world (after China, India, and the United States) with a total population of ~261 million inhabitants. The population growth rate in Indonesia is 1.34% per year with the population density rate of 137 people/km^2 and the total number of the household of ~67 million households (BPS 2018). The total population in the seventeen provinces with peatland areas shares about 30% of the Indonesia total population (~77 million inhabitants in Sumatra, Kalimantan, and Papua). In these provinces, the annual provincial population growth rate is ranging from 1.18% (in Lampung province) to 3.90% (in North Kalimantan province, a new province since 2012), with the population density rate is ranging from 9 people/km^2 (in North Kalimantan province and West Papua province) to 254 people/km^2 (in Riau province), and the total households are ranging from 155 thousand households (in North Kalimantan province) to 3.3 million households (in North Sumatra province) (BPS 2018). Typically, the peat areas are sparsely populated since they are unsuitable for constructing houses or roads. People used to live on the boundaries of the peat areas, often on the river banks. This also explains their rapid conversion to plantations: population densities are low and the area is, therefore, easy to convert to a plantation when drained.

1.1.3.2 Social characteristics

People living in and around peatland areas typically include indigenous people and migrant people (including transmigrant). Transmigrant settlers were brought to the rural areas of Indonesia often from Java and Madura in the 1980s and 1990s as part of agricultural development programs. Through the transmigration program, the Indonesia Government re-located people from some areas (mostly from areas with a high population density such as Java, Bali or other islands, having no peatlands) to live together with indigenous people in the provinces with low population density (mostly in Sumatra, Kalimantan, Papua islands). It is noted that some forest areas including peatland areas have also been converted to the transmigration areas. They spread through the rural villages (*desa*) or urban areas (*kota*). The two groups, therefore, have various ethnic customs, religious and ethnic languages.

Most of the transmigrants live as farmers in the transmigration areas, but lately, most of them work as employees in (oil palm or industrial trees) plantation companies or as labourers in forest concession or mining companies. Based on the national statistical data, about 16% of all labour forces that work in various sectors do not attain Elementary School. In rural areas, only 25% of the total population attend school, while about 75% of the total population do not have any education. The number of job applicants is not balanced with the job vacancies so that only 17% of the total job applicants obtain jobs (BPS 2018). Among the main industrial sectors, the agriculture-forestry-hunting-fisheries sector has the highest number of workers comprising about 30% of the total population of Indonesian workers, of which about 30% of this group is temporary workers, and 26% is family workers/unpaid workers.

In terms of the social structure, the local government leaders, urban leaders, and heads of villages have the most important role in the local social community's life. They involve on planning and managing administration and development of the area (urban or village). Besides, the religious leaders also play an important role in the community. Sometimes, their roles are more respected by the public than the other leaders. However, the top-down approach appears to be the most applicable approach for public management and governance/control in Indonesia. The top-down approach typically initiates command/control from the government to the people as the target groups (Ardiansyah et al. 2015). Regarding land use, the National Government has the power to determine how land-use changes can be made as well as the administrative approval, while the provincial government is recognised as the key actor in land use policy and developing land use plans, and the district government plays an important role in issuing permission or establishing formal locations and operational permits (Myers et al. 2016).

1.1.3.3 Economic development

Indonesia showed robust economic performance during the global financial crisis 2008–2009 as reflected from its Gross Domestic Product (GDP) growth rate recovery from 4.6% in 2009 to a relatively stable 6% in 2010-2012 and 5% until 2018 which was made possible by a rise in commodity exports, solid public finances and the strong domestic demands. Based on the Master Plan for Acceleration and Expansion of Indonesia's Economic Development 2011–2025, with the Government's goal of 7% average annual growth of GDP, Indonesia has potential to jump from the 16th largest economy in the world in 2012 to the 10th by 2025. From the year 1965 to 2017, Indonesia's economy has changed from being highly relying on agriculture sector to become a more balanced economy where the contribution of national GDP due to the industrial, manufacturing, and services (value-added) sectors were becoming more dominant and pronounced over the agricultural sector.

At the end of 2017, around 26.58 million Indonesians (about 10% of the total Indonesian population) were categorised as poor or vulnerable to falling into poverty class category with the highest percentage of the poor population (27%) in Papua (BPS 2018; World Bank Group 2018). Besides, 13.47% of the rural people was classified as poor compared with 7.26% of urban populations in 2017. Domestic consumption in Indonesia (especially personal consumption/ household consumption) contributes to around 55–58% of the country's total economic growth (56% in 2017). The contribution of the agricultural sector to the country's GDP declined significantly over the last five decades: from 51% in 1965 to 13% in 2017 (Indonesia–investments 2018). In 2017, one out of three Indonesians relies on farming as their main source of income (BPS 2018). Many smallholder farmers have less than half of a hectare of cultivated land. The poorest people in rural areas are the labourers working on other people’s lands, and/or smallholders operating on small plots of farming lands (< 0.5 ha) (BPS 2018). To facilitate a robust growth of the economy, the Indonesian Government focuses on revitalizing the agricultural sector particularly in the rural areas for example by providing 1 billion rupiah of village fund for each village.

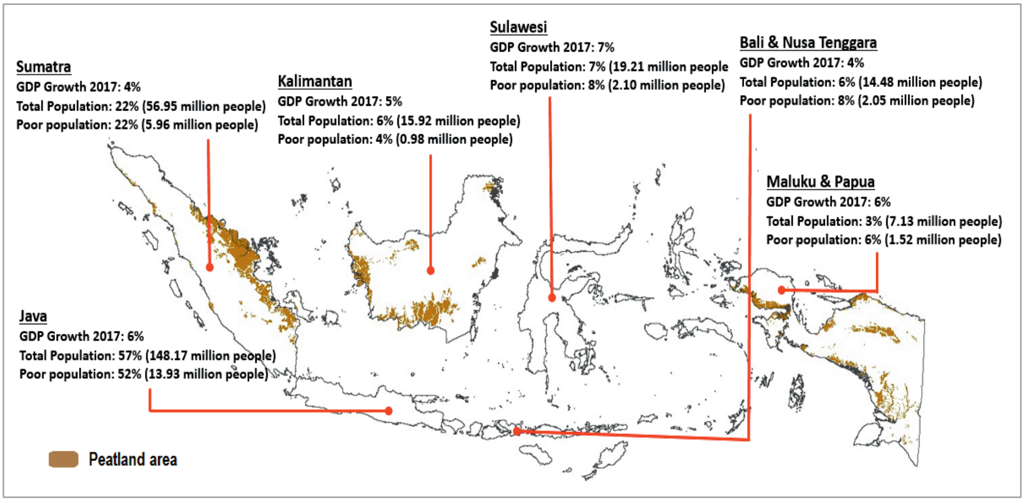

Figure 1.2 The spatial GDP growth, total population, and poor population in Indonesia during 2017 (adapted from BPS 2018).

The rapid development on peatlands also aimed to support Indonesia as one of the major global producer and exporter of various agricultural commodities particularly rice, palm oil, coffee, rubber, cocoa, spices (nutmeg, cinnamon, and cloves) and other tropical products. Crude palm oil (CPO) from Indonesia, for instance, comprises more than 50% of global exports, contributing between 1.5–2.5% of Indonesia's GDP (Indonesia–investments 2018). It has been estimated that currently around 20% of oil palm plantations are grown in peatlands in Indonesia (Miettinen et al. 2016).

In a period of 1997–1998, Indonesia had faced a political change and economic crisis which resulted in high pressures on natural resources including in its peatland areas. Deforestation and peatland degradation increased, mainly due to commercial logging, mining and opening forest for agricultural lands and transmigration/settlement. Coupled with the application of decentralization policy (since 2004) as well as the government policies for food and energy security, the forest and natural peatland conversion and annual fires still continue, including the latest vast peat fires in 2015. This led to additional CO_2 emissions as well as air pollution (smoke and haze due to peat fires) that cause adverse environmental and human health effects (Koplitz et al. 2016; Crippa et al. 2016). The vast fires in the period of 1997–1998 have produced huge carbon emissions of 2.9–9.4 Gton CO_2 (Page et al. 2002) while 2015 fires (during September–October 2015) were estimated to emit 11.3 Mton CO_2/day which exceeded the daily release of CO_2 from fossil fuel burning in the European Union of 8.9 Mton CO_2/day (Huijnen et al. 2016).

1.2 Knowledge gaps

From the background above, peatland environments are amongst the most dynamic landscapes in Indonesia which are currently experiencing major changes due to land use that mainly influenced by the economic development coupled with social, political and climatic changes. Although many studies related to peatland matters have been done in the past, it is difficult to judge whether the peatland ecosystems in Indonesia have been properly valued and managed yet. This is evidenced in four knowledge gaps that will be addressed in this study.

First, large areas of Indonesian natural peatland ecosystems have been converted, but information on the current status of peatlands and trends under different uses as well as the dynamics of ecosystem services supplied and the major differences in peat development at the scale of the country is scarce. Although the potential effects of changes in Indonesian peatlands are now increasingly well understood (e.g. Hooijer et al. 2012; Gunarso et al. 2013; Law et al. 2015; Miettinen et al. 2017) but the information regarding the spatial and temporal distribution of the peatland uses and ecosystem services supplied to estimate the contributions provided by peatlands under different uses at the scale of this country is lacking. Assessments to obtain information about the major differences in peat development at the national and regional scales are also lacking. This lack of assessments limit the ability to understand the sustainability issues in Indonesian peatlands particularly in relation to the effectiveness of proposed new policies on peatlands.

Second, the conversion of Indonesian tropical peatlands are often associated with the drainage and recurring problems of peatland fires and smoke affecting humans and the environment, but information about the impacts of episodic severe smoke from peatland fires on the local population in the affected areas is incomplete. Clear information on the potential short– and long–term effects of peat smog exposure to local people's health is lacking. Although the air quality conditions and the associated public health outcomes of Indonesian forest and peatland fires have been estimated (e.g. Koplitz et al. 2016; Crippa et al. 2016; Ruchi and Rajasekhar 2017), these assessments did not provide detailed information on the type of health outcomes due to long-term exposure to peat smog at the local scale in this country. Also, the assessments on the air pollution caused by peatland fires from the different peat depth as well as the related diseases on the local population with the different age groups are lacking. This health impact assessment is needed to understand the urgency of addressing the ongoing peatlands' conversion and degradation.

Third, various policies and regulations for better management of peatlands in Indonesia have been issued by the Government of Indonesia, but to what degree the implementation of these policies and regulations by peatland users in a specific locality is still unknown. Some later studies focused on the trade–off of peatland use particularly on plantation, fires and carbon emissions issues (e.g. Goldstein 2015; Thorburn & Kull 2015; Carmenta et al. 2017; Urák et al. 2017; Evers et al. 2017), but information on how the technical, political, and cultural interactions between peatland regulations and peatland users' practices is lacking. Also, the assessments on the implementation of peatland regulations by the peatland users are scarce.

Fourth, to prevent further degradation in Indonesian peatlands due to current drainage-based peatland uses, various potential paludiculture crops have been recommended for uses in Indonesian peatlands, but the information on the properties of each paludiculture crop particularly paludiculture crops for food is incomplete. Some studies and scattered trials have been done for several alternative paludiculture crops (e.g. Limin et al. 2007; Giesen 2013; Noor et al. 2014; Joosten et al. 2016; Tata & Susmianto 2016; Nishimura 2018), but the integrated assessment, as well as the comparison performance among these various paludiculture crops in term of their sustainability, profitability, scalability of market and the acceptability to the farmers, are lacking.

1.3 Research objectives and Research questions (RQs)

This PhD research aims to generate the relevant data and scientific analysis required for better peatland management in Indonesia by analysing selected social, health and ecological impacts of peatlands' utilisation and potential response options. To achieve this objective, four research questions (RQs) are formulated:

- RQ1 (Chapter 2): What are the peatlands' use and the ecosystem services supplied by the peatlands, the key sustainability issues and the potential response options to move towards sustainability?
- RQ2 (Chapter 3): What type of health effects are caused by the recurrent annual peatland fires in Indonesia, and how can these health effects on the local populations be quantified?
- RQ3 (Chapter 4): How is the institutional fit of the peatlands' governance in Indonesia and to what degree do these institutions promote sustainable peatland management?
- RQ4 (Chapter 5): What are the alternative development options for Indonesian peatlands, with regard to the sustainability, profitability, scalability of the market and the acceptability to the farmers?

The relevance of this research is based on the facts that (1) forests and peatlands in Indonesia are actively undergoing rapid change and development that affect the hydrology and peatsoil conditions; (2) change on peatland ecosystem conditions affect the environment and humans living in and near the peatlands; (3) air pollution from (annually recurrent) peatland fires has impacted the human health of local population and global climate; (4) local people's livelihoods may depend on the peatlands particularly the forestry and agriculture sectors; (5) the interests related to peatland utilisations are various among stakeholders; and (6) the involvement among stakeholders (particularly peatland users) is needed in order to deliver the sustainable management of peatlands.

Figure 1.3 visualises the framework in this study for analysing the socio-health-ecological impacts of peatland uses and the potential societal response options towards sustainable peatland management in Indonesia. I reviewed various literature about tropical peatland in Indonesia and analysed the drivers and pressures which influence the state of peatland ecosystem in Indonesia. I analysed economic development and social-demographic matters in Indonesian peatland areas (provinces) particularly on how these are related to people/peatland users activities (e.g. logging, forest and (peat)land clearing for agriculture and forest plantations, and drainage in peatlands) and how these have affected the peatland ecosystem regarding land cover, water depth level, and peatsoil subsidence issues. These findings are mainly used for the introduction and background in the chapters of this thesis. Addressing RQ1 and RQ2 focussed on assessing socio-ecological impacts through identifying and analysing: (i) trends the current distribution and land cover/land use of Indonesian tropical peatland at national scale particularly in zones of Sumatra, Kalimantan and Papua; (ii) trends of the ecosystem services supplied provided by these land cover/land use; (iii) human health impacts due to peat fire and smoke (specifically under RQ2); (iv) sustainability issues and the potential response options to move towards sustainability. Finally, two assessments were conducted to identify and analyse social responses with regard to the institutional fit of the peatland governance in Indonesia (under RQ3) and the alternatives development options in Indonesian peatlands (under RQ4).

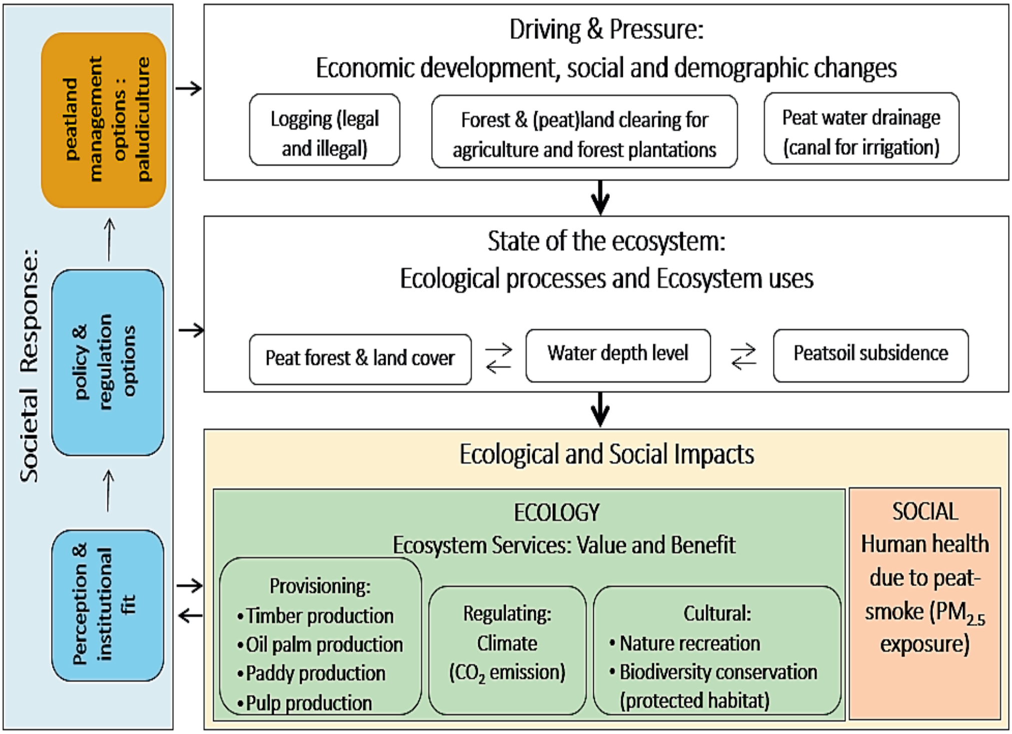

Figure 1.3 Framework of assessing the socio-ecological impacts on peatland uses and the potential societal response options in this thesis.

1.4 Study area

Following current official government map of peatlands in Indonesia, Indonesia has about 14.9 million hectare of peatland areas which covers about 8% of the total Indonesia's land area (Ritung et al. 2011). Peatlands in Indonesia are distributed widely along in the islands of Sumatra, Kalimantan and Papua. Figure 1.4 shows the peatland distribution in Indonesia and the specific locations (provinces) of this research.

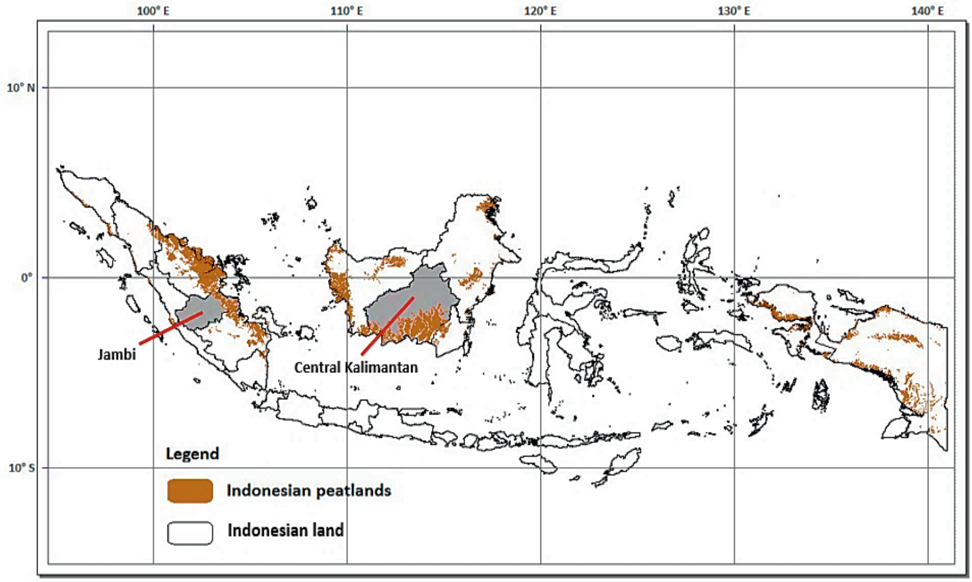

Figure 1.4. Indonesian peatland distribution map (Ritung et al. 2011); the provinces covered in the specific study sites (Jambi and Central Kalimantan) are in grey.

To address RQ1, the study areas focused on Indonesian tropical peatland areas in Sumatra, Kalimantan, and Papua covering 16 provinces of in total 33 provinces in Indonesia. This includes 10 provinces in Sumatra (Aceh, North–Sumatra, West–Sumatra, South–Sumatra, Riau, Kepulauan Riau, Jambi, Kepulauan Bangka Belitung, Bengkulu, and Lampung), 4 provinces in Kalimantan (West–Kalimantan, Central–Kalimantan, South–Kalimantan, and East–Kalimantan), and 2 provinces in Papua (Papua, and West–Papua). RQ2 and RQ4 are addressed by doing a case study in Central Kalimantan Province (Kalimantan). Addressing RQ3 specifically focused on two case study areas i.e. Jambi Province (Sumatra), and in Central Kalimantan Province (Kalimantan).

1.5 Outline of the thesis

The research questions are elaborated in the following four chapters (chapters 2, 3, 4 and 5) and subsequently synthesized and discussed in Chapter 6. Since chapters 2, 3, 4 and 5 have been published in, or have been submitted to, peer reviewed journals, they are independent research papers that can be read separately. Consequently, some repetition may occur in the introduction and methods sections of these chapters.

Chapter 2 describes the ecosystem services supplied by the Indonesian peatlands, the key sustainability issues in peatlands, and the potential responses to promote more sustainable uses of peatland. A literature review and spatial analysis are conducted mainly based on the government data in order to quantify the land cover/use and land use changes and estimate the dynamics of the ecosystem services provided by the Indonesian peatland since the year 2000. In this chapter, a general framework is proposed to identify the sustainability issues and explore how these sustainability issues differ for the three islands which have the most peatland areas in Indonesia (Sumatra, Kalimantan and Irian).

Chapter 3 focusses on the health effects of the peat smoke exposure from the recurrent annual peatland fires to the local populations. The long-term health impacts of $PM_{2.5}$ exposure on the local people in Central Kalimantan are quantified down to the village level-based from 2011 to 2015. This chapter confirms the importance of studying the long-term health effects and the great urgency for addressing the ongoing peatland conversion and degradation in Indonesia.

Chapter 4 gives an overview of the fit between national peatland regulations and the practices by peatland users in Indonesia. The concept of institutional fit is used for assessing the degree of fit between rules creators (policy–makers) and adopters (peatland users) with regard to the four peatland regulations in two provinces in Indonesia (Jambi and Central Kalimantan). Furthermore, this chapter also presents the technical, political, and cultural interactions between peatland regulations and peatland users. Some lessons for increasing the degree of fit for peatland regulations are discussed in this chapter.

Chapter 5 presents the integrated social-ecological appraisal on the various alternatives of paludiculture crops in peatlands with a particular study case conducted in Central Kalimantan. Several criteria and potentials for various paludiculture crops are proposed to assess the socio-economic-ecological aspects in terms of their sustainability, profitability, scalability of markets and acceptability to farmers. In this chapter, the key opportunities and bottlenecks for the development of these paludiculture crops are analysed in order to formulate some recommendations for the successful implementation of paludiculture in Indonesia.

The last chapter, Chapter 6, presents a synthesis of the research findings and draws the conclusions and provides further recommendations for better peatland management. This chapter discusses the main findings from the previous chapters in relation to the thesis research objectives and research questions, and their contribution to the previously identified knowledge gaps. The final section suggests several recommendations with particular references to support sustainable peatland management and peat policy in Indonesia.

CHAPTER 2

The Indonesian peatlands' use, ecosystem services and its sustainability issues

This chapter is based on:
Uda SK, Hein L & Sumarga E (2017) Towards sustainable management of Indonesian tropical peatlands.
Wetlands Ecology and Management, 25:683–701. DOI 10.1007/s11273-017-9544-0

Abstract

Large areas of Indonesian peatlands have been converted for agricultural and plantation forest purposes. This requires draining with associated CO_2 emissions and fire risks. In order to identify alternative management regimes for peatlands, it is important to understand the sustainability of different peatland uses as well as the economic benefits peatlands supply under different land uses. This study explores the key sustainability issues in Indonesian peatlands, the ecosystem services supplied by peatlands and potential responses to promote more sustainable peatland use. A literature review and spatial analysis were conducted. Based on predominantly government data, we estimate the amount of Indonesian peatlands that has been converted between 2000 to 2014. We quantify increases in oil palm and plantation forest crop production in this period, and we analyse key sustainability issues, i.e. peat fires and smoke-haze, soil subsidence and flood risk, CO_2 emissions, loss of habitat (in protected areas) and social conflicts that influence sustainability of Indonesian peatlands management. Among others we show that CO_2 emissions from peatlands in Indonesia can be estimated at between 350 and 400 million ton CO_2 per year, and that encroachment of oil palm and plantation forestry (acacia, rubber) has taken place on 28% of protected areas. However, as we examine, the uncertainties involved are substantial. Based on our findings, we distil several implications for the management of the peatlands.

2.1 Introduction

In the last twenty years, large areas of Indonesian peatland have been converted, mainly into agricultural lands for estate crop production, and plantation forest areas for pulp production (Rehman et al. 2014; Gunarso et al. 2013; Miettinen et al. 2011; Koh et al. 2011; Murdiyaso et al. 2010). This conversion brought short–term economic gains, but poses major environmental and economic risks, resulting from health and economic damages due to peat fires, soil subsidence potentially leading to flooding of millions of hectares of coastal peat lands in the course of the next decades, the very large CO_2 emissions from burning and oxidising peat, and from the loss of globally significant biodiversity contained in natural peat swamp forests (Wösten et al. 2008; Page et al. 2011; Joosten et al. 2009; Turetsky et al. 2015; Hooijer et al. 2012). For instance, drained peatland in Indonesia contributes 58% of global peatland CO_2 emissions, with marked spike during El Niño years when emissions from fire are particularly high (Hooijer et al. 2006). In addition, a range of social issues have been related to peat conversion such as the loss of access to land of traditional forest users (Thorburn & Kull 2015; Sumarga et al. 2016).

A number of Indonesian national policies aim to enhance peatland management, for instance the Ministry of Agriculture's Decree No.14 year 2009 which prohibits oil palm establishment in peatlands with more than 3–m depth. The Indonesian government has also established a strict moratorium on peat conversion since 2011. Yet, this decree is often not effective because of a lack of enforcement at the level where many of the land-use decisions are taken i.e. at village, district and provincial level (Boer et al. 2012). The national policy on peatland management has not yet been widely translated into sub-national regulation, in part due to the lack of knowledge of local policy makers on short– and long–term economic, social, and environmental consequences of different land use types. Nevertheless, in recent years, the emerging insights in the consequences of peat degradation including burning (e.g. World Bank. 2016; Turetsky et al. 2015), a better understanding of the various benefits provided by peatland ecosystems and their links to the stakeholders (e.g. Suwarno et al. 2016; Sumarga and Hein 2015) as well as new payment mechanisms (e.g. REDD+) have influenced the Indonesian playing field for peatland management. This may increase the chance for a transition to sustainability.

Although the potential effects of changes in Indonesian peatlands are now increasingly well understood, there is still no consensus on the economic benefits provided by peatlands under different uses at the scale of the country. This is important also in view of the major differences in peat development between the three major islands of the country that contain peat i.e. Sumatra, Kalimantan and Papua. In order to establish the effectiveness of proposed new policies on peatlands, based upon presidential guidance (PP No. 71 year 2014) and more recently articulated policy instructions (the direction of the President Republic Indonesia, on forest and peatland fires in a coordination meeting on 18 January 2016) a baseline assessment is needed of the current status of peatlands and the trends in their use.

The objective of this study is to analyse peatland uses and the ecosystem services supplied, the key sustainability issues, and the potential response options to move towards sustainability. We conduct a literature review and conduct spatial analysis to analyse peatland use in the period 2000–2014 in the three main islands (Sumatra, Kalimantan and Papua). We specifically discuss the uncertainties in the current datasets on peat, which is one of the main barriers for effective policy implementation. The novelty in our paper is in bringing out economic benefits and sustainability issues in Indonesian peatlands in one paper, and in the review we conduct of the often contradicting datasets on this issue. We also propose a basic framework for identifying peatland management options.

2.2 Material and methods

2.2.1 Study Area

We specifically focused on peatland areas covering Sumatra, Kalimantan, and Papua covering 16 provinces of in total 33 provinces in Indonesia. This includes 10 provinces in Sumatra (Aceh, North–Sumatra, West–Sumatra, South-Sumatra, Riau, Kepulauan Riau, Jambi, Kepulauan Bangka Belitung, Bengkulu, and Lampung), 4 provinces in Kalimantan (West–Kalimantan, Central–Kalimantan, South–Kalimantan, and East–Kalimantan), and 2 provinces in Papua (Papua, and West–Papua). These three main islands together comprise the large majority of Indonesian peatlands. We show that these islands experience entirely different trends in the conversion of peatlands.

2.2.2 Trends in peatland use and ecosystem services

We first analysed peatland cover and subsequently we link these changes in peatland use to changes in ecosystem services provided by the peatlands. We overlaid the *Indonesia Land Cover Map* for year 2000, 2003, 2006, 2009, 2012, 2014 produced by the Ministry of Forestry Republic Indonesia (MoFRI 2014) with the 2011 *Indonesia Peatland Map Scale 1:250,000* produced by Balai Besar Sumber Daya Lahan Pertanian (BBSDLP) the Ministry of Agriculture Republic

Indonesia (Ritung et al. 2011). The land cover map contains 23 land–-cover classes; and for the purpose of this study the classes were reclassified into 10 land cover classes, namely undisturbed natural forest, disturbed natural forest, plantation forest, estate crop, degraded land, paddy field, dryland agriculture, urban, open water, and other uses. We considered all primary forest as 'undisturbed natural forest' class and all secondary forest as 'disturbed natural forest' class. In addition, dry shrub, wet shrub, savanna, grasses, and open swamps areas are presented as 'degraded land' class (based on Law et al. 2015).

Agriculture areas for food crops are classified into 'dryland agriculture' class and 'paddy field' class, in which dryland agriculture class consist of pure and mixed dryland agriculture areas. The 'other uses' class is classified by aggregating fish pond/aquaculture areas, mining areas, port and harbour areas, and also cloud and no-data. In particular for analysing biodiversity habitat (protected areas), we overlaid this output with maps of protected areas produced by the Ministry of Forestry Republic of Indonesia. To analyse the trends in Indonesian peatland-use, we only considered peatland with the peat depth of at least 50 cm (Krisnawati et al. 2015) with an estimation of the total area around 14.9 million hectares (Ritung et al. 2011), although there is still uncertainty on the exact peat area and boundaries. We discussed uncertainty of the peatland data in the Discussion section of our paper. All spatial analyses were done with help of ArcGIS 10.2.

Next, we quantified seven ecosystem services i.e. timber production, oil palm production, biomass production for pulp, paddy production, carbon sequestration, biodiversity habitat, and ecotourism. These selected services are the most relevant ecosystem services in the Indonesian peatlands (Law et al. 2015; Sumarga and Hein 2014). The performance indicators, sources of data, and assessment methods for quantifying the flow of the seven selected ecosystem services (excluding carbon sequestration) are described in Table 2.1. Note that for oil palm plantation and plantation forest areas in Indonesian peatlands, we used data for the three islands recorded by various sources (see Appendix 2.2 and Appendix 2.3). Note also that we only considered forested areas inside protected areas in analysing biodiversity habitat given the difficulties and the high potential uncertainty in identifying habitat outside protected areas. This latter restriction is also based on the assumption that most of the forest outside (and to some extend also inside, in particular in Sumatra and Kalimantan) the national parks have been moderately to severely degraded due to in particular timber harvesting and slash and burn cultivation (Biancalani and Avagyan 2014; Posa et al. 2011). We acknowledge that there are many more ecosystem services provided by Indonesian peatlands (see e.g. Suwarno et al. 2015) but due to a lack of data we focus on the aforementioned services. We discuss the implications of our limited selection of services in the Discussion section.

Table 2.1 The physical units of selected ecosystem services

Type of ES	Ecosystem service	Indicator	Sources data	Method
Provisioning services	Timber production	m^3/year	Statistics Indonesia (BPS 2000-2014) Sumarga and Hein (2014)	Timber produced (m^3/year) = area of natural forest in peatland * average timber harvesting since 2000 (excluding timber in protected area).
	Oil palm production	ton/year	Statistics Indonesia (BPS 2000- 2014) Gunarso et al. (2013) Sumarga and Hein (2014)	Oil palm produced (ton/year) = area of oil palm plantation in peatland * average oil palm yields in peat since 2000.
	Biomass production for pulp	ton/year	Statistics Indonesia (BPS 2000-2014) Krisnawati et al. (2011)	Biomass produced for pulp (ton/year) = area of plantation forest in peatland * average biomass production since 2000.
	Paddy production	ton/year	Statistics Indonesia (BPS 2000-2014)	Paddy produced (ton/year) = area of paddy field in peatland * average paddy production since 2000.
Regulating Services and Disservices	Carbon sequestration and emissions	ton CO_2/year	Several sources, see text	Emission and sequestration factors were considered for different land uses, see text below.
Cultural Services	Ecotourism (Nature watching)	Number visitors/year	Statistics Indonesia (BPS 2000-2014) Forestry Statistics (MoFRI 2000-2014)	Nature watching = number of visitor to conservation areas in peatlands since 2000.
	Biodiversity conservation (protected habitat)	ha	Conservation area map Protected forest map	Biodiversity habitat = area of peat swamp forests inside protected areas[a] that are not converted to other land uses since 2000[b].

[a] Indonesian protected areas consist of two main categories: conservation areas (including national park, recreation park, nature reserve and wildlife sanctuary) and protected forest.

[b] The degraded peat forests, for example due to fires, which are not converted to other land uses are included in the calculation of biodiversity habitat.

The quantification method for carbon sequestration requires further explanation. We quantified carbon sequestration (a service) and carbon emissions (a disservice) based on the net carbon (CO_2) flux of different types of peatland use, derived from several previous studies as listed in Table 2.2. The net carbon flux may be positive (sequestration higher than emissions) or negative (emissions higher than sequestration). We quantified the net carbon flux of eight peatland uses: undisturbed natural forest, disturbed natural forest, plantation forest (referred to acacia plantation), oil palm plantation, agricultural crops, shrubs (degraded lands), water, and other land uses (referred to degraded lands), with values ranging from –85 ton CO_2/ha/year (in oil palm plantation, assuming a drainage depth of 90 cm) (Hooijer et al. 2010) to 19 ton CO_2/ha/year (in undisturbed natural forest) (Suzuki et al. 1999). Except for undisturbed natural forest and water, we assumed that the areas are drained. As shown in Table 2.2, the net carbon fluxes are negative in most types of peatland use in Indonesia, indicating that what ecosystem provides in those land uses is a disservice. We multiplied the area of each peatland use with its net carbon flux data, and finally aggregated them all to derive the estimate of carbon sequestration at national level from 2000 to 2014.

Table 2.2 The ecosystem services data used for assessing changes of ecosystem services

Ecosystem services	Ecosystem services data	Sources
Timber production (m^3/ha/year) [a]	0.49 (Sumatra), 0.29 (Kalimantan), 0.12 (Papua)	Statistics Indonesia (2000-2014)
Oil palm production (ton CPO/ha/year) [b]	2.80 (Sumatra), 2.20 (Kalimantan), 2.06 (Papua)	Statistics Indonesia (2000-2014)
Biomass production for pulp (ton/ ha/year) [c]	16.22	Krisnawati et al.(2011)
Paddy production (ton/ha/year)	4.14 (Sumatra), 3.54 (Kalimantan), 3.83 (Papua)	Statistics Indonesia (2000-2014)
Carbon sequestration (ton CO_2/ha/year) [d]	19 (undisturbed natural forest), –17 (disturbed natural forest), –80 (plantation forest, referred to acacia plantation), –85 (oil palm plantation), –48 (agricultural crops), –15 (shrubs/degraded lands), 0 (water), –15 (others land uses, referred to degraded lands)	Suzuki et al. (1999), Hirano et al. (2007), Hooijer et al. (2010), Jauhiainen et al.(2012), Hooijer et al. (2006)

[a] Timber productivity is referred to BPS data
[b] Oil palm productivity is referred to BPS data for Crude Palm Oil (CPO)
[c] Referred to biomass production of acacia plantation
[d] + indicates sequestration, – indicates emissions

2.2.3 Analysis of sustainability issues in peatland

Based on a literature review and supported by our spatial analysis, we analyse the key sustainability issues related to the current use of Indonesian peatlands. In particular, we include the following issues in our study: fires and smoke, peat soil subsidence and flood risks, CO_2 emissions (based on our analysis described above), loss of habitat, and social conflicts. We propose a general framework to order these sustainability issues. In this framework, we distinguish between four types of peatland condition: 1) non-productive or forest use, drained; 2) non-productive or forest use, no drainage; 3) productive (agricultural) use, drained; and 4) productive (agricultural) use, no drainage. With forest use is meant that the peatlands are not used for cropping systems including plantation crops or agroforestry and that they may be productive as forest systems with logging or supplying other ecosystem services (e.g. non-timber forest products, water regulation, carbon storage and sequestration), or that they may be degraded with little vegetation left. In the latter case the potential for rehabilitation to peat swamp forest exists, but rehabilitation may be hampered by recurrent fires that burn tree seedlings. The sustainability issues differ markedly for these categories as we will explore in our study. This has also repercussions for policy making, for example if peatlands are brought from the condition of productive use with drainage to non-productive use with drainage, for example because oil palm plantations are retired without subsequent peat rehabilitation including reducing drainage levels, this will not necessarily lead to sustainable peatland use. We also explore how these sustainability issues differ for the three islands that we consider.

2.3 Results

This section presents the results of our spatial analysis on peatland use and ecosystem services as well as our literature review on sustainability issues related to Indonesian peatlands. These sustainability issues are a consequence of the land use conversion to which the peatlands have been subject.

2.3.1 Indonesian peatland use

The distribution of the land cover in Sumatra, Kalimantan and Papua since 2000 reveals major changes in the use of Indonesian peatlands (see Table 2.3). Our study shows an ongoing, rapid conversion of natural forests to other land use in particular plantation crops (in particular but not only oil palm) and plantation forestry (in particular *Acacia crassicarpa* for pulp production). Indonesian tropical peatland occupied by disturbed and undisturbed natural forests decreased from about 9 million hectares in 2000 to about 6.4 million hectares in 2014. However, there is virtually no undisturbed peat swamp forest remaining in Sumatra and Kalimantan, i.e. all remaining undisturbed peat swamp forest is in Papua (where deforestation has been rapidly increasing in the last years). The fastest increase in land cover was related to expansion of oil palm plantations in Indonesian peatlands, which increased from about 700 thousands hectares in 2000 to almost 2 million hectares in 2014. Note that our figures are based on government data supplemented with data from industry for oil palm plantations. The figures are uncertain (see Appendix 2.2 and 2.3 for more detailed assessment of uncertainties) and are likely to be conservative because new plantations are not immediately reflected in government statistics.

Table 2.3 Peatland-use area (in thousands of hectares) based on land cover type in Indonesia since 2000 according to government data and various sources.

Land cover type	Year					
	2000	2003	2006	2009	2012	2014
Undisturbed natural forest	3,078	3,086	2,998	2,829	2,783	2,745
Disturbed natural forest	6,315	5,832	5,124	4,589	4,073	3,685
Plantation forest (acacia)	49	68	264	425	803	1,087[a]
Oil palm [b]	701	1,106	1,325	1,544	1,762	1,908
Dryland agriculture	691	691	712	774	797	924
Paddy field	369	373	373	384	384	362
Urban	67	67	67	67	67	67
Open water	70	70	70	70	70	70
Other uses	19	20	20	18	17	18
Degraded land	3,556	3,602	3,962	4,215	4,158	4,049

[a] industry data (see Appendix 2.3)

[b] Gunarso et al. (2013) with regression (see Appendix 2.2). Note that Gunarso et al. (2013) analysed oil palm on peat based on the Wetlands International map (Wahyunto and Suryadiputra 2008) which assumes a peatland area of 20.8 million ha. We renormalize to the 14.9 million ha of the BBSDLP MoARI map (Ritung et al. 2011) by adjusting the category disturbed forest based on the assumption that oil palm is in the large majority of cases developed in disturbed natural forest (Gunarso et al. 2013).

Our analysis also shows major differences in land conversion between the three islands. The highest conversion of natural peat swamp forest took place in Sumatra (Figure 2.1). Natural peat swamp forest has decreased from 51% (of which only 6% is undisturbed forests) of Sumatran peatlands in 2000 to only 17% in 2014 (of which 4% undisturbed forests, all located in protected areas). Recent years also show conversion of protected areas to plantation crops including in for example substantial encroachment in Berbak National Park in Jambi, Sumatra. Kalimantan takes an intermediate position with conversion of peatland to plantations still ongoing. In Kalimantan there are also large areas of degraded peatland, drained but not covered by plantations. These areas increased from 28% in 2000 to 35% of peatlands in 2014. As discussed in the next section, this has major repercussions for sustainability issues including peat fires. Most of the remaining peat swamp forests are in Papua. An issues is that data is particularly scarce and uncertain in Papua, for instance there are very few remote sensing based studies that we found with which we can compare government data. We compare our findings with other studies in the Discussion section, as well as in Appendix 2.2, Appendix 2.3, and Appendix 2.4.

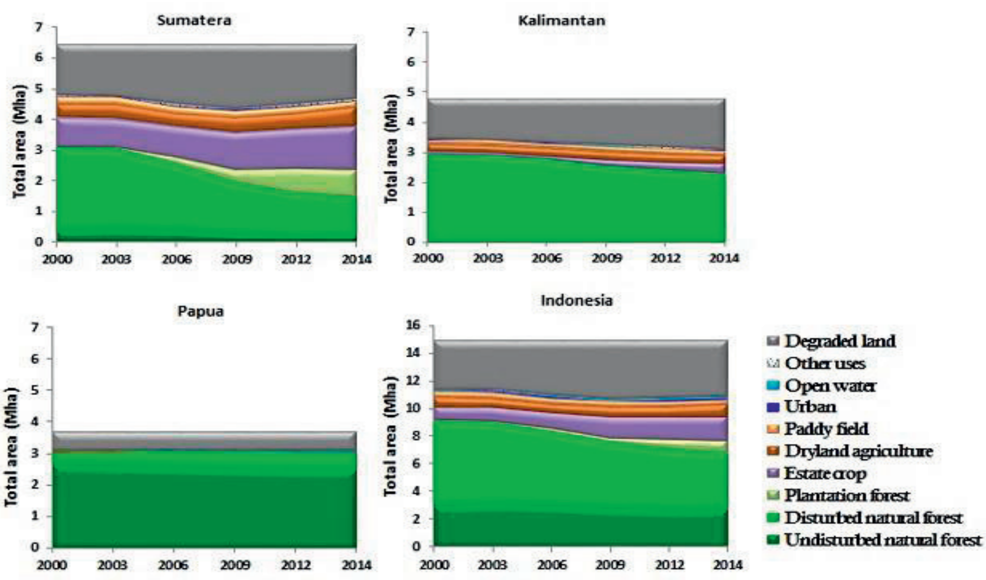

Figure 2.1 Trends of peatland use in Indonesia since 2000 (based on government data and various sources).

2.3.2 Ecosystem services provided by Indonesian peatland

Table 2.4 shows estimates of the dynamics of ecosystem services provided by Indonesian peatland since 2000. The details of the ecosystem services data used for this analysis are presented in Table 2.2.

Table 2.4 Ecosystem services provided by Indonesian peatland since 2000

Ecosystem services and disservices	Year					
	2000	**2003**	**2006**	**2009**	**2012**	**2014**
Timber production (1000 m3/year)	2272	2236	1955	1623	1430	1338
Oil palm production (1000 ton CPO/year)	1640	2518	3006	3494	3982	4307
Biomass production for pulp (1000 ton/year)	791	1102	4280	6889	13,025	17,631
Paddy production (1000 ton/year)	1336	1348	1350	1387	1386	1302
Nature watching (number of visitors in thousands/year)	97	15	41	178	65	117
Biodiversity habitat (1000 ha)	1728	1712	1690	1643	1634	1629
CO_2 emissions (million ton CO_2/year)	–210	–245	–278	–309	–352	–385

The conversion of natural peat swamp forests to oil palm and plantation forest led to an estimated almost 50% decrease of timber production within 14 years (2000–2014), and a significant increase of CPO production (almost threefold) and biomass production for pulp (more than twenty-fold), followed by a 3% decrease of paddy production during that period. Carbon emissions from peat nearly doubled in the period 2000–2014, to 210 million ton CO_2 per year or 385 million ton CO_2 per year. This compares to emissions from other sources (e.g. households, industry) of around 595 million ton CO_2 per year for Indonesia (DNPI 2010). Peatland deforestation also leads to loss of protected habitat with an average annual loss of about 8.6 thousands hectares. This reflects illegal encroachment in the protected forest areas. In 2014, around 28% of the total protected areas in peatlands in Indonesia were converted already. This protected peat swamp forest areas cover 17% of total peatland areas in Indonesia. For ecotourism, we calculated the number of visitors who visit national parks and recreation parks in peat. Our analysis shows a 21% increase of total number visitors from 97 thousands people in 2000 (of which 1% foreigners); to approximately 117 thousands people in 2014 (of which 33% foreigners). This reflects only 3% of total number visitors to all conservation parks in Indonesia during this period –given the specific biodiversity of peatlands this is relatively low but it may be relate to a lack of tourism infrastructure in peat areas where such infrastructure (e.g. boardwalks) is expensive to construct and maintain.

2.3.3 Sustainability issues in Indonesian tropical peatland management

Table 2.5 summarizes the sustainability issues in Indonesian peatlands. Note that degradation may occur in under non-productive uses.

Peatland areas with draining lead to abandoned areas, while peatland areas without draining remain as forest use areas. Shrubs, herbs, ferns or grasses are typically vegetation in abandoned areas which also categorized as degraded lands (Law et al. 2015) and having none of services and absent of Non Timber Forest Products (NTFPs). Peat swamp forest areas provide services like timber production and NTFPs, carbon stocks, biodiversity habitat, ecotourism, cultural services, etc. (Biancalani and Avagyan 2014). Peatland areas under productive uses, with or without draining conditions, provide crop production services, including oil palm plantations, paddy fields, other horticultural lands (in drained areas); and paludiculture crops plantations (in non-drained areas) such as jelutung (*Dyera* spp.), sago palm (*Metroxylon sagu*), illipenut *(Shorea* spp.), melaleuca, rattan, etc. Paludiculture is biomass cultivation in wet and or rewetted conditions (Biancalani and Avagyan 2014; Giesen 2013). Acacia plantations in peatlands are included as productive use with draining that provided biomass production for pulp service (Joosten et al. 2012).

Table 2.5 Sustainability issues in Indonesian peatlands

Condition:	Agricultural use		Non-productive or Forest use	
	Drained	**Non-drained**	**Drained**	**Non-drained**
Land cover	Plantation crops such as oil palm, rubber, acacia for pulp and paper, etc. and also food crops such as paddy and horticultural plants.	Paludiculture crops such as jelutung, sago palm, illipe nut, etc.	Abandoned and degraded lands covered by herbs, ferns, or grasses.	Ranging from degraded forest to peat swamp forest.
Sustainability issues	(i) High fire risk, in particular in not well-managed plantations. (ii) CO_2 emissions depending upon drainage depth. (iii) Soil subsidence leading to flood risks affecting production of crops during wet season. (iv) Habitat loss. (v) Social issues, in particular loss of access of local people to forest and land.	(i) Habitat loss. (ii) Social issues may occur depending upon business models (large-scale vs small-scale, inclusive versus exclusive development model).	(i) Very high fire risk, often annual burning. (ii) CO_2 emissions depending upon drainage depth. (iii) Soil subsidence leading to flood risk depending upon drainage depth. (iv) No income for local people.	Ecosystems may be well preserved or degraded (but recovery through regeneration possible in many cases), ecosystems provide different ecosystem services (e.g. various non-timber forest products, water regulation).

Fires and smoke

Fire and smoke occur through the burning of drained peat. Fire may involve burning of both above ground biomass and below ground peat. Often, Indonesian peat fires are the result of deliberate or accidental human interventions (Glover and Jessup 2006; Harrison et al. 2009). Plantation companies as well as smallholder farmers may deliberately use fire to clear land with the associated benefit that the ashes increases the pH of the otherwise acidic peat soils (Islam et al. 2016). In some cases, fire may be started accidentally or spread beyond the areas in which it was ignited (Harrison et al. 2009). Once started, fires in drained peat can spread easily (Miettinen et al. 2012; Turetsky et al. 2015). Peat swamp forests and other lands with wet conditions seldom burn (Turetsky et al. 2015). Peat fires have been reported on drained unused land, on drained peat used for wood pulp and paper (in particular in Sumatra) and on drained land used for oil palm plantations (Marlier et al. 2015b). Peat fires contribute strongly to CO_2 emissions and also cause smoke and haze (Marlier et al. 2015a; Heil et al. 2007). Because of often incomplete burning, the smoke contains a mixture of various gases including carbon monoxide, carbon dioxide, methane, ammonia, and particulate matter (PM or soot) (Stockwell et al. 2016; Gaveau et al. 2014; Heil et al. 2007). In the dry season, in particular during El Niño years, smoke can cover major parts of Indonesia and even neighboring countries (Islam et al 2016), with associated effects on human health. Reported impacts include negative health effects (acute and chronic), disruption on tourism, transport, and business, reduced enjoyment of life, contribution to the production of ozone, acid rain, and greenhouse gases, and reduced photosynthesis in plants by blocking some solar radiation (World Bank 2016). The cumulative impacts of (sequential) peatland fires, in combination with other disturbance factors such as forest conversion and peat subsidence, lead to the extinction and irreversible changes in forest species composition and vegetation structure and the disappearance of peat (Glover and Jessup 2006). Indonesia government data stated in World Bank (2016) indicated that during the fires from June to October 2015 about 2.6 million ha of land burned in Indonesia, of which 33 % was peatlands. The total costs of the fires were estimated at IDR 221 trillion (USD 16.1 billion) (World Bank 2016). About 500 thousand people were hospitalized and other thousands people suffered including people in neighborhood countries Malaysia and Singapore.

Soil subsidence and flood risks

Soil subsidence occurs when peatlands are drained. Soil subsidence rates can be as high as 1.5–m in the first 5–year after the drainage and 3–5 cm in subsequent years as observed in drained peatland for acacia and oil palm plantation in Sumatra with a typical water table depth of about 70 to 90 cm below peat surface (Hooijer et al. 2012). Subsidence is a consequence of both the physical drainage of the water (in particular in the first 5 years) as well as the chemical oxidation of dry peat. We assess (see Table 2.3) that there is about 4 million ha of drained peatland in Indonesia (in 2014), within the land cover types plantation forest, estate crops, dryland agriculture, paddy fields, and other uses. Other sources mention that about 7 to 12 million ha of peat is drained (Hooijer et al. 2010; Joosten et al. 2012; Miettinen et al. 2016). Consequently, soil subsidence leads to flood risks because many Indonesian peatlands are situated in coastal lowlands which will also be affected by sea–level rise because of climate change (Dommain et al. 2011; Hooijer and Vernimmen 2013). Soil subsidence progressively affects the possibility to use peat for crop production (Sumarga et al. 2016). Although water management involving 40–60 cm drainage levels has been promoted as best practice (Lim et al. 2012), this still involves considerable and irreversible peat subsidence (Sumarga et al. 2016). Peatland uses that do not require drainage (e.g. paludiculture crops) substantially lower the risk of subsidence (Joosten et al. 2012). Note that our assessment indicates that drainage of peatlands is still ongoing on all three islands, since new crop (including oil palm and Hevea rubber) and forestry (including Acacia) plantations require drainage.

CO_2 emission

Carbon emission results from peat fires and peat oxidation (Hirano et al. 2007). Drained peat swamp forests for other peatland uses contribute to peat fires events and increasing peat oxidation that related to increase of CO_2 emission (Hooijer et al. 2010), while the increased frequency and duration of flooding will slow down the processes of oxidation and subsidence (Biancalani and Avagyan 2014). Our calculation for CO_2 sequestration in Table 2.4 shows that the historical emission from Indonesian peatland uses i.e. disturbed forests, plantation forests, oil palm plantations, agriculture crops (paddy fields and dryland agriculture areas), degraded lands, urban and other uses areas increased over time to almost 400 million tonnes CO_2 per year in 2014. Sumatra is still the biggest emitter, contributing around 70% of the total carbon emission from Indonesian peat.

Loss of forest in protected areas

Forests are recognized as habitats with high biodiversity. Conversion of peat swamp forests to other land uses is associated with habitat loss and fragmentation affecting a range of endemic animal and plants species (Miettinen et al. 2012; Posa et al. 2011; Yule 2010). Given that many lowland forests on mineral soils have been converted to other land uses, in particular to oil palm plantations (e.g. Sumarga and Hein 2015; Sumarga et al. 2016), peat swamp forests are the last remaining refugium for a range of species including the Sumatran tigers and rhino, and including species that occur in peat but prefer forests on mineral land such as the orangutans. Logging and fire are additional pressures on biodiversity. In our study area, there are about 2.6 million hectare of protected peat swamp forests (equal to 17% of total Indonesian peatland areas). Based on our analysis, plantation forests and crop areas are also found inside these protected areas covering about 28% of land designated as protected area in 2014 (Figure 2.2), which we interpret to be the result of illegal forest encroachment. This occurs in particular in Sumatra and Kalimantan, such as in Sembilang and Danau Sentarum National Parks.

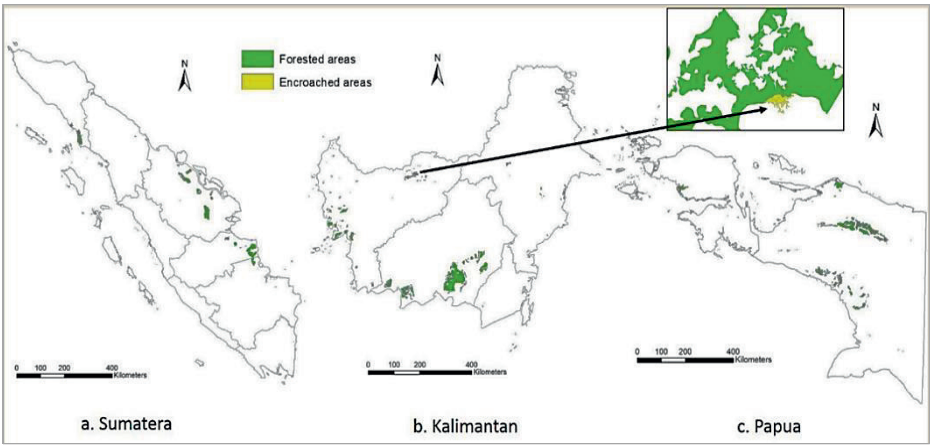

Figure 2.2. Map of habitat inside protected areas in Indonesian peatlands in 2014 (insert area: Danau Sentarum National Park, West Kalimantan).

Social conflicts

In Indonesia, social conflicts related to land use are often triggered by overlapping land ownership or land use rights. This is the result of a lack of consistent national base map integrating cadaster information, land use, concessions applied for or granted, etc., in combination with sometimes opaque procedures involving a range of government agencies (Goldstein 2015; Galudra et al. 2011; Galudra et al. 2014; Marlier et al. 2015b). Indonesia has about 8 sectoral maps of government agencies that have the authority to make their own sectoral maps for their own purposes (e.g. Ministry of Forestry with forestry maps for determining forestry areas, Ministry of Agriculture with maps of standard competence of agriculture human resources in order to support allocating land for agriculture purposes, etc.). We analysed maps from several government agencies and noted that they were indeed different, even though they covered the same subject matter such as forestry, conservation, mining areas, etc. The different outputs of these maps lead to conflicts between different companies but more often between companies and local residents whose traditional land use rights are often set aside by new permits and concessions. However, there are differences between the islands. For instance in Sumatra, there is increasing competition between companies (acacia and oil palm plantation) and local people (both transmigrants and indigenous) who also want to start or expand oil palm plantations (including on peat). This is related to the increasing scarcity of mineral land available for new plantations. On a specific occasion, local people protested outside the Regency Forest Agency until they were granted a concession to plant oil palm inside a protected area (Galudra et al. 2014). In Kalimantan, for instance, there are reports on conflicts between local communities who started to reclaim peatlands based on customary/tribal right, whereas the central and local governments used a different interpretation of the legality of different management regimes (Galudra et al. 2011; Suwarno et al. 2015). In Papua, conflicts on forestland utilization and concessions occurred due to overlapping regulations issued at the national level, provincial level, and district level leading to protests and human right violations against the local indigenous people (Hidayat et al. 2014). Hence, the pressure of land and the culture differ between the islands, but the lack of transparency in allocating land is a common factor.

2.4 Discussion

2.4.1 Uncertainties in baseline data

There is much uncertainty related to the occurrence of Indonesian peatland. The absence of common definitions, measurement techniques and other peatland-related information (forest status or intensive converted peatlands) leads to major differences in the various estimates of the area covered by Indonesian peatland. In this study, we considered peatland with at least 50–cm peat depth, however the lack of data on peat depth in many parts of the country means that this boundary is often highly uncertain. Studies reporting on the area covered by Indonesian peatlands, provide a considerable range from 12 to 26.4 million ha (see Appendix 2.1). There are also substantial differences in the maps of peatland distribution in Indonesia, including the maps published by BBSDLP Ministry of Agriculture (Ritung et al. 2011), Wetlands International (Wahyunto and Suryadiputra 2008), and the Ministry of Environment (MoEFRI 2015). These different maps reflect the potential uncertainty related to estimation of both Indonesian peatland area and its spatial distribution (see Appendix 2.1, Appendix 2.2, and Appendix 2.3), and the uncertainty propagates when it is combined with other sources of data, for example to estimate ecosystem services provided by multiple uses of peatland as analysed in this study.

We estimate ecosystem services supply based on data on land use in peatlands from a range of sources but in particular from Indonesian government data. Estimates of visitors to national parks, forest production, paddy production, acacia production are from the Indonesian government, and are generally based on survey and census data. The area covered by oil palm was analysed using remote sensing (Gunarso et al. 2013) in a study for the RSPO and we believed this to be more up-to-date than Indonesian government data. We were not able to map the spatial diversity of the supply of these services, for example forest timber production will not be equally spread over the different peat swamp forests but depend upon forest quality and species composition. Given the status of Sumatran and Kalimantan lowland forests (MoFRI 2014) it is likely that currently the majority of timber production takes places in Papua. We may also underreport the supply of specific services. For instance, oil palm productivity in Indonesia ranges from 4 to 8.6 tonnes Crude Palm Oil (CPO)/ha/year according to World Growth (2011) whereas census data from BPS (2000–2014) indicates an average yield of between 3 to 4 tonnes CPO/ha/year (depending upon the year).

The uncertainty in peat cover, and in particular in peat depth and the current land use on peat makes the implementation of policies at the local level very difficult. The various government agencies involved in evaluating applications for concessions sometimes lack accurate and up-to-date information on peat location, peat depth, existing concessions and pending concessions applications. By preparing an updated national peat map, the current One-Map policy by Indonesia government may improve the basic data as a basis for decision making (Wibowo and Giessen 2015).

2.5 Policy recommendations

The Indonesian government has voluntary pledged in 2009 to reduce GHG emissions nationally 26% by its own efforts, and up to 41% with international assistance in 2020. A more ambitious target was unveiled in 2015, specifically GHG emissions reduction up to 29% by 2030 (INDC 2015). To support these targets, the Indonesian government published government regulation PP number 71 year 2014 on the protection and management of peat ecosystems. This regulation mandated a maximum water drainage in peat of 0.4 meter where appropriate. This has the potential to reduce emissions by around 60 tonnes of CO_2/ha/year if applied, however the challenge is that in practice it is extremely difficult to maintain the water level in large areas, year round, at this level. The level is also very close to when crops will start experiencing flood damages, and hence it may be very difficult for plantations in peat to implement this water level. In addition, even a drainage of 0.4–m still leads to soil subsidence. Hence, we believe that whereas this is a welcome initiative, it will not be sufficient to safeguard peat from fires and soil subsidence. Our analysis of Indonesian peatland conditions points to four main potential approaches for Indonesian peatland use depending upon their condition (Table 2.6).

Paludiculture crops (e.g. jelutung, sago palm, etc.) are crops that do not require drainage and therefore pose much lower fire risks, CO_2 emissions and enable cropping over the long-term given that there is no soil subsidence. However, currently they are less financially attractive compared to oil palm and rubber productions (Giesen 2013; Joosten et al. 2012; Sumarga et al. 2016) and therefore their cropping will depend upon policies and regulations that limit growing the crops that require drainage in peat. We also note that the 'traditional' crops such as oil palm have benefitted from a long period of breeding and value chain development, which is still in its infancy for the paludiculture crops. From an economic perspective, i.e. when the costs of externalities such as CO_2 emissions, health effects, soil subsidence and loss of productive land in the longer term are considered (e.g. World Bank Group 2016), paludiculture crops such as jelutung already are more profitable than oil palm and Hevea rubber on peat (Sumarga et al. 2016).

Table 2.6 Policy priorities for sustainable peatland uses in Indonesia

Condition:	Agricultural use	Non-productive and Forest use
Drained	• Productive uses with paludiculture crops, phase out oil palm and plantation crops that require drainage over time • Withdraw strategically located areas where drainage has major effects on surrounding, non-drained areas • Fire control	• Protect remaining forests • Rehabilitate and rewet peatlands by blocking drainage canals • Fire control
Non-drained	• Stop new drainage • Promote productive uses with paludiculture crops • Fire control	• Protect remaining forests • In degraded forests: reforestation • Fire control
All areas and uses	• Improve monitoring of the condition of peat areas, including land cover, land use and drainage • Improve monitoring of the local implementation of peat related policies • Improve enforcement of peat related policies	

2.6 Conclusion

Indonesian peatlands have increasingly been converted for agricultural and plantation forest purposes in particular for oil palm, acacia and rubber. In the process, ecosystem services provided by peat swamp forest (e.g. carbon sequestration, biodiversity conservation) have been replaced by the production of agricultural commodities. The highest conversion of natural peat swamp forest took place in Sumatra. In Kalimantan conversion started later, and some peat swamp forest is still remaining – but the island is undergoing rapid land use change at the moment. Most of the remaining peat swamp forests are in Papua, where unfortunately there is also the largest lack of reliable information on forests and peatlands. On the positive side, this has led to major increases in palm oil production (nearly a factor 3 increase in production on peatlands between 2000 and 2014) and biomass production for pulp (a factor 20 increase in the same period). On the negative side, these production levels are not sustainable since progressive soil subsidence will lead to seasonal flooding of the drained plantations in the coming decades ensuring that they will need to be taken out of production (e.g. Sumarga et al. 2016). In addition there are significant externalities related to peat fires and health problems, CO_2 emissions and loss of habitat. To move towards sustainability, alternative peat development scenarios should be developed, which should involve a gradual phasing out of oil palm and other drained crops on peat and replacing them by crops that do not require drainage in combination with forestry including timber and non-timber forest production.

Acknowledgements

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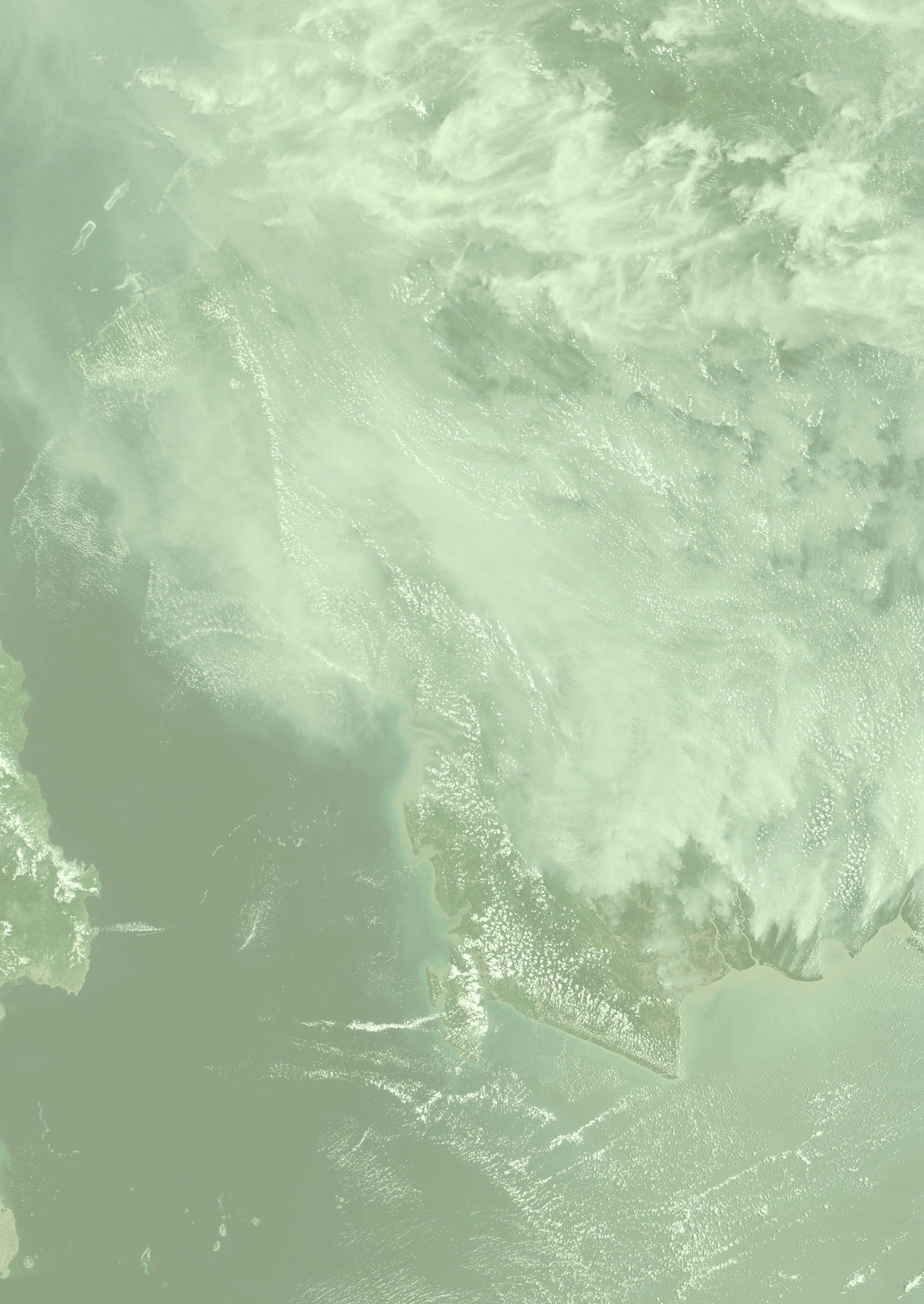

CHAPTER 3

Assessing the health impacts of peatland fires in Indonesia

This chapter is based on:
Uda SK, Hein L & Atmoko D (2019) Assessing the health impacts of peatland fires: a case study for Central Kalimantan, Indonesia.
Environmental Science and Pollution Research, 26(30):31315–31327.
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Abstract

The conversion of Indonesian tropical peatlands has been associated with the recurring problems of peatland fires and smoke affecting humans and the environment. Yet, the local government and public in the affected areas have paid little attention to the impacts and costs of the poor air quality on human health. This study aims to analyse the long-term health impacts of the peat smoke exposure to the local populations. We applied the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model to determine the smoke dispersion and the associated $PM_{2.5}$ concentrations of the resulted plumes from the fire hotspots in the deep and shallow peatlands in Central Kalimantan, Indonesia that occurred during a 5-year period (2011–2015). We subsequently quantified the long-term health impacts of $PM_{2.5}$ on the local people down to the village level based on the human health risk assessment approach. Our study shows that the average increase in the annual mean $PM_{2.5}$ concentration due to peatland fires in Central Kalimantan was 26 $\mu g/m^3$ which is more than twice the recommended value of the World Health Organisation Air Quality Guidelines. This increase in $PM_{2.5}$ leads to increased occurrence of a range of air pollution–related diseases and premature mortality. The number of premature mortality cases can be estimated at 648 cases per year (26 mortality cases per 100,000 population) among others due to chronic respiratory, cardiovascular and lung cancer. Our results shed further light on the long-term health impacts of peatland fires in Indonesia and the importance of sustainable peatland management.

3.1 Introduction

Smoke from peatland fires is a significant air pollution source associated with harmful impacts on human health and the environment. In Indonesia, peatland fires are mostly anthropogenic that may be started by farmers as part of small–scale land clearing activities, and by private companies to prepare for plantation establishment (Miettinen et al. 2017; Uda et al. 2017; Atwood et al. 2016; Turetsky et al. 2015; Marlier et al. 2015). In particular in the dry season, peat fires are difficult to control and may spread well beyond the area of ignition. Because of incomplete burning, peatland fires strongly contribute to emission of smoke haze pollutants, which contain a mixture of (fine and coarse) particulate matters or roots and various toxic and non–toxic gases (Stockwell et al. 2016). During the peatland fire episodes, in particular during the dry seasons in El Niño years, smoke covers major parts of Indonesia and even neighbouring countries (Tacconi 2016; Crippa et al. 2016). This results in negative impacts on people's health and imposes substantial costs to society. Reported impacts include general negative health effects; disruption on transportation (flights, road trips) and tourism business; reduced enjoyment and quality of life; increased production of ozone, acid rain, and greenhouse gases; biodiversity loss; and reduced photosynthesis in plants because of the blocked solar radiation (Benjamin et al. 2017; World Bank 2016; Koplitz et al. 2016; Hirano et al. 2012).

To further specify the impacts of peat fires, in the El Niño year of 2015 approximately 4.6 million hectares were burned, with 37% located on peatland areas, and half of the total burned area was in Kalimantan (Lohberger et al. 2018). During the period August–November 2015, many parts of Indonesia, particularly in Kalimantan and Sumatra, were reported to be heavily blanked in thick smoke (Stockwell et al. 2016). The average daily CO_2 emissions over the Maritime southeast Asia region (including Indonesia, Malaysia, Singapore) during the 2015 Indonesia forest and peatland fires (biomass burning) reached 11.3 Mton CO_2/day. This figure surpassed the daily release of CO_2 from fossil fuel burning in the European Union (8.9 Mton CO_2/day) (Huijnen et al. 2016). The fires also led to very high atmospheric particulate matter (PM) concentrations. For instance, in Central Kalimantan province, the Pollutant Standards Index (PSI) of fine particulate matter ($PM_{2.5}$) had been reported to exceed 1500 ($PM_{2.5} > 1250$ μg/m^3), considerably above short–term exposure levels considered hazardous for human health (PSI > 300, $PM_{2.5} > 250$ μg/m^3) (Atwood et al. 2016). The health effects of the inhalable PM both in short–term and long–term are well documented which include respiratory and cardiovascular morbidity (e.g. aggravation of asthma, respiratory symptoms and an increase in hospital admissions) and mortality from cardiovascular and respiratory diseases and from lung cancer (WHO 2013).

Chapter 3

Indonesia lacks real-time and regional air quality data due to the absence of an integrated air quality monitoring network. The air quality monitoring stations are sparse which results in insufficient data about high-risk air pollution exposures, thereby limiting the assessment of the severity of the fire–related air pollution episodes. Although the air quality conditions and the associated public health outcomes (e.g. mortality) of Indonesian forest and peatland fires have been estimated (e.g. Koplitz et al. 2016; Crippa et al. 2016; Ruchi and Rajasekhar 2017), there is still a lack of information about the potential short– and long–term related diseases at the local scale in this country (Carmenta et al. 2017). Consequently, local governments and communities in the affected areas have paid little attention to the impacts and costs of the poor air quality on the human health and environment that are caused by the mentioned annual peatland fires (Sumarga 2017; Uda et al. 2018).

This study aims to estimate the human health outcomes of the long-term exposure to peat smoke in the province of Central Kalimantan. The results can inform policymakers and stakeholders (including peatland users) on the urgency of tackling (recurrence) peatland fires and also help to increase public awareness on the importance of healthy air quality. We considered peatland fire evidences from Central Kalimantan during a 5-year period (2011, 2012, 2013, 2014 and 2015) and conducted a literature review and spatial analysis to analyse the smoke dispersion in order to estimate the annual $PM_{2.5}$ concentrations of the peatland fires from the deep and shallow peatland areas. We assume that the conditions during this 5-year period are representative of the long-term conditions. Subsequently, we assess long-term effects of $PM_{2.5}$ exposure to local people's health based on the average concentration in these 5 years, assuming that this period, which includes one El Niño year, is representative for people's long–term exposure.

3.2 Material and methods

3.2.1 Study Area

Indonesia has about 14.9 million hectares of tropical peatlands (about 8% of its total land area) that are mainly distributed across the regions of Sumatra, Kalimantan and Papua. This study specifically focuses on Central Kalimantan Province, Indonesia (see Figure 3.1) which comprises about 56% of the total peatland area of the Kalimantan island and about 18% of the total Indonesia peatlands (Ritung et al. 2011). Central Kalimantan is the third largest province in Indonesia, located between latitudes 0° 45' North and 3° 30' South, and longitudes 110° 45'–115° 51' East, with a total area of 153,564 km^2. It has about 2.7 million hectares of peatland areas (about 18% of the total Central Kalimantan Province area), of which 59% is deep peatlands (over 3–m deep). Central Kalimantan Province covers 14 regencies (about 1569 villages), with a population of approximately 2.5 million people (BPS Central Kalimantan 2016). Central Kalimantan has approximately 13 million hectares of forest areas (INCAS 2016). However, over the past 20 years, the forest and peatland areas in this province have been converted extensively due to land use changes and annual fires from land clearing which have been contributing significantly to the total greenhouse emissions in Indonesia (Miettinen et al. 2016; Sumarga 2017).

3.2.2 Analysis of smoke dispersion and associated $PM_{2.5}$ concentration of peat smoke

To estimate the long-term health effects of peat smoke, we first calculated the increase in annual concentration of $PM_{2.5}$ resulting from peat fire hotspots in Central Kalimantan peatland areas during 2011–2015. We assumed that the 5-year period of 2011–2015 (that includes one El Niño year) is representative for the long-term concentration and exposure of peat smoke on the people living in the areas. We randomly selected 200 fire hotspots each year (100 in deep and 100 in shallow peat) that occurred in the peatlands located in Central Kalimantan, and subsequently we used the processed data as input for the smoke dispersion model that was used to analyse the associated $PM_{2.5}$ concentration. Fire hotspots are identified with the MODIS Aqua/Terra sensor, and smoke plumes were aggregated to obtain a map depicting the distribution of smoke over Central Kalimantan. We scaled up the smoke concentration by multiplying the found, averaged, smoke concentration caused by a peat fire by the number of hotspots occurring in shallow respectively deep peat in a given year, and further calibrated the model to the Palangka Raya air quality monitoring site (there is only one air quality measurement station in Central Kalimantan, which provides daily estimates of $PM_{2.5}$ concentrations). We combined this with information on population density and thereby local exposures to $PM_{2.5}$, and subsequently estimated the long-term health effects for the local populations on village-based analysis.

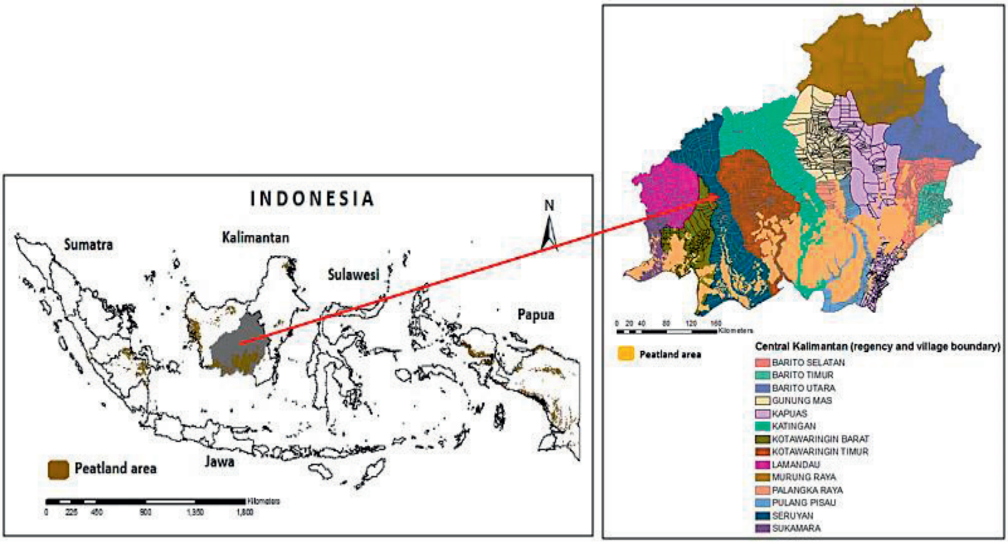

Figure 3.1. Indonesian peatland distribution map (Ritung et al. 2011); Central Kalimantan province as the study area is in grey, covering 14 regencies.

In order to generate a Central Kalimantan peatland map, we overlaid the Indonesia Peatland Map Scale 1:250,000, produced by Balai Besar Sumber Daya Lahan Pertanian (BBSDLP), the Ministry of Agriculture Republic Indonesia (Ritung et al. 2011), with the Central Kalimantan Land Cover Map, produced by the Ministry of Forestry Republic Indonesia (MoFRI 2014). Next, we overlaid the aforementioned result with the burned area and the hotspot datasets from 2011 to 2015 (containing information about latitude and longitude coordinates, date and time, confidence values; obtained from the MODIS Aqua/Terra satellites) that was obtained from the Sipongi output programs by Ministry of Environment and Forestry Republic Indonesia (MoEFRI 2015) and the Lembaga Penerbangan dan Antariksa Nasional/LAPAN (The Indonesian National Institute of Aeronautics and Space 2015). The hotspots indicate the temperatures in a specific sensor element above a certain threshold that are defined as active fire events (burning material on the surface). Here, the MODIS sensor defines a hotspot as a detected temperature above 47° C located within a spatial resolution of about 1 km^2 (Giglio 2015; MoEFRI 2015). We only constrained the data with a confidence degree of hotspot equal to 80–100% corresponding to the high likelihood of real fires (in line with Giglio 2015; The Indonesian National Institute of Aeronautics and Space 2015). Based on this result, we then analysed the distribution of the hotspots in the deep and shallow peatland areas in Central Kalimantan. In total, there are about 3155, 3604, 1246, 7454 and 21,408 hotspots in peatland areas that were recorded during the year of 2011, 2012, 2013, 2014 and 2015 respectively.

For the purpose of this study, it is impossible to analyse all of these hotspots, so we analysed 200 randomly selected hotspots each year and we analysed and averaged them to define an 'average' smoke plumes of a peat fire hotspot in a given year. Of the selected 200 hotspots, 100 hotspots were selected to occur in shallow peatlands and 100 hotspots in deep peatlands. We followed code of peat depth by Ritung et al. (2011) to distinguish these hotspots in the peatlands, i.e. codes of D1 and D2 are for the shallow peatlands (50–200 cm peat depth) and codes of D3 and D4 are for the deep peatlands (> 200–cm peat depth). The monthly hotspot data were extracted and those with confidence degree ≥ 80 were then selected and overlaid on the peat map.

Next, we applied the Hybrid Single-Particle Lagrangian Integrated Trajectory model (HYSPLIT version 4.9) to determine the atmospheric dispersions and plume trajectory as well as the $PM_{2.5}$ concentration produced by each selected hotspot. With the HYSPLIT model, we estimated the spatial and temporal evolution of $PM_{2.5}$ from a prescribed burn using the location and the burned area as inputs (Stein et al. 2015). The Global Data Assimilation System (GDAS) with a horizontal resolution of 0.5° was used as the meteorological and emission data input. GDAS is daily archive files that contain global 3-dimensional gridded meteorological model output. The files contain 3-hourly data, at a half-degree latitude by half-degree longitude with resolution 720 × 361 grid points, on 55 hybrid sigma-pressure surfaces. Here, the HYSPLIT model does not take into account the effect of the following: chemical reactions; dense gases; by-products from fires, explosions, or chemical reactions; complex terrain–other than what is resolved by the meteorological model's terrain (see https://ready.arl.noaa.gov/hypub/limitations.html). We also applied several assumptions in the HYSPLIT modelling for the runtime and deposition parameters. This included 24 hours for the total duration of transported pollutant material downwind (mostly peatland fires in Central Kalimantan were more than 24 hours), 24 hours for the pollutant averaging period (output interval of concentration released), 100 m AGL (above-ground-level) for the top averaged plume's layer (100 m AGL is the minimum height to adequately represent the plume and indicate the concentration), and deposition parameters for the dry deposition rate (0.001 m/s) and for the wet deposition rate (8.0E-05 litter/s). The output of the HYSPLIT model shows the dispersion within the direction of the plumes, with the range concentrations of $PM_{2.5}$ (including the maximum and minimum concentrations).

We then aggregated all the plumes of "observed hotspots" resulting from the HYSPLIT model and adjusted the resulting $PM_{2.5}$ concentrations by calibrating them with the annual average concentration of $PM_{2.5}$ in Palangka Raya city for the total amount of hotspots in peatland areas during 2011–2015. We used these average concentrations of $PM_{2.5}$ to estimate the annual concentration of $PM_{2.5}$ of all observed hotspots in a given year. The resulting $PM_{2.5}$ concentrations were aggregated (spatially) in order to produce a map of annual mean concentration of $PM_{2.5}$ for a 5-year period (2011–2015). The ground-based observation data used for the calibration was taken from the Air Quality Monitoring System/AQMS (or Indeks Standar Pencemaran Udara/ISPU), published by the Environmental Agency (Badan Lingkungan Hidup Daerah/BLHD) of Palangka Raya city, Central Kalimantan, and Badan Meteorologi Klimatologi dan Geofisika/BMKG (the Indonesian Agency for Meteorological Climatological and Geophysics). By using the Central Kalimantan administration map (published by Central Kalimantan Statistical Bureau), we spatially quantified the annual average concentration of $PM_{2.5}$ in every village based on the village boundaries. We subsequently used this output to assess the exposure of people to $PM_{2.5}$ on a village-based analysis as described in the next step. All spatial analyses were implemented using ArcGIS 10.5 at a spatial resolution of 1–km^2 grid cell and with the output coordinate system of WGS 1984 UTM Zone 49S. All of the HYSPLIT models were done using NOAA ARL (Air Resources Laboratory NOAA) software (Stein et al. 2015).

3.2.3 Analysis of the long-term human health impacts of the $PM_{2.5}$ exposure

In order to analyse the mortality impacts of $PM_{2.5}$ exposure resulting from the peat smoke, we quantified the health impacts (number of premature mortality cases including total mortality and mortality due to different diseases) in the receptors (inhabitants) in each village. We applied a human health risk assessment based on Ostro (2004), Burnett et al. (2014), Crippa et al. (2016) and Koplitz et al. (2016). We calculated the Relative Risk (RR) and the Attributable Fraction (AF or Impact Fraction, IF) of premature mortality for three types of the health case categories, i.e. cardiovascular, lung cancer and chronic respiratory diseases due to long-term exposure to $PM_{2.5}$ (Crippa et al. 2016). We applied the log-linear exposure formula for the relative risk function as $RR = [(X + 1)/(X_o + 1)]^{\beta}$ for $X \geq X_o$, where X refers to the average of the annual mean concentration of $PM_{2.5}$ (in $\mu g/m^3$), during the period of observation. X_o is the lowest observed concentration from the average of annual mean of $PM_{2.5}$ concentration ($\mu g/m^3$, as the lowest effect level) and β is the excess mortality per-unit increase in $PM_{2.5}$ with suggested β coefficients of 0.1551, 0.23218, 0.003794 and 0.001829 for measuring cardiovascular case, lung cancer case, chronic respiratory case and premature mortality, respectively (Ostro 2004). For the purpose of this study, we renormalize the suggested β coefficient for all-cause of mortality (0.0008) and chronic respiratory case due to PM_{10} exposure (0.00166) by multiplying the coefficient with the Indonesia conversion factor 48/21 ($PM_{10}/PM_{2.5}$ ratio) (WHO 2014).

Next, we calculated the attributable fraction by using AF function as $AF_d = RR_d(X) - RR_d(X_o)$ where RR_d is relative risk of disease (Crippa et al. 2016). The total number of mortality cases due to long-term exposure of $PM_{2.5}$ from peatland fires and smoke in the study area were calculated by multiplying the attributable fraction (AF) with the baseline mortality risk of the related health case and the number of population in the study area (Ostro 2004; Koplitz et al. 2016; Crippa et al. 2016).

It is noted that in this study, the baseline mortality rate is based on the overall death rate (CDR) for Central Kalimantan in 2015 which was 5.8 per 1000 population of all ages (BPS Central Kalimantan 2017), reflecting a still growing population (Bappenas Indonesia 2013). We used village-based data for year 2015 provided by the Central Kalimantan Statistical Bureau (BPS Central Kalimantan 2016) which were supplemented with the health data (e.g. number of live birth, number of registered patients) from the Central Kalimantan Health Department (Dinas Kesehatan Provinsi Kalimantan Tengah 2016; The Indonesian Ministry of Health 2016). We calculated the number of deaths in each village by multiplying the value of the death rate 0.0058 with the total population of each village. We then defined the number of mortality for each health case by multiplying the total number of deaths in each village with the percentage of deaths for the related health case categories obtained from IHME-GHDx Data 2017 (IHME-GHDx 2018). Specifically for Central Kalimantan, the percent of deaths in 2015 for all ages are 33%, 4% and 2% for the related health case categories of cardiovascular, chronic respiratory and lung cancer, respectively. The performance health case categories, the percent of deaths, the relative risk functions, and the age group and its fraction values are described in Table 3.1. A sensitivity analysis was conducted by changing the relative risk function as linear exposure formula i.e. $RR = \exp[\beta(X - X_o)]$ or as well as varying X (the decreasing and increasing) by 10 $\mu g/m^3$ and X_o at 10 $\mu g/m^3$ (the lowest level according to WHO 2016).

Table 3.1. The potential health case categories, percent of deaths, age groups and fraction values, and relative risk function to $PM_{2.5}$

Health case categories	**Percent of deaths from exposure to $PM_{2.5}$ for all ages (%)** [a]	**RR function and β coefficient for $PM_{2.5}$** [b]	**Age group and fraction (%)**
Premature mortality (all-cause) [c]	100	Linear exposure; 0.001829	All ages (100%)
Chronic respiratory [c]	4	Linear exposure; 0.003794	Children < 5 years (10%)
Cardiovascular	33	Log-linear exposure; 0.15515	Adults 30 and above (44.5%)
Lung cancer	2	Log-linear exposure; 0.23218	Adults 30 and above (44.5%)

[a] The percent of deaths in 2015 for all ages in Central Kalimantan based on IHME-GHDx (2018).

[b] The suggested β coefficients are based on Ostro (2004).

[c] We renormalize the suggested β coefficient of PM_{10} by multiplying with the Indonesia conversion factor 48/21 ($PM_{10}/PM_{2.5}$ ratio) (WHO 2014).

3.3 Results

3.3.1 Smoke dispersion and associated $PM_{2.5}$ concentrations from the peat smoke

Based on our spatial analysis, the average of annual mean concentration of $PM_{2.5}$ from the smokes due to peatland fires in Central Kalimantan in the period 2011–2015 was 26 $\mu g/m^3$ (ranging from 4 to 103 $\mu g/m^3$ on the village-based analysis). This is more than twice the recommended WHO AQG annual mean for $PM_{2.5}$ concentration exposure limit which is 10 $\mu g/m^3$ (WHO 2006). Among all regencies in Central Kalimantan, Palangka Raya city showed the highest annual mean of $PM_{2.5}$ concentrations with the average level of 38 $\mu g/m^3$ (ranging from 27 to 43 $\mu g/m^3$ on the village-based analysis) over the 5-year period. Notably, the average concentration of $PM_{2.5}$ in Central Kalimantan for the year 2015 alone (the year with the highest peatland fire occurrence) was 48 $\mu g/m^3$ (ranging from 40 to 190 $\mu g/m^3$), while in Palangka Raya alone was 65 $\mu g/m^3$ (ranging from 53 to 84 $\mu g/m^3$). It is noted that the study by Koplitz et al. (2016) estimated the average of $PM_{2.5}$ concentration across Indonesia, Malaysia and Singapore due to the 2015 fires was ~60 $\mu g/m^3$ (over the 2 month period September–October 2015).

Our analysis also shows that fires in both deep and shallow peatlands in Central Kalimantan are important sources of air pollution (see Appendix 3.1). Fires from deep and shallow peat contribute roughly the same to the annual mean increase in $PM_{2.5}$ concentration, i.e. both contribute approximately 13 μg/m^3 (ranging from 2 to 131 μg/m^3 for the deep peatlands, and ranging from 0.7 to 50 μg/m^3 for the shallow peatlands). During the 5-year period 2011–2015 from peatland fires, 99% of total villages (1554 of 1569 villages) showed an average annual mean $PM_{2.5}$ concentration above 10 μg/m^3. Among the 1569 villages in Central Kalimantan, 4 villages (all are in Kapuas regency) showed annual mean $PM_{2.5}$ concentrations above 80 μg/m^3 (ranging from 82 to 103 μg/m^3 on the village-based analysis). This means the 4 villages (with the total population of 5886 inhabitants) experience annual mean $PM_{2.5}$ concentrations that exceed more than eight times the exposure limit of $PM_{2.5}$ concentration indicated by the WHO AQG. We have noted that some villages (including the 4 villages with the annual mean $PM_{2.5}$ concentrations above 80 μg/m^3) are also located in ex-Mega Rice Project's area with intensive peatland utilisations over the last decade. In Central Kalimantan during 2011–2015, the total number of hotspots that occurred in deep peatlands was 8% greater than that occurred in shallow peatlands–hence both shallow and deep peatlands contribute substantially to the health effects resulting from peat fires.

Figure 3.2 displays the distribution of the annual mean value of $PM_{2.5}$ concentration based on village boundaries in Central Kalimantan from one aggregated plumes of hotspots located in the peatland areas. Our spatial analysis revealed that only 1% of total villages (15 of 1569 villages) in Central Kalimantan showed low $PM_{2.5}$ concentrations (less than 10 μg/m^3) in accordance with the exposure limit for $PM_{2.5}$ suggested by WHO AQG. More concerning, about 78% of total villages in Central Kalimantan (1230 of 1569) experience $PM_{2.5}$ exposures with annual average $PM_{2.5}$ concentrations $\geq$ 20 μg/m^3. This means that about 2 million inhabitants (about 80% of the total population in Central Kalimantan), including more than 430 thousand children aged 5 to 14 years, 65 thousand infants aged between 0 and 1 year, and over 1.4 million adult people aged 27 years and older, experience health impacts due to the inhalation of $PM_{2.5}$.

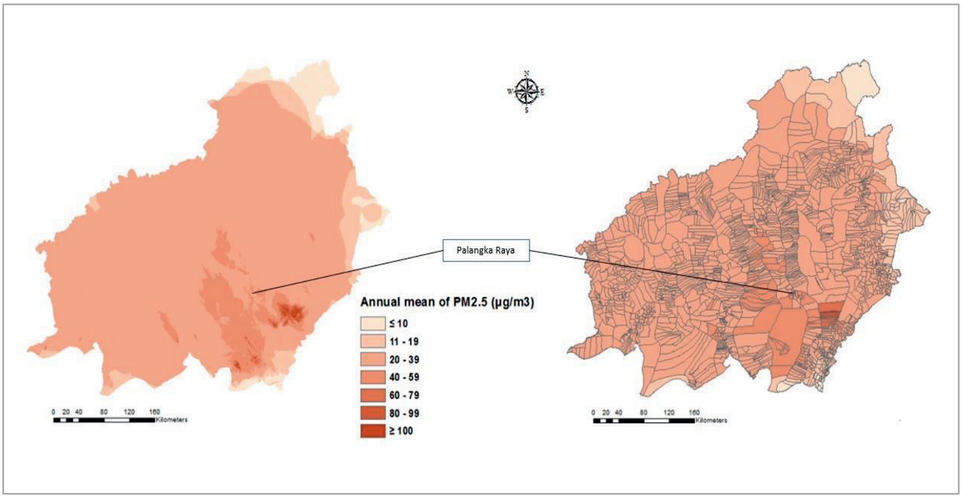

Figure 3.2. Smoke dispersion and associated average increase in annual mean $PM_{2.5}$ concentrations (μg/m^3) in Central Kalimantan, Indonesia from hotspots in peatlands during a 5–year period (2011– 2015); the right-hand map is based on 1569 village boundaries.

3.3.2 Potential human health outcomes

Table 3.2 summarizes the potential health outcomes with the number of premature mortality and disease cases experienced by the local populations in Central Kalimantan due to long-term exposure to $PM_{2.5}$ with an increase in annual mean $PM_{2.5}$ concentration of 26 μg/m^3 during 2011 to 2015. Appendix 3.2 presents the sensitivity analysis for changing the relative risk function and varying X and X_o (concentrations of $PM_{2.5}$).

Table 3.2. The potential health outcomes due to exposure to $PM_{2.5}$ emissions from peat smoke in Central Kalimantan, Indonesia during a 5–year period (2011–2015)

Health case categories	**Relevant age group and number of population in age group (people)**	**Estimated number of deaths for all ages**	**Estimated number of deaths due to peat smoke**	**Estimated number of deaths due to peat smoke per 100,000 people in age group**
Premature mortality (all-cause) - of which, due to:	All ages (2.5×10^6)	14,601	648	26
Chronic respiratory	All ages (2.5×10^6)	584	55	2
	Children < 5 years (2.5×10^5)	58	6	2
Cardiovascular	All ages (2.5×10^6)	4818	266	11
	Adults 30 and above (1.1×10^6)	2144	119	11
Lung cancer	All ages (2.5×10^6)	292	95	4
	Adults 30 and above (1.1×10^6)	130	42	4

We estimate that the long-term exposure to $PM_{2.5}$ from peat smoke, as estimated during a 5–year period (2011–2015), causes 648 premature mortality cases per year (26 mortality cases per 100,000 people). These include 55 mortality cases due to chronic respiratory diseases, 266 mortality cases from cardiovascular diseases and 95 mortality cases from lung cancer. It is noted that the mortality cases due to chronic respiratory diseases include 6 mortality cases of children aged below 5 years (this equates to 2 mortality cases per 100,000 children aged below 5 years).

Our sensitivity analysis revealed that with an increase of 10 $\mu g/m^3$ in the $PM_{2.5}$ concentration, the premature mortality cases increase with 34%, while the mortality cases due to chronic respiratory disease, cardiovascular diseases and lung cancer will increase with 27%, 108% and 15%, respectively. With a decrease of 10 $\mu g/m^3$ in the $PM_{2.5}$ concentration, the premature mortality will decrease with 45%, and the mortality due to chronic respiratory disease, cardiovascular diseases, and lung cancer will decrease by 47%, 27% and 26%, respectively. Also, the value of RR for premature mortality is ranging from 1.00 to 1.09 within the different exposure functions and background concentrations. The highest numbers of cases were in Kotawaringin Timur regency which has a relatively large population and a high exposure to smog from peat fires.

3.4 Discussion

This present study has several limitations. Uncertainties are generated from the meteorological inventory datasets and the referenced values used as inputs in the HYSPLIT model which are used in the analysis of the average concentration of $PM_{2.5}$ in Central Kalimantan. We recognise that the differences in default inputs among meteorological inventory data (e.g. GDAS 1°, NCEP/NCAR Reanalysis (the National Centres for Environmental Prediction/National Centre for Atmospheric Research), GFS (Global Forecast System) and GFAS (Global Fire Assimilation System), have different spatial resolutions) cause uncertainty related to the estimation of plume trajectory which then affects the estimation of both $PM_{2.5}$ concentration and its spatial distribution (Khairullah et al. 2017; Koplitz et al. 2016; Crippa et al. 2016). In the HYSPLIT model, the plume trajectories and dispersions of $PM_{2.5}$ are simulated based on the Bluesky model in which the GDAS archive is set up as default input meteorological data. The GDAS data have resulted in the enhanced data assimilation methods, having the highest horizontal, vertical and temporal resolution (Godlowska et al. 2015). Also, using a 1–km^2 resolution for input values might contribute to the differences in the calculated results of $PM_{2.5}$ concentrations.

However, a sensitivity experiment that we conducted by changing a 1–km^2 resolution to a 2 × 2 km resolution using the same procedure as for the 1–km^2 model resulted in no significant changes in calculated $PM_{2.5}$ concentrations. The wind directions and topography are the main factors that influence the smoke dispersion and associated distribution of $PM_{2.5}$ concentrations (Khairullah et al. 2017).

Besides, in this study we did not address the smoke dispersion from the neighbouring provinces. Peat fires in adjacent provinces will also contribute to smog in Central Kalimantan. We did not consider this effect, and we are therefore underestimating the health effects from peat fires.

In relation to the health impact estimation, several uncertainties were associated with our assumptions. First, we averaged the smoke concentrations over the year to assess the health effects. However, in reality smoke has a seasonal occurrence. Most of the (thick) smoke occurred from July to November (months when the land clearing activities usually start). We are not able to indicate if taking an annual average is leading to an over– or underestimate of the mortality and morbidity assessment. Our study also assessed the average of the annual mean of $PM_{2.5}$ concentration in 2011–2015 which included an El Niño period. The El Niño period (e.g. 2015) has months with an extreme reduction of precipitation and heavy fire activity and risks. Nevertheless, fires in peatland areas have occurred during non-drought years as well (see Gaveau et al. 2014). Our assumption is that the period 2011 to 2015 is representative. We cannot be sure that this is the case. However, we note that land conversion of peatlands in Central Kalimantan is still ongoing which implies that future smog may be worse than present conditions.

Second, we used the logarithm exposure function by Ostro (2004) to estimate the health impacts. The logarithm functions are recommended by WHO to estimate the health impacts in the areas with the high concentrations of air pollution (Burnett et al. 2014). However, the uncertainty on the estimation will be related to the unknown parameters such as the suggested β coefficients for $PM_{2.5}$ in this model. These parameters were estimated from the American Cancer Society (ACS) cohort studies (Ostro 2004; WHO 2006). This uncertainty can lead to different outcomes when the coefficients are not consistent with the risk model form (Burnet et al. 2014; Héroux et al. 2015). Thus, conducting proper epidemiological studies in the area is recommended in order to refine the exposure functions especially for the purpose of evaluating the impacts of episodic severe smoke from landscape fires. It is noted that we were not able to assess the morbidity impacts (such as cardiovascular diseases, lung diseases and lost working days) since the baseline data for the occurrence of such diseases is missing in Kalimantan.

Third, we calibrated our model based on air quality data available for only one city, i.e. Palangka Raya. No other data points are available in Central Kalimantan, in spite of the significant health risks related to peat fires, as indicated by our study. We therefore recommend the Government of Indonesia to expand the number of air quality monitoring stations in the province.

In order to assess the accuracy of our study, we compared our findings with available reported data on health impacts. The Central Kalimantan government reported (without mentioned specific data per case) that 2483 people (including 407 infants) died in 2015 (Dinas Kesehatan Provinsi Kalimantan Tengah 2016). However, causes for mortality were not specified. There were also no reports on the occurrence of air pollution–related diseases, even though newspaper reports in 2015 reported increases in hospital admissions (Dinas Kesehatan Provinsi Kalimantan Tengah 2016). It is noted that the Indonesia Government reported the total number of mortality cases in the whole of Indonesia due to the 2015 haze caused by forest and land fires to be 19 people, with more than 500,000 cases of acute respiratory infections (World Bank 2016). In the same report, for Central Kalimantan, the health impacts of forest and peatland fires in 2015 were reported to be only 1 mortality case and nearly 25,000 cases of upper respiratory tract infections (BNPB Indonesia 2017; The Indonesian Ministry of Health 2015). However, our study shows that this is an underestimate of the actual health impacts of fires, which is related to the government only analysing the short–term health effects of exposure to fire in a specific year. Also, the latter studies by Koplitz et al. (2016) and Crippa et al. (2016) estimated the health impacts in Indonesia by analysing a short–term period of the 2015 haze event caused by forest and land fires (September–October 2015). Koplitz et al. estimated 91,600 excess mortality for Indonesian population aged over 25 years with the average $PM_{2.5}$ concentrations of ~60 μg/m^3, while Crippa et al estimated 11,880 excess all–cause premature mortalities due to short–term exposure to unhealthy air quality conditions (using simulated 24–hr $PM_{2.5}$ of 56–160 μg/m^3) and ~75,600 excess all-cause premature mortalities due to long–term exposure to the $PM_{2.5}$ concentrations for the overall population in Indonesia, Malaysia and Singapore (including 3223 premature mortality cases due to lung cancer in the adult population aged over 25 years). In our study, we calculate the long-term health effects of the recurrent annual exposure to smoke from the peat fires (based on average fire and smoke conditions over 2011-2015). We cannot scale up our results to the whole of Indonesia given that the smoke concentration varies considerably over the different islands, but note that Central Kalimantan has a relatively low population of only 2.5 million, only 1% of the country's population.

A range of studies show that the long-term exposure to $PM_{2.5}$ is a main driver for the health effects of air pollution (e.g. see Burnett et al. 2018; Hoek et al. 2013; Pope et al. 2002; Pope and Dockery 1999). Even though the fires of 2015 were large compared with these of preceding years, also in other years the people of Central Kalimantan are exposed to smoke from peat fires. This study shows the importance of considering these long-term health effects.

3.5 Conclusions

Our study estimated the long-term health impacts of frequent exposure to high $PM_{2.5}$ concentration on the human population in Central Kalimantan due to smoke and peatland fires. We model fire and smoke occurrence in the period 2011–2015 and assume that this period is representative for people's long-term exposure. We showed that the 2.5 million people in Central Kalimantan are exposed to annual mean $PM_{2.5}$ concentrations, due to peat fires, that are well above the WHO AQG of 10 μg/m^3. The average increase in annual mean $PM_{2.5}$ concentrations due to peat fires (in shallow and deep peat) in Central Kalimantan was 26 μg/m^3 (ranging from 4 to 103 μg/m^3), of which the annual mean $PM_{2.5}$ concentrations from hotspots in deep peat were 13 μg/m^3 (ranging from 2 to 131 μg/m^3) and from the shallow peat were also 13 μg/m^3 (ranging from 0.7 to 50 μg/m^3). This long-term exposure of $PM_{2.5}$ from recurrent peat fires and smoke events causes a number of negative health outcomes, including 648 premature mortality cases which included 55 mortality cases due to chronic respiratory diseases, 266 mortality cases due to cardiovascular diseases, and 95 mortality cases due to lung cancer. This equates to 26 premature mortality cases per 100,000 people. This includes 2 mortality cases due to chronic respiratory per 100,000 children below 5 years and 11 mortality cases due to cardiovascular per 100,000 adults aged 30 and above, and also 4 mortality cases due to lung cancer per 100,000 people aged 30 and above.

The assessment of long-term health impacts on the local population will help the local government and stakeholders in Central Kalimantan province to better assess the health implications of different peatland uses and to take the initiatives to set and enforce higher standards for sustainable peatland management (particularly mitigation policies on fires and drained peatland uses; and also adding air quality monitoring stations). Although the estimation in this present study cannot be extrapolated, it still indicates that a large number of fatalities due to peat fires may occur in Indonesia at large. There are about 57 million inhabitants in Sumatra and about 16 million inhabitants in Kalimantan, and most of these are affected on an annual basis by smoke from burning peatlands. Our work confirms the high urgency of addressing the ongoing peatland conversion and degradation in Indonesia.

Acknowledgments

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CHAPTER 4

The institutional fit of peatland governance in Indonesia

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Abstract

The Government of Indonesia has published a number of policies and regulations to better manage its vast amount of tropical peatland, yet the degradation and conversion of Indonesian peatlands still continues. This paper analyses the institutional fit between Indonesian regulations related to peatland use and the characteristics of peatland users. We reviewed Indonesian legal policies and regulations on peatland use and management and conducted questionnaires and interviews with peatland users and policy makers in order to understand their practices and incentives in relation to the implementation of the four main peatland regulations. We focus on two provinces with large peatland areas: Jambi and Central Kalimantan. Using a framework for assessing the degrees of fit between the rule creators and adopters for peatland management, this paper shows that the degree of technical, political, and cultural fit of Indonesian peatland regulations can be classified as low to moderate. The paper shows that many peatland users are insufficiently aware of peatland regulations. The lack of socialisation on the contents of the regulations and the alternatives for peatland best practices, together with the lack of field monitoring and law enforcement are the important causes of non-compliance with peatland regulations. However, there are ongoing processes of fitting visible that are largely driven by the local government and NGOs. We discuss the degrees of fit and present some lessons for increasing the degree of fit for peatland regulations.

4.1 Introduction

Peatlands have been recognised as the largest carbon sink among other terrestrial ecosystems on earth, but their proper management is still problematic (Goldstein 2015). A key issue is that drainage of peatlands, including for agricultural uses, evokes an irreversible process of soil subsidence leading to substantial CO2 emissions (Wösten et al. 2008; Hooijer et al. 2012). Degraded peat is also prone to high fire risks with associated additional CO2 emissions as well as leading to smoke and haze causing adverse health effects (Hooijer et al. 2010; Marlier et al. 2015; Turetsky et al. 2015; Urák et al. 2017). Peatland covers about ten percent of Indonesia's land area, comprising the world's largest tropical peatland area. About 45% of the 14.9 million hectare Indonesian peatlands have been drained and converted into other uses including timber and pulp plantations, oil palm plantations, agricultural food lands (e.g. paddy), settlements, and degraded lands without plantations (Gunarso et al. 2013; Law et al. 2015; Miettinen et al. 2016; Austin et al. 2017; Uda et al. 2017).

Despite global concerns about the impacts of peatland conversion (Kimmel and Mander 2010; Page et al. 2011; Law et al. 2015), the effects of policy interventions on peatland management remains uncertain due to the lack of assessment of how these peatland policies and regulations are implemented by peatland users in a specific locality. A new practice that is prescribed by policy or regulation is not automatically accepted and adopted in all localities. Adoption may vary across actors, organizations and locations and may occur through phases of conflict and cooperation (Ansari et al. 2010; Schouten et al. 2016; Slade and Carter 2016). In order to assess the adoption of proposed sustainable peatland management policies, the concept of institutional fit is used to better understand whether and how national policies and regulations are adopted by local actors and incorporated into their strategies and practices (Ansari et al. 2010). The institutional fit is defined as the process of diagnostic analysis, whereby the attributes of a problem are examined in order to identify the governance arrangements that generate a desirable outcome (Young 2002; Cox 2012).

This study aims to analyse the institutional fit of Indonesian regulations on peatland uses in two provinces in Indonesia, and to identify the main issues to adopt the regulations, as well as the options for promoting efficient and sustainable peatland management. We conducted a literature review to analyse peat policies and regulations at different levels, and then carried out questionnaires and interviews with peatland users and policy makers in order to understand their incentives and decision making related to the implementation of peat regulations. We specifically discussed the main issues that prevent effective policy implementation.

4.2 Theory and methods

4.2.1 Applying the concept of Institutional Fit to Indonesia

The Indonesian Government has published a number of policies and regulations on peatland use. A first regulation that explicitly mentioned the need to protect peatland was issued in 1990 (Presidential Decree No. 32 year 1990), followed by a ratification of the convention on wetlands in 1991. In 2007, the Indonesian Government began to pay more attention to the rehabilitation of its degraded peatlands, followed by developing guidance for the utilization of peatland for oil palm cultivation in 2009 and a strict moratorium on forest and peatland conversion since 2011. Recently, the Government Regulation (PP) No. 71 year 2014 on protection and management of peatland ecosystems was issued. Yet, these peatland policies are often not effective in part due to unclear management authority for all peatlands as well as the lack of law/policy enforcement in the field at the level where many of the land-use decisions are taken (i.e. at village, district and provincial level) (Evers et al. 2017; Uda et al. 2017).

To assess the capacity of the current Indonesian policies and regulations to halt peat conversion, we turn to the literature on institutional theory in the field of management and organization, which poses that institutional contexts influence what practices are considered legitimate, and whether and through what processes these are adopted (Bromley et al. 2012). New rules and practices may diffuse under the same name, but may attain very different meanings when adopted in different organisational and institutional contexts (Boxenbaum and Pederson 2009; Bromley et al. 2012). New practices, therefore, are expected to be modified as processes of blending with local practices take place (Vellema et al. 2015). The adoption of new practices may vary across different actors because actors adapt new practices through custom adaptation, domestication and reconfiguration to make the new practice fit their own characteristics (Ansari et al. 2010; Slade and Carter 2016).

Fit is a two-sided concept, and therefore the analysis of institutional fit requires analysing both the characteristics of the rule creators – in this case, the national regulations and the practices engrained in this regulation – as well as those of the rule adopters – local land users that need to comply with the national regulations. Land users are not operating in isolation, but are functioning in a specific context in which local public and private actors play an important role. On the side of the adopter, we, therefore, needed to study both individual level characteristics as well as the characteristics of the institutional field as a whole, as it influences and determines the behaviour of individual land users.

Ansari et al. (2010) make a distinction between technical, cultural and political fit. Technical fit indicates the degree of compatibility of the characteristics of the new technical practices embedded in the national regulations with the local technical practices already in use by the actors that need to adopt the regulations. On the side of the rule creator, the characteristics refer to the factors that relate to the new practice's technological foundation. On the side of the adopter, characteristics related to the technological advancement of individual adopters, but also to the characteristics of the technological advancement of the institutional field as a whole, including technological standards, infrastructure, educational and financial institutions.

Next, cultural fit is the degree to which the characteristics of the practice embedded in the national regulations are compatible with the cultural values, beliefs, and practices of the adopters. On the side of the rule creator, practice-level factors refer to the meaning, structures and cultural values the practice embodies. National regulations do not diffuse into a cultural void but into a pre-existing cultural context, in which the specific roles and responsibilities of actors and the boundaries of appropriate behaviour are delineated.

Lastly, political fit refers to the degree to which the implicit or explicit normative characteristics of a diffusing practice are compatible with the interests, power structures and agendas on the side of potential adopters. This specifically relates to how the regulation's enforcement may affect the balance of power and the interests of a specific locality (Schouten et al. 2016). New practices stemming from national regulations are not neutral but instead are loaded with normative claims about the world, which may or may not be in line with the agendas, power structures and interests of adopters. Furthermore, some powerful interest groups may block the adoption of certain aspects of the practices that might be technically feasible.

4.2.2 Study area

Indonesian peatlands are mainly found in the islands of Sumatra (about 40% of total Indonesian peatlands), Kalimantan (about 30%) and Papua (about 20%) (Ritung et al. 2011). Our specific study sites are Jambi Province (Sumatra), and Central Kalimantan province (Kalimantan) (Figure 4.1). These areas both have extensively converted forest peatlands, with annual fires and land cover changes that have attracted global attention due to the high amount of greenhouse emissions released (Miettinen et al. 2016).

Jambi province with a total population of approximately 3.4 million people (BPS 2016) covers approximately 5 million hectares in total of which 2.1 million hectares is forest (INCAS 2016) and 0.6 million hectares (11%) is peatland (Ritung et al. 2011). Central Kalimantan province with a total population of approximately 2.5 million people (BPS 2016) has around 15.4 million hectares in total of which 2.7 million hectares (18%) is peatland (Ritung et al. 2011). The peatland conversion in Central Kalimantan accelerated in 1995 when the large scale Mega Rice Project (MRP) was implemented to convert one million hectares of peat swamp forests into rice fields (van Beukering et al. 2008; Galudra et al. 2011). Nowadays, a substantial part of the peatlands in this province is utilised for agricultural and forest plantations (BPS 2016).

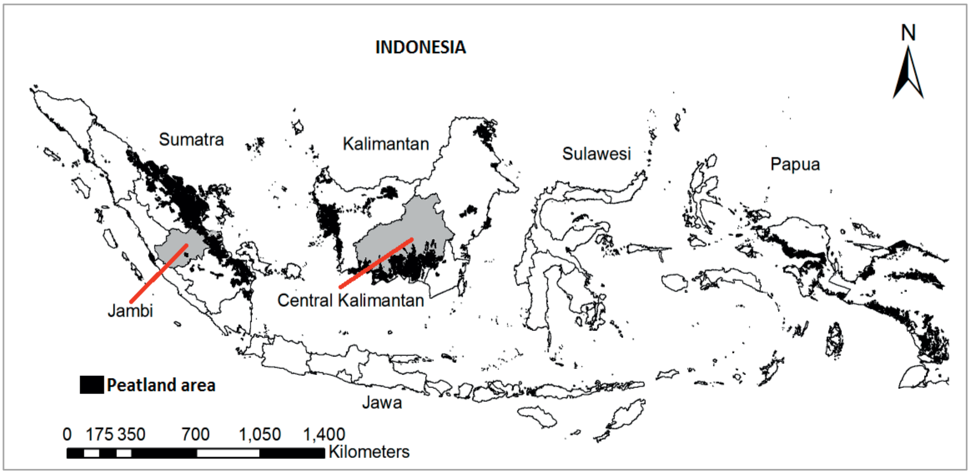

Figure 4.1 Indonesian peatland distribution map (Ritung et al. 2011); the provinces covered in this study (Jambi and Central Kalimantan) are in grey.

4.2.3 Data collection

We first summarised the direct and indirect Indonesian regulations related to peatland utilisation based on a review of relevant Indonesian legal framework documents and also overall literature such as policy briefs, journal articles and various reports. We also reviewed provincial and regency level regulations of Jambi province and Central Kalimantan province related to peatland issues (we accessed the official websites of the Government of Central Kalimantan Province 2018; Government of Jambi Province 2018). We then summarised the practices engrained in selected peat regulations (content) for analysing institutional fit. Meanwhile, data related to practices by creators and adopters were gathered by conducting interview and questionnaires among the relevant stakeholders.

Stakeholder opinions on peatland uses and the most important legal and policy issues according to the relevant key actors have been analysed by the use of questionnaires and in-depth interviews (n = 250, see Table 4.1). We categorised our respondents into two main groups i.e. peatlands users (local farmers, small, medium, and large scale companies), and policy makers (at village, district, provincial, and national levels). We supplemented this with the input from experts from academic and other organizations and NGOs in order to substantiate our results (see Appendix 4.1 for the list of interview respondents). The data collection was undertaken during September–November 2015. We consulted local government and peatland experts to select the villages which are located in the major peatland areas with diverse peatland utilisation and different type of inhabitants (including indigenous people and transmigrants). We selected our respondents (peatland users) by following a classified random sampling method.

Table 4.1 Distribution of interview respondents

Location		Number of respondents		
		Peatland users	**Policy makers**	**Experts**
CENTRAL KALIMANTAN			6	3
Pulang Pisau Regency	Desa Buntoi	30	4	
	Desa Gohong	30		
Kapuas Regency	Desa Dadahup (Ex-MRP)	30	4	
Palangka Raya city	Desa Kalampangan	30	4	
JAMBI			5	2
Muaro Jambi Regency	Desa Gedong Karya	30	5	
Tajub Jabung Timur Regency	Desa Delima	30	1	
Tajub Jabung Barat Regency	Desa Sungai Beras	30	1	
NATIONAL	Jakarta		3	2

The survey and interview questions for peatland users covered: personal data of respondents including their household and income sources; land uses including type of land ownerships and type of cultivations; peatland management including land production, reasons to grow the plants, management practices on the peatlands (e.g. drainage canals, peat depth), and their future plans for land uses; opinions on peatland regulations including their knowledge of and compliance with the regulations; their impressions of peatland uses including trends in peatland uses, problems and planning; and interactions with the stakeholders (their relationships and communications on peatland issues). For policy makers, the survey and questions covered: background information on the respondents including their organizations, positions, main duties, length of work experiences; impressions of peatland uses including land ownerships, type of peatland uses, current trends in peatlands uses, main problems and their data sources; their knowledge of and opinions about peatland regulations and the implementation of the regulations in the field; their impressions about sustainable peatland management; and interactions with stakeholders (peatland users and other partners) on peatland issues. Using a similar set of questions to those given to peatland users, a number of experts from NGOs and researchers were also interviewed in order to get other perspectives and to validate our information.

4.2.4 Data analysis

We followed the definition of technical, cultural and political fit by Ansari et al. (2010), and classified the degree of fit relevant to the selected peatland regulations. We propose a classification as shown in Table 4.2 in order to assess the degree of fit for each dimension of the each selected peatland regulation.

Table 4.2 Classification of the degree of fit

Classification the degree of fit	Description
None	Incompatible with all identified practices
Low	Compatible with less than half of identified practices
Moderate	Compatible with more than half of identified practices
High	Compatible with all identified practices

Based on this classification, we analysed the degree of fit between rule creators and adopters both in Jambi and Central Kalimantan. The creator is, in the case of our analysis, composed of the national and provincial level government bodies that define the policies regulating peatland use. These include the Ministry of Environment and Forestry (MoEF) as the main authority and coordinator for the implementation of peatland regulations over peatland areas, the Ministry of Agriculture (MoA) and the Ministry of Public Works and Public Housing (MoPWPH or called PU) as authority for maintaining peatland use in non-forested state, and also Peatland Restoration Agency (called BRG) as the authority overseeing the restoration of peatland areas, as well as the provincial regulators (i.e. governors, regents, and mayors) as the authority for giving or taking over licences on peatland utilisations in the provincial or regency levels. The adopters are the various peatland users including local people using peatlands for various purposes, smallholder crop farmers in peatlands, and the small, medium and large plantation companies with land holdings in peatlands. We also explore causes of misfit and how these issues differ for the two provinces. From our interview and questionnaire results, we analysed the key issues related to the adoption of peatland regulations.

4.3 Results

4.3.1 Institutional fit

We have identified four main Indonesian peatland regulations (see Appendix 4.2 for the national legal framework related to peatland management in Indonesia) which directly affect peatland use. There are a) Government Regulation (PP) No. 4/2001 on the Control of Natural Damage and or Pollutions related to Land and Forest Fire (stating that everybody is banned from setting land and forest fires) (Indonesia Government Regulation 2001); b) the Minister of Agriculture Decree (Kepmentan) No. 14/2009 on the Guidance for the Utilisation of Peatland for Oil Palm Cultivation (stating that establishing oil palm plantations in peatland is only allowed in peatlands with less than 3–m depth) (Indonesia Minister of Agriculture Decree 2009); c) the Presidential Instruction (Inpres) No. 10/2011, No. 6/2013 and No. 8/2015 on the (Extended) Moratorium of Granting of New Licences and Improvement of Governance of Natural Primary Forest and Peatland (stating that activities relating to the issuing of new permits related to natural forest and peatland conversion are suspended) (Indonesia Presidential Instruction 2015); and d) the Government Regulation (PP) No. 71/2014 on the Protection and Management of the Peatland Ecosystems (stating that peatland with more than 3–m depth is classified as a protected area and its use is prohibited; that setting fires in peatlands is banned, and that peatland with a surface water depth of less than 0.4–m is categorized as a damaged area) (Indonesia Government Regulation 2014). The latter regulation, PP No. 71/2014, has a considerable overlap with the other regulations (e.g. with the ban on setting land fires from PP No. 4/2001). The main results of our analysis of the degrees of fit between the identified regulation and the organisational fields in Jambi and Central Kalimantan are shown in Table 4.3 (with the detailed analysis is in Appendices 4.3, 4.4, 4.5 and 4.6).

Table 4.3 Summary of degrees of institutional fit of Indonesian peatland regulations in Jambi and Central Kalimantan

Regulation	Degree of Fit					
	Jambi			**Central Kalimantan**		
	Technical	Political	Cultural	Technical	Political	Cultural
1. Government Regulation (PP) No. 4/2001 on Control of Natural Damage and or Pollution related to Land and Forest Fires.	Low	Low	Low	Low	Low	Low
2. Minister of Agriculture Decree (Kepmentan) No. 14/2009 on Guidance for the Utilization of Peatland for Oil Palm Cultivation.	Low	Moderate	Moderate	Low	Moderate	Moderate
3. Presidential Instruction (Inpres) No.10/2011, No.6/2013, and No.8/2015 on (Extended) Moratorium on Granting of New Licences and Improvement of Governance of Natural Primary Forest and Peatland.	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
4. Government Regulation (PP) No.71/2014 on the Protection and Management of Peatland Ecosystems.	Low	Low	None	Low	Low	Low

4.3.2 Technical fit

The degree of technical fit of Indonesia's peatland regulations is rated as low to moderate in both Jambi and Central Kalimantan. The four peatland regulations require the adoption of quite complicated technical practices to measure peatland distribution, peatland depth, and the ground water table. The 3–m peat depth is the main criterion used to distinguish between protected and developed peatland areas. Meanwhile, the surface water height with less than 0.4–m is a criterion for monitoring utilisation of peatland areas (also related to Kepmentan 14/2009 on the utilisation of peatlands for oil palm cultivation) and for categorising of damaged peatland areas. The government provided an indicative map of national peatland ecosystem distribution (PP No. 71/2014) and an indicative map of moratorium new licences (Inpres No. 10/2011, No. 6/2013, No. 8/2015) to determine whether the concerned areas of peatlands can be utilised or not.

There are differences between the degrees of fit of the four regulations. The degree of fit for PP No. 4/2001 on banning land and forest fires is rated as low both in Jambi and Central Kalimantan. The annual episodes of peatland fires in these two provinces indicate that burning are still a common practice. Local farmers and landowners clear their lands not only for preparing the land for planting, but also to indicate ownership. The lack of technical knowledge of zero burning methods on the different types of peatland clearing, and no effective technology to put out (sometimes massive) peatland fires are the leading causes for the lack of fit for PP No. 4/2001 regulation. In Central Kalimantan, controlled burning is allowed for local inhabitants who do not belong to a corporate body, and who have a land area not exceeding 2 ha, and on mineral lands or shallow peatlands. However, the implementation of this controlled burning sub-regulation often causes (sometimes massive) wildfires. Hence, according to our respondents, fire management systems are established (both based on private and community's initiative and government's initiative) to prevent and combat (wild) fires in their forests and peatlands until village level (village community based and company-based). The degree of fit of Kepmentan No. 14/2009 is also rated as low both in Jambi and Central Kalimantan. The local practices are compatible with one out of five identified practices of Kepmentan No. 14/2009, i.e. not cultivate oil palm in forested areas (only cultivated oil palm in community lands and cultivation areas). Peatland users hardly ever measure the peat and water depths of their peatlands, and thus there are lack of information on the actual (accurate) location of deep peatlands and the ground water table. Both oil palm farmers in Jambi and Central Kalimantan believe that peatland with a depth more than three meters is still suitable for oil palm cultivation and has no significant environmental impacts when properly managed. Therefore, it is often very difficult to protect the deep peatlands from conversion due to the uncertainty on the actual boundaries of the utilisation zones. Different from the other three peatland regulations, the degree of fit of Inpres 10/2011, No. 6/2013, No. 8/2015 on the moratorium of granting new licences and improvement of governance of natural primary forest and peatland is rated as moderate (compatible with two out of four identified practices of Inpres 10/2011, No. 6/2013, No. 8/2015, i.e. suspension of activities related to the issuing of new permits for conversion of natural forest and peatland areas and application of the indicative moratorium maps) both in Jambi and Central Kalimantan. The causes of misfit between the regulation and local practices are often due to the dissimilarities in interpretations of peatland depth category and other peatland-related information (e.g. forest or non-forest status and pending concessions applications). Overlapping and unclear land status (protected or non-protected peatland) and landownership often leads to social conflicts. The degree of fit of PP No. 71/2014 on protecting and management of peatland ecosystems is rated as low (compatible with one out of three identified practices of PP No. 71/2014, i.e. no use/limited use of deep peat) both in Jambi and Central Kalimantan. Local farmers, both in Central Kalimantan and Jambi, use rods to measure their peat and water depths manually. These measurement results are also often used for making a decision on whether to apply no used or limited used on their deep peatlands for the specific type of crops (e.g. in Jambi, deep peatlands were only planted for coconut, while shallow peatlands were used for tidal rice fields), and on managing the groundwater table as well. Although the PP No. 71/2014 prescribe no drainage in peatlands, still peatland users dig (sometimes deep) canals in their peatlands, having objectives not only for peatland drainage and managing water but also for blocking (wild) fires. We have found that more than 80% of our respondents use drained peatland management, with various range of depths between 0.6 to 2–m in Jambi, and between 0.5 to 5–m in Central Kalimantan.

4.2.5 Political fit

We have found several specific political practices engrained in the four regulations that we have analysed. According to these regulations, the MoEF is the main authority for implementation of these peatland regulations, collaborating with other organizations including the MoA, the MoPWPH, the Ministry of Home Affairs (MoHA), the Peatland Restoration Agency, the National Land Agency (called BPN), and the National Spatial Planning Coordinating Agency (called BAPPENAS), together with the governors, regents, and mayors, for giving or taking over licences on peatland utilisations. We have found that the degree of political fit of Indonesia's peatland regulations is low to moderate in both Jambi and Central Kalimantan. The regulation on the utilisation of peatland for oil palm cultivation (Kepmentan No. 14/2009) and the regulation on the moratorium of granting of new licences and improvement of governance of natural primary forest and peatland (Inpres No. 10/2011, No. 6/2013 and No. 8/2015) have the best fit (which are rated as moderate) both in Jambi and Central Kalimantan. Given that the characteristics of the practices that are embedded in these two regulations are more than half compatible with the interest, power structures, and agendas of the adopters. Our analysis showed that the field practices of adopters in Jambi and Central Kalimantan are compatible with three out of six identified practices of Kepmentan No. 14/2009, i.e. cultivate oil palm; companies with prior issued licenses can continue their cultivation activities; and apply (eco-hydro) water management. Local farmers, both in Central Kalimantan and Jambi, use their lands based on licences given by the government or and customary right. Local people desire to have transparency on the status of lands in surrounding their areas. The degree of fit of PP No. 4/2001 on banning land and forest fires is rated as low both in Jambi and Central Kalimantan (compatible with one out of four identified practices of PP No. 4/2001, i.e. interest on REDD+). The degree of fit of PP No. 71/2014 on protecting and management of peatland ecosystems is rated as low both in Jambi and Central Kalimantan (compatible with one out of three identified practices of PP No. 71/2014, i.e. agenda to rehabilitate the damaged peatlands). For adopters, the main issues relate to landownership (e.g. overlapping landownership, land grabbing, etc.), land use permits (e.g. change of land use permits, inherited lands and customary rights, etc.), and peatland utilisation (e.g. domestic consumption, business plantation, etc.). Based on our interview results, most of local smallholder farmers in Jambi (almost 70%) and Central Kalimantan (almost 60%) do not have the highest level of landownership certificate, sometimes only letters from heads of the villages acknowledging the land, or the letters acknowledging the customary land right from customary heads. We also have found that although the national government has promoted paludiculture, there is lack of interest from adopters in part due to the lack of markets for the paludiculture's products.

We have pronounced several barriers to implementing these regulations in the field by adopters in Jambi and Central Kalimantan. For instance, there is a lack of information sharing between different government agencies. The MoA and the MoPWPH do not share the same concerns about maintaining peatlands in a non–drained and forested state, while conflict of interest with landowners is due to the increased demand for food security (agricultural lands). Lack of monitoring and law enforcement by the government makes peatland users insufficiently incentivised to use peatlands according to the regulations. At the district level, the representatives of the MoEF face multiple incentives including incentives promoting the giving of licences on peatland use to local farmers and companies. In addition, forest and land areas are managed based on regency administrative boundaries, while peatland should be managed based on a dome systems which could cross regency boundaries.

4.2.6 Cultural fit

The degree of cultural fit of Indonesian peatland regulations is rated as none to moderate. It means that, in some cases, the characteristics of the practices that are embedded in these national regulations are incompatible with the cultural values, beliefs, and practices of the adopters. Peatland regulations are aimed at reducing negative externalities (smoke, haze, and associated health effects) and reducing negative long-term effects (soil subsidence and climate change). The practice-level factors referred to in these regulations banned the use of fire for land burning, specified the allowed boundaries of water level and peat depth, and also banned access to/use of forest areas. The government developed standards for peatland utilisation by mostly referring to the scientific knowledge base. The government has involved private sector representatives, academic researchers, environmental and social NGOs (local, national, international) for dialogues to provide scientific inputs on the development of standards as the basis of these peatland regulations. However, on the side of the adopter, the main issue is that landowners already used or cultivated their peatlands before the peatland regulations were issued. Land uses are mostly continuing heritage uses, for instance, indigenous farmers already use shallow peatland for fish ponds and wet agricultures. We also have identified some cultural practices by adopters in the field. For example, canals are made by local farmers in order to dispose of peat water because they believe that the peat water are toxic for the plants. Meanwhile, burning land method is believed can increase soil fertility and easily kill pests. Also, for local communities, forests are considered unowned lands and/or heritage and so open to encroachment.

We have found that there are differences between the degrees of fit of the four regulations. The degree of fit of PP No. 4/2001 on banning land and forest fires is rated as low in Jambi as well as in Central Kalimantan (compatible with one out of three identified practices of PP No. 4/2001, i.e. on fire prevention). Remarkably, the slash-and-burn method (including under controlled burning regulation) is still used by adopters both in Central Kalimantan and Jambi, because it is still the easiest, fastest, and cheapest method for land clearing. Besides, land clearing (clean land) is also a sign of landownership, in which uncleaned lands will be taken back by the local government as well as part of local traditional practices (e.g. *Handep system*/ hand-in-hand for traditional land clearing in Central Kalimantan, and *Manduk*/community working together for land clearing in Jambi). The degree of fit of Kepmentan No. 14/2009 on the utilisation of peatlands for oil palm cultivation in both Jambi and Central Kalimantan is rated as moderate, means compatible with two out of three identified practices of Kepmentan No. 14/2009, i.e. plant oil palm based on land characteristics, and cultivate oil palm only on community land. Meanwhile, the degree of fit of Inpres No. 10/2011, No. 6/2013 and No. 8/2015 on the moratorium of granting of new licences and improvement of governance of natural primary forest and peatland in both Jambi and Central Kalimantan is rated as moderate, means compatible with two out of three identified practices of Inpres 10/2011, No. 6/2013 and No. 8/2015, i.e. manage forested areas for Non–Timber Forest Productions, and develop transparent and participatory process. Interestingly, we found that the degree of fit of PP No. 71/2014 on banning land and forest fires in Jambi is rated as none, means that this regulation is largely incompatible with the cultural values, beliefs, and practices of the adopters in Jambi.

Meanwhile, in Central Kalimantan, the degree of fit of PP No. 71/2014 is rated as low, compatible with one out of four identified practices of PP No. 71/2014, i.e. no use/limited use deep peatland. Our respondents have mentioned some causes of lack of fit, including that local communities have not been consulted nor consideration given to their traditional knowledge about peatland use (e.g. use of fire in agriculture). Also, the provision of incentives for local communities and other stakeholders for not using of peat or fire were not considered (also in line with the study by Herawati & Santoso 2011). Besides, peatland users (especially transmigrants mostly from Java, Bali, Nusa Tenggara, etc.) usually treat their peatland in a similar way to mineral land since they came from areas with no peatland.

4.4 Discussion: emergent signals of fitting

We summarised in Table 4.4 degrees of technical, political, and cultural fit from our findings. Notably, the degrees of fit are mostly low to moderate. However, fit is not a static concept, and processes of fitting can be identified that are embedded in on–going endeavours including those to protect forest and peatlands, to work with local communities and or landowners, and to address wise use for sustainable peatlands management.

First, we found signs of technical fitting. Village governments and NGOs assist landowners to comply to the regulations through village development plans. The (national and provincial) governments and NGOs (e.g. Indonesia Wetlands International, WWF Central Kalimantan, Walhi, WARSI–Jambi, etc.) predominantly work with topics relating to zero burning issue (fire early warning systems, fire combat managements, etc.). The plan to continue with topics relating to peatland restoration programs (including blocking canals, rewetting, etc.), and later, they will also continue to work with topics relating to water table monitoring, wise use, and paludiculture programs (not applied yet).

Table 4.4 Degrees of fit

Dimension	Content	Degree of fit
Technical	No deep peatland use No drainage with water level deeper than 0.4–m No burning	Low – Moderate
Political	Permanent forest and peatland conversion moratorium Carbon emission reduction and carbon trading Taking over damaged peatlands areas	Low – Moderate
Cultural	Local knowledge (wise use)-based criteria Peatland use changing to no–drainage peat commodity (paludiculture) Provision of incentives for peatland users for non-use of peatland (or fire)	None – Moderate

A participatory approach, initiated by the government and NGOs, which involves local communities (village based), including farmers and companies, is applied to achieve consensus on mapping areas (including identification of peat depth and peatland utilisation) as well as restoration activities. NGOs, extension agencies, and academic researchers play the main role in giving assistance to local (village) governments in applying this participatory approach in their villages, for instance, in mapping potential and ecosystem services of the village. Some pilot villages have been selected for applying sustainable peatland management and protection programs (e.g. including restoration program in our study areas). Specifically on the issue of oil palm plantations in peatland, NGOs, extension agencies, and researchers also act as mediators between the regulation's standard and other organizations' standards (e.g. RSPO).

Second, we found signs of political fitting. The National Government tried to diminish contradictory regulations (mostly due to sectoral-based visions) through its One-Map Policy, while the Provincial Governments abolished their contradictory-sub-regulations (e.g. controlled burning policy in Central Kalimantan was abolished after the massive land fires in 2015). The government and NGOs began to develop social institutions to strengthen communities' capacities to protect their peatlands and increase their welfare, including social forestry (e.g. forest village, community forestry, village fire combat community, etc.). Under REDD+ and Green Economic projects, the government and NGOs try to ensure incentives for peatland users to gradually phase out drained crops on peatland and replace them with non-drained crops (e.g. paludiculture) and forestry/agroforestry commodities (timber and non-timber). However, it is crucial to ensure a market for these paludiculture commodities so that they are attractive for local farmers or companies (producers). Training and workshops on sustainable and wise use of peatlands as well as increase their production are provided by the government and NGOs (e.g. buying living tress system, seedling and nursery of paludiculture crops, canal blocking technique, etc.). The government is taking over damaged peatland areas and recently starting to restore as many as 2 million hectares of damaged peatlands by involving local communities.

Third, we found signs of cultural fitting. Based on our interview result, most of the peatland users show remarkable willingness to comply the peatland regulations over the management of their peatlands, although they have limited knowledge on content of the regulations, as well as the lack of field/ground checking by the government to meet these peatland regulations (see Figure 4.2; based on Appendix 4.3 and Appendix 4.4).

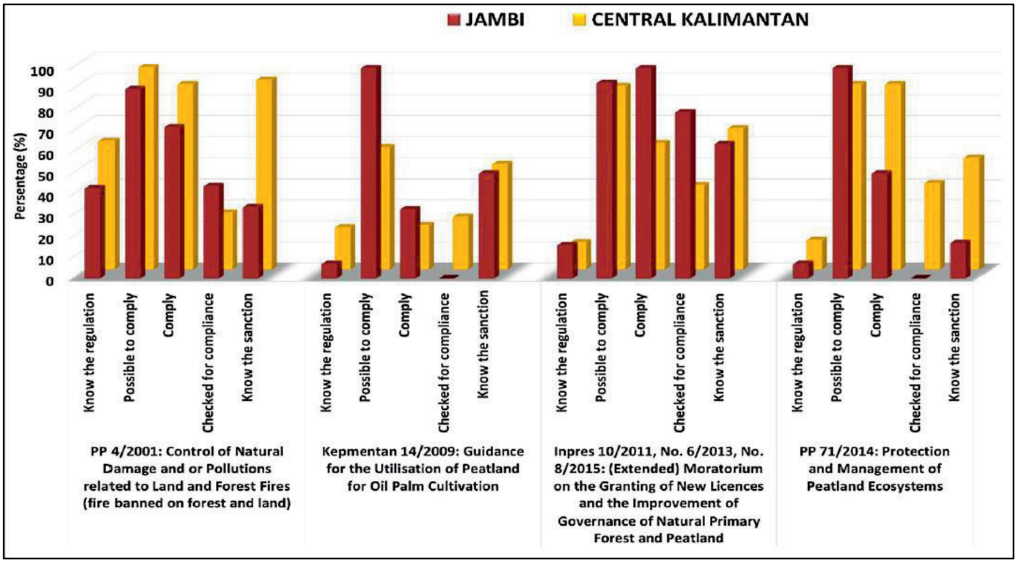

Figure 4.2 Interview results of peatland users in Indonesia on the implementation of peat regulation according to relative share (%).

Different with our respondents in Jambi, our respondents in Central Kalimantan have more knowledge of peatland regulations and their sanctions, but complied to less regulations related to peatland management due to often using their traditional knowledge while using peatland (e.g. *Handep* system/hand-in-hand for land clearing and *Handil* system for water management of villages in Central Kalimantan). The local government tries to recognise traditional knowledge on peatland management by consulting with the local indigenous leaders. Local NGOs (e.g. WARSI–Jambi, GAAs–Central Kalimantan, WALHI, etc.) and customary communities (*masyarakat adat*, such as *Dewan Adat*, AMAN, etc.) help to mediate between the regulations and the landowners, particularly with indigenous peoples in their customary lands. Yet, it remains difficult to help farmers change their practices mainly due to additional costs (e.g. canal blockings costs, water monitoring costs, etc.) and absence of incentives for peatland users for non-use of peatland (or fire).

A solution pathway, therefore, should include addressing the three aspects examined in this paper. In terms of technologies, there is an urgent need to develop alternative technologies to use peatlands in a manner that does not require drainage, and to assist land users in moving towards such new cropping systems (e.g. by demonstrating the financial benefits of alternative land uses, see e.g. Sumarga et al. 2016). There is also an urgent need to better monitor peatlands including their land use and hydrology –and to share information from these monitoring efforts with local decision makers. Indeed, these aspects are currently being considered by Indonesia's peatland restoration agency (*Badan Restorasi Gambut*/BRG).

In terms of improving the political fit there is an urgent need for better communication between government agencies – it is crucial that information on the costs of peat degradation including health effects are shared between agencies, and that there is alignment in the management of peatlands between these agencies. Our analysis shows that many peatland users are insufficiently aware of peatland regulations. Lack of socialisation on contents of regulations and alternative for peatland best practices, also field monitoring and law enforcement are halting the implementation of peat regulations by Indonesian peatland users. Village governments, farmer groups (associations), and NGOs (including local branches of international NGOs) can play important mediating roles in shaping processes for better degrees of fit. Local communities and other stakeholders, as well as districts that manage their peatlands well (for not draining any peatland or not constructing a single drainage canal or not using fire) should be financially rewarded (as a part of the regular government budget).

In terms of cultural fit, there is a need to educate people living in and around peatlands of the regulations governing peatland use but also of the reasons why such regulations have been established, including the massive health effects that peatland fires cause (Herawati & Santoso 2011; Thorburn & Kull 2015; Carmenta et al. 2017). This involves also working with NGOs and other stakeholders in testing and rolling out alternative peatland uses that generate local incomes (van Beukering et al. 2008; Sumarga et al. 2016). We by no means want to suggest that increasing institutional fit and engaging in processes of fitting is an easy endeavour as problems in peatland areas often unfold in (isolated) contexts afflicted by poverty, corruption, insufficient government budgets, etc. Addressing these issues requires efforts that go beyond the capacities of a single actor.

4.5 Conclusion

Our research used the concept of institutional fit for assessing the degree of fit between rules creators and adopters regarding peatland regulations in two provinces in Indonesia. The degrees of fit between the practices engrained in the four main Indonesian peatland regulations and the practices used by peatland users are mostly low to moderate for both Jambi and Central Kalimantan. The lack of technical knowledge on the different types of zero burning methods, the lack of availability of technology to put out (sometimes massive) peatland fires, as well as a lack information on the actual (accurate) location of deep peatlands and the ground water table, are leading causes of the low technical fit of these four regulations. The low political fit can largely be explained by issues related to unclear land titles and the lack of information sharing between different governmental agencies. The low cultural fit seems to be related to the absence of (knowledge on) alternatives for traditional forms of peat management and land clearing in particular.

Our research shows that there are currently insufficient economic incentives for moving towards sustainable peatland management. Oil palm in particular is highly profitable –at least in the short–time horizon considered by most stakeholders. Further work is needed to establish value chains for paludiculture crops that require little or no drainage of peat so that profitable alternatives for oil palm can be promoted (e.g. Giesen 2013; Sumarga et al. 2016).

A deeper understanding of institutional fit including technical, political, and cultural interactions between peatland regulations and peatland users' practices is important. Indeed, the institutional fit assessment as a two-sided concept including rule creators as well as rule adopters provides further insights in how to enhance the effectiveness of policy implementation. The successful transformation of Indonesian peatlands to sustainable use involves addressing technical, political and cultural fit in a coherent and comprehensive manner.

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CHAPTER 5

A socio-ecological assessments of paludiculture food crops as an alternative for tropical peatland development in Indonesia

This chapter is based on:
Uda SK, Hein L & Adventa A (2019) A socio-ecological assessment of paludiculture food crops as an alternative for tropical peatland development in Indonesia. *Wetland Ecology and Management.* (submitted WETL-D-19-00173).

Abstract

The current drainage-based peatland uses in Indonesia result in high fire risks, CO_2 emissions, and soil subsidence. This study aims to assess different alternative crops that do not require drainage (paludiculture crops) and minimum drainage in order to help prevent further degradation of peatlands in Indonesia. We focus on paludiculture crops that provide foods and that are of particular interest to smallholders; and we assess and compare the potential of various paludiculture crops in our study area, Central Kalimantan, Indonesia in terms of sustainability, profitability, scalability of the market and acceptability to farmers. Our results show that among the paludiculture food crops, sago (*Metroxylon sagu*), mangosteen/manggis (*Garcinia mangostana*), water spinach/kangkong (*Ipomoea aquatica*), kelakai edible fern (*Stenochlaena palustris*), dragon fruit/buah naga (*Hylocereus undatus*), pineapple/nanas (*Ananas comosus*) and banana/pisang (*Musa paradisiaca*) are the best options based on the aggregated scores of this socio-ecological assessment. However their specific potential will always depend upon the local context; and we acknowledge that some species still require drainage (albeit lower than current plantation crops). We also address the key opportunities and bottlenecks for the development of these paludiculture food crops and present some recommendations for the implementation of paludiculture in Indonesian peatlands.

5.1 Introduction

The conversion of natural tropical peatlands into other land uses in Indonesia has gained much attention in the recent years as it will lead to increasing soil subsidence and greenhouse gas emissions and detrimental effects on the hydrology, peatland ecosystem, and biodiversity. Among others, this also leads to recurrent peatland fires and smoke events (Miettinen et al. 2017; Page et al. 2011). Historically, all peatlands in Indonesia were forested and have sequestered and stored atmospheric carbon for many thousands of years (Warren et al. 2017; Miettinen et al. 2016). Traditionally, indigenous peoples use peatlands through small-scale activities, in particular for harvesting non-timber forest products/species and timber harvest to a lesser extent (Osaki et al. 2016; Limin et al. 2007). Starting from the 1980s, very large areas of Indonesian peatland have been extensively drained and cultivated for plantation and smallholder cropping. Other areas have been opened for timber logging and land claiming but where then abandoned, which has led to extensive areas of degraded peatlands (Law et al. 2015). Oil palm, acacia, and rubber plantations are the largest peatland utilisations in Indonesian peatlands (Gunarso et al. 2013; Miettinen et al. 2016). Between 2000 and 2014, palm oil production from peatlands alone has increased by almost threefold in production (Uda et al. 2017). However, despite their short–time economic benefits, the conversion of natural peatlands has resulted in many negative impacts on the environment and society (Evers et al. 2017; World Bank Group 2016).

In Indonesia, the drainage of natural peatlands is carried out through both legal (government programs, such as primary canals in MRP) and illegal canal constructions and have extensively damaged the hydrological system within the natural peatlands mainly due to the decrease in the water table levels (Dohong et al. 2018). The drained peatlands are also prone to peat subsidence which in the future will lead to extensive flooding over Indonesian lowland peatland areas as the soil levels are then lower than the river or sea water levels (Hooijer and Vernimmen 2013). Thus in order to move towards sustainable uses of peatlands, non-drainage peatland development should be pursued (Sumarga et al. 2016).

An alternative for utilizing peatland without drainage is paludiculture which is the cultivation of biomass on wet and rewetted peatlands. With paludiculture there is no need to drain the peat leading to lower fire risks and CO_2 emissions. This system also enables long-term cropping with no or limited soil subsidence (Joosten et al. 2016). Paludiculture is designed to preserve and restore the peatlands (through rewetting of the drained peatlands) as well as to provide sustainable income for the peatland users (Joosten et al. 2016). Some paludiculture crops suitable for Indonesian climate have been recommended for use in forestry, agroforestry, agro-food, and raw material for energy, construction, biochemical products, etc. (Tata & Susmianto 2016; Giesen 2013). Yet, it is important to understand the properties of each paludiculture crop before considering its widespread implementation. The socio-ecological assessment of paludiculture crops is especially crucial in order to establish the effectiveness of the current paludiculture campaigns and for sustainable peatland management policy by the Indonesian government.

This study assesses various paludiculture crops that require no drainage or minimum drainage to prevent further peatland degradation and give recommendations for their uses in the peatlands in Indonesia. In this study, we focus on paludiculture crops that support food provisions and food security in the country while also recognise that there are other promising non-food paludiculture crops such as resin, timber or other commodities (e.g. jelutung (*Dyera* sp.), ramin (*Gonystylus bancanus*), gemor (*Nothaphoebe* sp.), gelam/cajuput oil (*Melaleuca cajuputi*), etc.) (Graham et al. 2016). It is important to note that paludiculture crops identified in the previous sources (e.g. Giesen 2013; Noor et al. 2014; MoEFRI 2017; Giesen & Nirmala 2018) also include crops with minimum drainage required (less than 30–50 cm). We propose several criteria and levels of potentials for different paludiculture crops in order to integrate the socio-economic-ecological dimensions in terms of their sustainability, profitability, scalability of markets and acceptability to local farmers. We then select and compare the various paludiculture food crops available in our study area. A number of key opportunities and bottlenecks on the implementation of these crops (and their commodities) are addressed. We then provide some recommendations for the successful implementations of paludiculture (especially food crops) and sustainable peatland management policy in Indonesia.

5.2 Methods

5.2.1 Selection of study area

Indonesia has the largest total of tropical peatland areas among tropical countries (Page et al. 2011). They cover at least 8% of its land area and are mainly distributed in the three islands Sumatra (about 40% of total Indonesian peatlands), Kalimantan (about 30%) and Papua (about 20%) (Ritung et al. 2011). Central Kalimantan province contains one of the largest peatland areas in Indonesia (2.6 million hectares, Ritung et al. 2011) and we have good access to local data through various ongoing and completed projects (Uda et al. 2017; Uda et al. 2018). Approximately 47% of total peatland areas in Central Kalimantan (1.2 million ha) was categorised as forested areas (undisturbed and disturbed forests), while 43% of total peatland areas (1.1 million ha) was degraded peatlands (Surahman et al. 2018). Since 2016 Central Kalimantan has been designated as one of the seven priority provinces for peatland restoration by the Peatland Restoration Agency (*Badan Restorasi Gambut* or *BRG*) set up by Indonesian government to coordinate the restoration of the 2.4 million hectares of degraded peatlands in Indonesia within five years (2016-2020). Based on the BRG's indicative maps of peatland restoration priority areas, around 774,773 hectares of peatland areas Central Kalimantan (distributed in 11 regencies of 14 regencies in Central Kalimantan) are part of the BRG's peatland restoration target (see Figure 5.1, BRG 2018).

5.2.2 Interviews and selection of paludiculture crops

For the purpose of this study, we only focus on the paludiculture food crops that are commonly grown in our study area. There are currently somewhat different interpretations of paludiculture crops, ranging from crops that require no drainage at all to crops that require more limited drainage compared to current peat management practices. We consider a broad range of crops, also crops that require limited drainage, but explicitly indicate which crops are suitable under no drainage, and which are suitable for limited drainage conditions. We selected 15 selected crops for our survey based on a literature survey, and discussions with local experts. These included the head of the local farmer groups, and researchers from University of Palangka Raya, the Indonesian Peatland Restoration Agency, and the Food Crop and Horticultural Agency of Central Kalimantan Province. Subsequently, we consulted farmer groups in order to retrieve information on the socio-economic–ecological dimensions of the crops (e.g. cultivation and marketing aspects). The data collection was undertaken during September–December 2017 following the purposive sampling method in ten villages located in peatland areas, distributed over five regencies. These villages were selected randomly comprising Kapuas Regency (Basarang, Terusan Raya and Dadahup/Ex–MRP villages villages), Pulang Pisau Regency (Buntoi, Gohong and Jabiren villages), Katingan Regency (Kasongan Lama village), Gunung Mas Regency (Tampang Tumbang Anjir village), Palangka Raya city (Kalampangan and Menteng villages). In each village, a group of 10 to 15 farmers discussed the questions in the questionnaire and collectively filled in the responses. The village discussions were moderated by the head of the local farmers' association. The questionnaire is shown in Appendix 5.1. All groups were also contacted online following their response to clarify and discuss their answers. Furthermore, six in–depth interviews were held with the researchers from the University of Palangka Raya (3 people), staff in the Food Crop and Horticultural Agency of Central Kalimantan Province (1 staff) and the Indonesian Peatland Restoration Agency (2 staff). These were open interviews to discuss profitability, sustainability and scalability of various paludiculture crops.

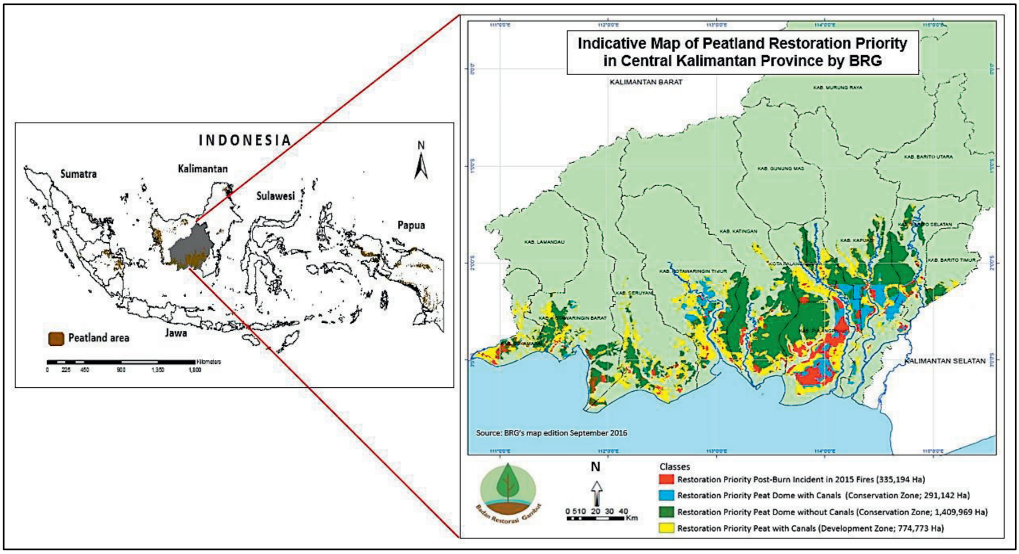

Figure 5.1 Central Kalimantan peatland distribution map (adapted from BRG 2018).

5.2.3 Performance criteria

In this study, we propose a number of criteria and indicators for assessing the social and ecological aspects of the paludiculture food crops. The criteria are related to the economic performance (Net Present Value) of the crop, the scalability (access to markets), the acceptability for farmers, and the reduction of CO_2 emissions compared to a situation where peat is drained for plantation agriculture with for instance oil palm. We are aware that there are other ecological factors than CO_2 emissions, but in the scope of this study we are not able to assess other indicators, and we consider that drainage and CO_2 emissions are closely related to fire risk, haze and local health impacts. Acceptability of farmers is assessed on the basis of the ease of growing the crop (e.g. access to seedlings) and the amount of years the farmer has to wait to obtain a first income. The performance indicators and assessment methods are described in Table 5.1.

The data are obtained from the questionnaires and interviews with the farmers/peatland users, experts and other relevant stakeholders and also from various case studies and government reports (e.g. BPS 2018a, 2018b; BPS Central Kalimantan 2018a, 2018b; MoARI 2018, etc.). The general ecological and social attributes of paludiculture crops which are commonly grown/cultivated in Central Kalimantan peatland areas are presented in Appendix 5.2 and Appendix 5.3. Subsequently, we aggregate all scores of the indicators for sustainability, profitability, scalability of market and acceptability to the farmers.

Table 5.1 Indicators and methods for integrated assessment of socio-ecological aspects of paludiculture crops

Indicator	Method	Description	Sources
(1) Sustainability - tree crops group (the planted areas are assumed similar to the drained natural forest peatlands)	CO_2 emission ($t\ CO_2\ ha^{-1}\ year^{-1}$)	$\boldsymbol{CO2\ emission = -98 \times WTDx}$ *WTD* is the water table depth below the peat surface (-m, negative) of the crop, *x* is the crop, 98 is the factor for CO_2 emissions for drained natural forest peatlands, using the subsidence relation with an intercept zero ($t\ CO_2\ ha^{-1}\ year^{-1}\ m^{-1}$).	Hooijer et al. 2012; Study cases from various sources, particularly with regard to water table depth of the tree crops.
- non-tree crops group (the planted areas are assumed similar to the deforested unproductive peatlands).	CO_2 emission ($t\ CO_2\ ha^{-1}\ year^{-1}$)	$\boldsymbol{CO2\ emission = 9 - 84 \times WTDx}$ *WTD* is the water table depth below the peat surface (-m, negative) of the crop, *x* is the crop, 9 and 84 are the factors for CO_2 emissions for deforested unproductive peatlands ($t\ CO_2\ ha^{-1}\ year^{-1}\ m^{-1}$).	Hooijer et al. 2012; Study cases from various sources, particularly with regard to water table depth of the non-tree crops.
(2) Profitability	Net Present Value (NPV)	$\boldsymbol{NPV = \sum_{t=0}^{n} (Bt - Ct) \times \frac{1}{(1+r)^t}}$ *NPV* is the Net Present Value of the crop (euro), *B* is the benefits of the crop (euro), *C* is the costs of the crop (euro), *r* is the discount rate (%, using a 10% discount rate), *t* is the year, *n* is the time period considered (25 years).	Hanley and Barbier 2009; Study cases from various sources, supplemented by data from questionnaires and interviews.
(3) Scalability of market	Scoring based on the available markets	The number of available markets of the paludiculture crops in local (village), provincial, national and international scales.	Study cases from various sources, supplemented by data from questionnaires and interviews with the farmers/peatland users.
(4) Acceptability to farmers	Score reflects the easy of cultivation	Includes the following criteria: the ease of obtaining seedlings, the ease of maintaining and harvesting, and the time until the first harvest of the crop.	Study cases from various sources, supplemented by data from questionnaires and interviews with the farmers/peatland users.

Sustainability

We use the typical water table depth of the crop when cultivated in peatlands as the predictor for estimating the CO_2 emissions of the crop, following Hooijer et al. (2012). We group the crops in tree and non-tree crops (Ecocrop 2018). The tree crop–group contains the crops with woody stems, usually perennial plants. For the tree crops group, we apply a linear relationship between water table depth and carbon losses for drained natural forest peatlands. For the non-tree crops group, we use the linear relationship between water table depth and carbon losses for deforested unproductive peatlands. Although the water table depth of a crop varies in the field, for this study we use the minimum value for the optimistic estimation of the CO_2 emission from the cultivation of the crop. Here, we propose a general framework to score the sustainability performance of each paludiculture crop as shown in Table 2. As a comparison, in natural peat forests over time, there is a sequestration of CO_2, but in specific years or circumstances (e.g. climate, precipitation and vegetation change) there can also be an emission of CO_2 of 10 tonnes CO_2/ha/year at most (Rieley et al. 2008). Oil palm plantations, on the other hand, were estimated to emit about 78 tonnes CO_2/ha/year at a mean water table depth of 0.7–m below peat surface (Hooijer et al. 2012).

Table 5.2 Score classification used to assess the sustainability performance of the paludiculture crops

Class	Description
3	Paludiculture crop with estimated CO_2 emissions ranging from 0 to 10 t CO_2 ha^{-1} $year^{-1}$
2	Paludiculture crop with estimated CO_2 emissions ranging from 11 to 30 t CO_2 ha^{-1} $year^{-1}$
1	Paludiculture crop with estimated CO_2 emissions ranging from 31 to 60 t CO_2 ha^{-1} $year^{-1}$
0	Paludiculture crop with estimated CO_2 emissions more than 60 t CO_2 ha^{-1} $year^{-1}$

Profitability

The profitable characteristic is investigated using Net Present Value (NPV) as an indicator (Hanley and Barbier 2009). In the NPV calculation of each crop, we use a discount rate of 10% and a discount period of 25 years. Costs for land are not included, i.e. it is assumed that smallholders have access to the land and do not need to pay a lease (which is typically the case for smallholders in Central Kalimantan). The prices and costs of each crop's products/commodities are referred to as the values in the year 2017. The costs refer to the investment costs (e.g. farmer tools, costs for seedling and initial land preparation) and operational costs (e.g. labour cost, fertiliser, pesticide/herbicide, irrigation/water management/ monitoring, etc.). We exclude the costs of converting the degraded peatland suitable for paludiculture (e.g. costs for building dams to block drainage canals, see Hansson and Dargusch 2018). Here, we use a score for the profitability of each paludiculture crop (Table 5.3). For comparison, the average expenditure on food and non-food per capita in Central Kalimantan province in 2017 is € 888/year (BPS Central Kalimantan 2018a), and the NPV of the resource rent of oil palm production on peatland has been estimated at around €40,000 per hectare for a 25–year discounting period at a 10% discount rate, as long as drainage conditions are suitable for the crop (Sumarga et al. 2015).

Table 5.3 Score classification used to assess the profitability performance of the paludiculture crops

Class	Description
3	Paludiculture crop with estimated NPV more than €50,000.-
2	Paludiculture crop with estimated NPV ranging from €35,001.- to €50,000.-
1	Paludiculture crop with estimated NPV ranging from €20,000 to €35,000.-
0	Paludiculture crop with estimated NPV less than €20,000.-

Scalability of market

We analyse the market availability for each crop in the local (village), provincial, national and international scales. The data are obtained from various sources of literature and supplemented by our questionnaires and interviews with the farmers and relevant stakeholders. In order to assess our findings, we propose four classes for the score as shown in Table 5.4. We include the international market because the area of peatlands that need rehabilitation in Indonesia is very large (several million ha). Therefore, eventually, crops need to be identified and promoted for which there is a large market. It is of course not obvious that individual smallholders can access international or even national markets, but potentially there is a role for cooperatives, or for plantation companies to grow such crops.

Table 5.4 Score classification used to assess the performance of market scalability of paludiculture crops

Class	Description
3	Paludiculture crop with available markets in local, provincial, national and international levels
2	Paludiculture crop with available markets in local, provincial and national levels
1	Paludiculture crop with available markets in both local and provincial levels
0	Paludiculture crop with available markets only in local (village) level

Acceptability to farmers

We analyse the acceptability of the cultivation processes for each paludiculture crop to the farmers. Here, the cultivation processes comprise the ease of seedling, maintaining and harvesting and the time period until the first harvest. With regard to the ease of seedling, maintenance and harvest process, we assign a score of 1 for "easy" and score of 0 (zero) for "not easy". With regard to the time period until the first harvest, we propose to give a score of 1 if the first harvest of the crop can be harvested in less than 2 years and a score of 0 (zero) if the crop needs more than 2 years to produce the first harvest. We then aggregate all scores to obtain the total scores for each particular crop.

5.3 Results

5.3.1 Sustainability

Table 5.5 shows the estimates of the CO_2 emissions and score for 15 paludiculture food crops species cultivated in the peatland areas of Central Kalimantan which then indicate their sustainability performance.

Our analysis shows that the paludiculture crops cultivated in the peatland emit CO_2 less than 50 tonnes CO_2/ha/year (values ranging from 0 to 49 tonnes CO_2/ha/year) depending upon the species, group and the water table depth applied (ranging from 0 to –0.5 m below the peat surface). Interestingly, our calculation shows that sago palm/sagu (*Metroxylon sagu*) and illipenut/tengkawang (*Shorea* spp.) are able to generate zero CO_2 emissions. On the other hand, two vegetables grown/cultivated within a zero water table depth (i.e. kelakai edible fern/ *Stenochlaena palustris* and water spinach/*Ipomoea aquatic*) still produce CO_2 emissions due to the absence or limited shade provided by the trees vegetation cover in peatland which then result in the peat oxidation. It is important to note that the presence of tree cover will reduce oxidation, even when the water table is lowered (Hooijer et al. 2012). Water management with a range of 0.4–0.6 m drainage levels has been promoted as best practice for the peatland use (Lim et al. 2012). However, this best practice will still emit about 36 tonnes CO_2/ha/year to 60 tonnes CO_2/ha/year.

Table 5.5 The estimation of the CO_2 emissions and the sustainability scores for 15 paludiculture food crops cultivated in the peatland areas of Central Kalimantan

Type of paludiculture food crop	Group	Assumed minimum Water Table Depth (–m, negative, below peat surface)	Estimated CO_2 emissions (t CO_2/ha/year)	Score
Sago palm/sagu (*Metroxylon sagu*)	Tree	0	0	3
Illipenut/tengkawang (*Shorea* spp.)	Tree	0	0	3
Water spinach/kangkong (*Ipomoea aquatica*)	Non-tree	0	9	3
Kelakai edible fern (*Stenochlaena palustris*)	Non-tree	0	9	3
Snake fruit/salak (*Salacca/Eleiodoxa sp.*)	Tree	–0.2	20	2
Durian (*Durio zibethinus*)	Tree	–0.3	29	2
Rambutan (*Nephelium lappaceum*)	Tree	–0.3	29	2
Mangosteen/manggis (*Garcinia mangostana*)	Tree	–0.3	29	2
Banana/pisang (*Musa paradisiaca*)	Non-tree	–0.3	34	1
Dragon fruit/buah naga (*Hylocereus undatus*)	Non-tree	–0.3	34	1
Sweet melon/melon (*Cucumis melo*)	Non-tree	–0.3	34	1
Bitter gourd/pare (*Momordica charantia*)	Non-tree	–0.3	34	1
Pineapple/nanas (*Ananas comosus*)	Non-tree	–0.3	34	1
Candlenut/kemiri (*Aleurites moluccana*)	Tree	–0.5	49	1
Liberica coffee/kopi liberika (*Coffea liberica*)	Tree	–0.5	49	1

5.3.2 Profitability

The estimations of the Net Present Value (NPV) and the score for the profitability for each paludiculture food crop species which are commonly grown in Central Kalimantan peatlands is presented in Figure 5.2. The values are converted into euro (€) based on the year 2017 average exchange rate of IDR 15,270 or US$ 1.10 for € 1 according to European Central Bank (ECB 2018).

Our analysis shows that only three paludiculture food crops have NPVs of more than €40,000/ha/25 years which are dragon fruit/buah naga (*Hylocereus undatus*), candlenut/kemiri (*Aleurites moluccana*) and mangosteen/manggis (*Garcinia mangostana*). Candlenuts are already in high demand among the local markets as they are used for spice and seasoning in Indonesian cuisines and would reach their peak prices during the religious celebrations in Indonesia (e.g. Eid-al-Fitr and Christmas). Dragon fruits are one of the favourite fruits because of their high health benefits (raw fruit), their beauty for decoration and their other uses for food products such as sherbet and food colouring agent (PROSEA 2018). It is important to note that the illipenuts (*Shorea* spp.) are harvested just once in every 4 years, and that the harvests are varied.

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In one area illipe trees tend to flower and produce nuts at the same year, followed by several years of very low harvest. These variations pose a challenge for processing the fruit, which is one of the reasons why illipenuts have not been cultivated at any significant scale in Kalimantan. Furthermore, it needs to be noted that there are several different crops that are labelled at present as illipenuts, with different productivity, oil quality, and variability in the yields. Dragon fruits have been considered for peat rehabilitation, but this would still require to some extent drainage of the peatlands and therefore will ultimately not be sustainable, and the stability and scalability of the market may be more limited compared to, for instance, banana and sweet melon, which are grown in the shallow peat in already sizeable volumes in Central Kalimantan. On the other hand, Central Kalimantan is also an important producer of water spinach (BPS Central Kalimantan 2018a, 2018b), which can be grown under undrained conditions.

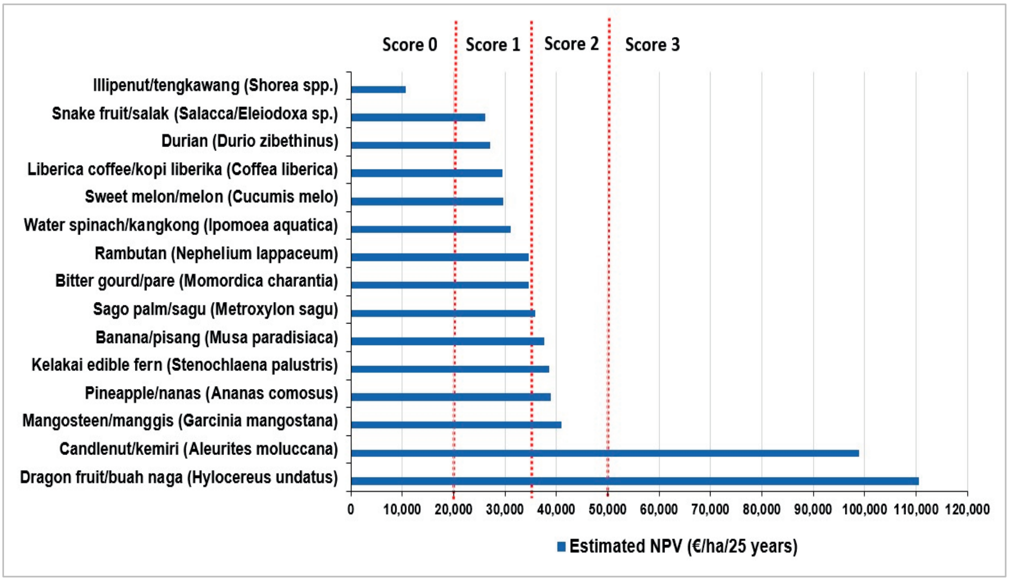

Figure 5.2 The estimation of the NPVs per hectare for 25 years and the profitability scores for 15 paludiculture food crops grown in the peatland areas of Central Kalimantan.

We also note that although swamp rice farming may be considered as an important alternative for agro-food development on the (degraded) peatlands in Indonesia (Surahman et al. 2018), it would be very difficult to implement due to higher requirements of soil improvement techniques (tillage, amelioration and fertilisation) and water level control. Also, rice is only suitable to be cultivated in the shallow peat areas. Yet, the farming of some recommended rice varieties which are adaptive to peatlands conditions (e.g. *Inbrida Padi Rawa/Impara, IR42, IR64, IR66, Kapuas,* etc.) may make rice one good option for agro-food paludiculture crop (JICA 2017). Also, rice farming still requires drainage/water level control and the local people often apply slash-and-burn practices for the land preparation which may create another threats for the peatland (Noor et al. 2014; Giesen & Nirmala 2018). On the other hand, it is important to note that the market price of these recommended swamp rice varieties is often lower than the market price of the other local rice varieties (e.g. *Siam unus*, *Lemo*, and *Pandak*) because the local rice varieties are more preferable for the local communities in our study area (in line with Surahman et al. 2018; Noor et al. 2014). This low market price can hinder peatland farmers to further implement the rice swamp agriculture.

5.3.3 Scalability of market

Table 5.6 presents the availability of the market and the score of the scalability of the market for each paludiculture food crop species analysed in this study.

Table 5.6 The market availability and the scores of scalability of the market for 15 paludiculture food crops from Central Kalimantan peatlands based

Type of paludiculture food crop and product	Market availability				Score
	Local (Village)	Provincial	National	International	
Sweet melon/melon/*Cucumis melo* (fruit)	> 3	> 3	3	0	2
Pineapple/nanas/*Ananas comosus* (fruit)	> 3	> 3	1	0	2
Dragon fruit/buah naga/*Hylocereus undatus* (fruit)	> 3	> 3	1	0	2
Durian/*Durio zibethinus* (fruit)	> 3	> 3	1	0	2
Mangosteen/manggis/*Garcinia mangostana* (fruit)	> 3	> 3	1	0	2
Rambutan/*Nephelium lappaceum* (fruit)	> 3	> 3	1	0	2
Banana/pisang/*Musa paradisiaca* (fruit)	> 3	> 3	1	0	2
Snake fruit/salak/*Salacca (Eleiodoxa)* sp. (fruit)	> 3	> 3	1	0	2
Liberica coffee/kopi liberika/*Coffea liberica* (drained bean)	2	2	1	0	2
Sago palm/sagu/*Metroxylon sagu* (wet sago)	>3	2	1	0	2
Illipenut/tengkawang/*Shorea* spp. (nut)	1	2	1	0	2
Water spinach/kangkong/*Ipomoea aquatica* (vegetable)	> 3	2	0	0	1
Bitter-gourd/pare/*Momordica charantia* (vegetable)	> 3	2	0	0	1
Candlenut/kemiri/*Aleurites moluccana* (nut)	2	2	0	0	1
Kelakai edible-fern/*Stenochlaena palustris* (vegetable)	> 3	0	0	0	0

Our analysis reveals that every paludiculture product is traded by farmers in at least one village, some products have been marketed across the regencies/districts in Central Kalimantan, or even to the other provinces outside Central Kalimantan province. Our respondents also mentioned that there is as yet no direct trading of their products to the international markets. We also noted that in term of the farming size, most of the cultivation areas are small and medium scales (less than 5 ha per farmer). The domestic market destinations are limited to provinces in the Java island whereas the identified potential export market destinations are both regional (South-East Asia e.g. Malaysia and Singapore) and global (e.g. China, Uni Arab Emirates, USA, EU, etc.) (BPS Central Kalimantan 2018b; BPS 2018b). It is important to note that kelakai edible fern/midin vegetables (*Stenochlaena palustris*) is a vegetable that is popular for the local cuisines in Borneo island (Kalimantan-Indonesia and Sarawak-Malaysia, see Nion et al. 2016; Chai 2016). However, this kelakai vegetables (*Stenochlaena palustris*) will be difficult to export because of its short shelf life (will begin to turn black after 24 hours, even if stored in a refrigerator), unless better packaging system is invented or made as processed foods such as kelakai snack chips and crackers. Sago is another potentially interesting crop, since it can be processed into starch for a wide variety of purposes including potentially bioplastic and bioethanol.

5.3.4 Acceptability to farmer

Table 5.7 shows the acceptability of the 15 paludiculture food crops to farmers in Central Kalimantan with regard to the cultivation process. Clearly, the acceptability of the farmer is related to the profitability of the crop as expressed with the NPV. However other important aspects are the time that the farmer needs to wait before he can get his first income, the access to (high yielding) seedlings, and the amount of initial investment needed.

Most of the peatland farmers in Central Kalimantan in our survey stated that the seedlings are relatively easy for them to obtain from local sources, although in some cases they have to buy the seeds in order to obtain seeds with higher quality. In the case of harvesting, currently only manual (traditional) techniques are used by the farmers as the machinery techniques are not yet available for the farmers to use. It is noted that kelakai edible ferns (*Stenochlaena palustris*) is a wild–grown species or can be cultivated without requiring any agricultural treatment (off–farm). Yet, these *Stenochlaena palustris* plants are often considered by the farmers as weeds in their farming fields despite their high profits as vegetable crops. The paludiculture crops which are first harvested after more than two years are generally woody crops (mostly fruit trees) and in many cases, farmers should combine their annual woody crops with some other seasonal crops (e.g. vegetable crops) and/or livestock and/or fish culture in order to increase their incomes. It is noted that during 2017, water spinach/*kangkong* is one of vegetable crops with the largest harvested areas in Central Kalimantan (together with cucumber/ketimun (*Cucumis sativus*), yard-long bean/kacang panjang (*Vigna unguiculata sesquipedalis*), egg-plant/terong (*Solanum melongena*) and chili/cabe (*Capsicum annum*)) (BPS Central Kalimantan 2018a; MoARI 2018). Among the perennial fruits in Central Kalimantan, rambutan, durian and banana have been harvested at a large number of areas (MoARI 2018).

Table 5.7 The crops acceptability to farmers in Central Kalimantan related to the cultivation process in Central Kalimantan peatlands

Type of paludiculture food crop	The ease of obtaining seedlings	The ease of maintaining & harvesting	Time period until the first harvest		Score
			< 2 year	> 2 year	
Pineapple/nanas (*Ananas comosus*)	easy (1)	easy (1)	✓ (1)		3
Sweet melon/melon (*Cucumis melo*)	easy (1)	easy (1)	✓ (1)		3
Banana/pisang (*Musa paradisiaca*)	easy (1)	easy (1)	✓ (1)		3
Water spinach/kangkong (*Ipomoea aquatica*)	easy (1)	easy (1)	✓ (1)		3
Bitter gourd/pare (*Momordica charantia*)	easy (1)	easy (1)	✓ (1)		3
Kelakai edible fern (*Stenochlaena palustris*)	easy (1)	easy (1)	✓ (1)		3
Dragon fruit/buah naga (*Hylocereus undatus*)	difficult (0)	easy (1)	✓ (1)		2
Mangosteen/manggis (*Garcinia mangostana*)	easy (1)	easy (1)		✓ (0)	2
Snake fruit/salak (*Salacca/Eleiodoxa sp.*)	easy (1)	easy (1)		✓ (0)	2
Illipenut/tengkawang (*Shorea macrophylla*)	easy (1)	easy (1)		✓ (0)	2
Rambutan (*Nephelium lappaceum*)	easy (1)	easy (1)		✓ (0)	2
Sago palm/sagu (*Metroxylon sagu*)	easy (1)	difficult (0)		✓ (0)	1
Durian (*Durio zibethinus*)	easy (1)	difficult (0)		✓ (0)	1
Candlenut/kemiri (*Aleurites moluccana*)	difficult (0)	easy (1)		✓ (0)	1
Liberica coffee/kopi liberika (*Coffea liberica*)	difficult (0)	easy (1)		✓ (0)	1

It is important to note that sago palms (*Metroxylon sagu*) are naturally ubiquitous in Central Kalimantan ecosystems including the peatland ecosystem. Sago starch extracted from the pith of the plant stems is known to be one of the main staple foods for the local population in the area before rice took over as the favourite source of carbohydrates. In the peatland areas, they can be easily cultivated in shallow and medium depth peat as well as on the riverbanks by planting the suckers (Tata & Susmianto 2016). Other than for food, sago starches can be used in textile and paper industries and for the production of bioethanol and bioplastic. Many different parts of sago palm can also be used for food (the young stems can be cooked for some dishes), construction and weaving crafts materials, food pellets ingredients for poultry and fishery farms, biomass (ethanol made from sago), growing media for *Volvariella volvacea* mushrooms and breeding *Rhynchophorus* larvae which is a good source of protein (JICA 2017). However, three main factors that might hinder farmers to cultivate sago palm are the time to wait before the first crop can be harvested (at least 8 years, TECA 2015a), the laborious starch extraction process, the limited size of the market for sago and the lack of access to the sago markets at the provincial and national levels hence the sago extracted are mainly consumed by the farmers themselves and at present considered less profitable crop (Nishimura 2018). In this study, we point out that sago palm cultivation has a high potential as an alternative for more sustainable use of peatlands but support is needed for farmers to overcome the 8 years period before harvest. However, once the sago is mature harvesting can take place every year, and –unlike oil palm– there is no need to replant after 25 years or so. There is also a need to further explore processing opportunities for sago including for bioethanol and bioplastic.

5.3.5 Aggregated assessment

Figure 5.3 shows the aggregated scores of the indicators in the sustainability, profitability, scalability of market and the acceptability to the farmers in Central Kalimantan for each paludiculture food crop.

Our analysis reveals that mangosteen/manggis (*Garcinia mangostana*), sago palm/sagu (*Metroxylon sagu*), water spinach/kangkong (*Ipomoea aquatica*), kelakai edible fern (*Stenochlaena palustris*), dragon fruit/buah naga (*Hylocereus undatus*), pineapple/nanas (*Ananas comosus*) and banana/pisang (*Musa paradisiaca*) have the highest scores, whereas liberica coffee/kopi liberika (*Coffea liberica*) has the lowest score. Interestingly, from the crops with the highest scores, mangosteen/manggis (*Garcinia mangostana*) has same scores in its all indicators, sago palm/sagu (*Metroxylon sagu*) has particularly the highest score for the sustainability indicator, whereas water spinach/kangkong (*Ipomoea aquatica*) and kelakai edible fern (*Stenochlaena palustris*) show the highest scores for both the sustainability indicator and the acceptability to farmers. Dragon fruit/buah naga (*Hylocereus undatus*) is particularly profitable, while banana/pisang (*Musa paradisiaca*) and pineapple/nenas (*Ananas comosus*) have the highest scores for the acceptability to farmers (and indeed these crops are increasingly grown on peatlands in Central Kalimantan).

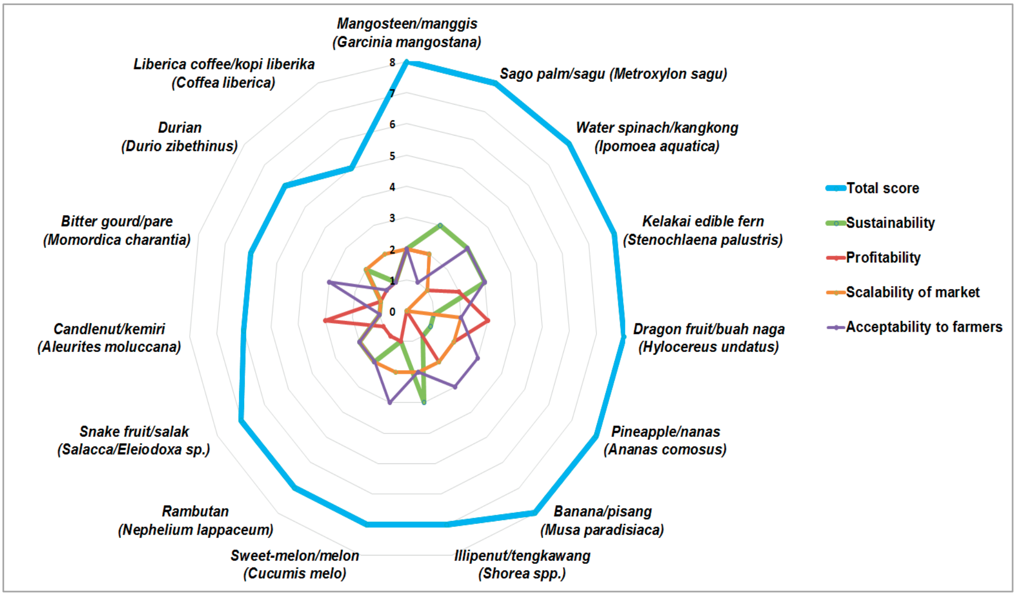

Figure 5.3 Results of aggregated scores of the socio-ecological indicators for 15 paludiculture food crops from Central Kalimantan peatlands.

5.4 Discussion

5.4.1 Data uncertainties and limitations

It is clear that there are uncertainties related to the scoring of each crops as per our indicators. Even though we indicate the thresholds for each score, in reality there will be differences, partly depending upon local context, that are not considered in this methodology. For example, profitability on local markets depends upon local prices, which may vary considerably between markets. Also, our emission factors assume a certain drainage level per crop, but in practice each crop is grown under a range of drainage conditions. In case where peatlands were drained before planting, it is unlikely that farmers will increase water levels to the maximum level that the crop can sustain (see also Giesen & Nirmala 2018). This affects, as we witnessed in several villages, for example rambutan, durian, dragon fruits, pineapples and melons that are sometimes grown at deeper water tables than assumed in our study. An exception is water spinach, which requires near sub-merged conditions. Hence, our scoring should be seen as indicative yet useful in terms of assessing the barriers to the cultivation of the individual paludiculture crops. Another important limitation of our study is that we assessed the crops in isolation as in reality the smallholder farmers often planting a combination of crops in order to spread risks, diverse income and spread food availability throughout the years. Intercropping may reduce some of the disadvantages of planting individual crops. For example, sago could be grown in combination with vegetables that can provide an income early in the cropping cycle. By providing shade, sago trees would reduce CO_2 emissions from peat areas. In addition, we did not consider combinations of crop farming and livestock (e.g. cow/cattle, water buffalo, poultry/chicken and duck) and/or aquaculture (e.g. in blocked drainage canals). We also exclude non-food crops such as jelutung resin (*Dyera* sp.) which is an example of a crop that can be grown as industrial plantations without draining the peatlands (Giesen & Nirmala 2018). Hence, opportunities for promoting sustainable livelihoods in peatlands are actually larger than the options we present in our paper. Yet, in the selection of the paludiculture crops for the scaling up in Central Kalimantan and potentially other provinces of Kalimantan, some of our findings would be very relevant.

5.4.2 Opportunities and bottlenecks for paludiculture development on peatland areas

In Central Kalimantan, the conversion of peat to croplands and plantations is still ongoing. While more regulations are in place nowadays for plantation companies, there are currently little controls and support for the smallholders/farmers. To illustrate this trend, in the year 2000 around 144,500 ha of peatlands was used for cropping and this increased to 241,408 ha in 2014 (an increase of 40%). In 2017, this increased to 702,408 ha, i.e. nearly a fivefold increase in 17 years (Uda et al. 2017; MoEFRI 2018). In 2017, the total area of protected peatland only covers about 55% of the total area of peat hydrological units (PHU or Kawasan Hidrologi Gambut/KHG) in Central Kalimantan (MoEFRI 2018). A crucial element for better managing Indonesian peatlands is to stop the ongoing conversion of peatlands. Drainage always leads to high CO_2 emissions, and –once drained– rewetting the peat through a mix of canal blocking, fire control, and rehabilitation of the vegetation is very expensive (Hansson and Dargusch 2018; BRG 2019).

In this study, we only focus on the food crops. Some insights into the opportunities and barriers for the cultivation of paludiculture food crops are presented in Appendix 5.4. All the crops are already cultivated by farmers who selected mostly on the cases of profitability and ease of cultivation. Seven crops are tolerant to inundation while others warrant strict water management or limited drainage. Some crops are not recommended for scaling-up to plantation-based systems because there is only a limited market for them (e.g. bitter gourds, water spinach). Therefore, it is important to separately assess the recommended species for the farmers/communities and/or plantation-based peatland developments (Giesen 2013). In our paper, we focus on the community-based systems which more likely will lead to poverty reduction. We find that peatland uses by indigenous farmers are mostly a long continued heritage (e.g. durian, rambutan, illipe nut, mangosteen) while other ethnic farmers (e.g. transmigrants from Java, Bali or Sumatra) are more open to introduce new crops such as dragon fruit, snake fruit, sweet melon, liberica coffee, candlenut, etc. to cultivate in the peatlands.

Our analysis shows that for the farmers, however, the market demand and the possibility to access the market are the most important factors in implementing paludiculture. The current markets for the paludiculture food products in Central Kalimantan are mostly for domestic markets in the local areas/villages while direct trading to the international markets (direct exports) are still not available. However, marketing the products to the other provinces (mainly in Java island) may supply the available export markets (e.g. the main export centre of Indonesian sago is in Riau province, mangosteen is in Bali, illipe nut is in West Kalimantan, etc.) (Giesen & Nirmala 2018).

It is also highlighted that technology and facilities to help the farmers in maintaining, harvesting and processing their crop products are still lacking. The main obstacle observed from the low exports of agro-food products might relate to the quality of the products which often do not meet the standard quality required for export (Moïsé et al. 2013). Thus, socialisation of the export standards to the farmers and support to achieve them are crucial. Some regencies in our study area have developed a number of community trials for paludiculture crops in the peatland restoration areas (e.g. sago in Pulang Pisau regency, dragon fruit in Palangka Raya), and have initiated some new paludiculture plantation trials (e.g. philippine-tung/kemiri sunan (*Reutealis trisperma*), tamanu/nyamplung (*Calophyllum inophyllum*) plantations in Palangka Raya, Pulang Pisau regency and Katingan regency) (CIFOR 2016). The outcomes of these trials showed that these crops can also adapt in the degraded and burned peatlands and perform very well in an agroforestry system (Maimunah et al. 2018). Another concern relates to the government policies on the bans of the trading of raw materials of some commodities for export (e.g. illipenut seeds and also raw rattan) which cause low market prices and limited access to market for the commodities.

5.5 Policy recommendations

The Indonesian Government has been stepping up the protection and management of peatland ecosystems in Indonesia through a number of regulations including the recent National Government regulations PP No. 57 year 2016 on peatland ecosystems protection and management (Indonesia Government Regulation 2016). The government has prescribed 3–m peat depth as the main criterion for distinguishing between protected and developed peatland areas and the surface water table depth of less than 0.4–m as the criterion for categorizing a damaged peatland area. Depending on whether the regulation can be applied consistently, these will increase the chance for a successful transition towards sustainable peatland uses and management in Indonesia including through paludiculture.

Paludiculture commodities had been introduced in Indonesia for around ten years. Yet, when compared to the current "traditional" drained-peatland-based crops such as oil palm, acacia, and rubbers, they are still less attractive to farmers (Joosten et al. 2016; Sumarga et al. 2016; Giesen & Nirmala 2018). The adoption of paludiculture for the non-drained peatland uses will depend greatly upon the policies and regulations that can limit increased cultivation on the drained-peatland-based crops (Uda et al. 2017).

The barriers described in the previous section are very different for each of the paludiculture crops. Hence, promoting paludiculture requires a targeted approach for each crop. We have identified several ways to promote paludiculture crops (see Appendix 5.5) which include support to water management (to avoid excessive drainage); providing access to (free) seedlings which are resistant to pest and weeds; subsidies for fertilisers, pesticide and herbicide; providing assistances (e.g. via agricultural extension agents) for post-harvest handlings/technology and product quality (certification product) particularly for exports of fruits; providing facilities for making processed food (e.g. ice cream, cake, pasta, snack chips, etc.) and other potential products such as for medicinal uses and fuel (e.g. bioethanol/biofuel from sagu, fuel from dried rind of the fruits); and financial support for farmers for crops which need a long-time period before the first harvest (such as sago). We also believe the bans on raw rattan export should be revoked as soon as possible. The ban on rattan has been in place since 2012 (MoTRI 2012) but there are still no signs of a domestic rattan industry emerging while suppressing the income of rattan farmers who are actually protecting the peatland forest through their rattan farming.

Our analysis points out that the paludiculture crops such as sago, water spinach, mangosteen, etc. will generate profits without or with minimum externalities costs such as CO_2 emissions, peat subsidence, loss of productive land, peatland fires haze and the related health effects. Also, given that the smallholders (land < 2 ha) take the largest share in the Indonesian agricultural sector, the improvement and support to the family farming are preferable. We realise that no single crop shall be cultivated on the paludiculture plots as cultivating a mix of crops with the local mix depending upon local context such as access and proximity to markets, seeds availability, farmers' preferences, etc. will create a more resilient and sustainable farming. To achieve this, different national and local government bodies have to support and collaborate with peatland users to design and operate the paludiculture development based on single hydrological units (peat dome) as part of NAMA (National Appropriate Mitigation Action) and GHG reduction strategy (at the community and/or plantation scales). Alongside their potential direct profits to the farmers, paludiculture crops may also generate profits through carbon trading which in turn will accelerate Indonesian achievement in the reduction of GHG emissions to which Indonesian government has voluntary pledged in 2015 to reduce its GHG emissions up to 29% by 2030 (INDC 2015). If carbon trading can be fully implemented in Indonesia the non-drained peatland uses for paludiculture will be financially more attractive to the farmers.

Moreover, growing agro-food paludiculture crops will support the food provisions and strengthen the food security particularly in the region. This can also support the national development strategy on "food estate" which is to develop large-scale crop cultivation areas (> 25 ha) (see Indonesia Government Regulation 2010). The involvement of private actors (investors) may effectively support the development of paludiculture. Therefore, developing the local partnerships among the stakeholders (e.g. government, businessmen, farmers, consumers, NGOs, academic, etc.) to promote medium-large scale paludiculture without shifting landownerships (to avoid land grabbing) is recommended. It is important that the communities as well as the regencies/districts that have successfully managed their peatlands are recognised and rewarded for their contributions to sustainably maintain the peatlands. A fiscal policy by integrating the ecological and social aspects into the intergovernmental fiscal transfer instruments should be invented to promote and support the sustainable development in peatland areas (e.g. provide general-purpose transfer (*Dana Alokasi Umum, DAU*), specific-purpose fund (*Dana Alokasi Khusus, DAK*), and/or shared revenue fund from taxes, non-taxes and/or natural resources (*Dana Bagi Hasil, DBH*)) (Cadman et al. 2019). Lastly, while focusing on that restoring the damaged peatlands, it is crucial to keep the policy of "no drainage" on the peatland areas, given that many natural/undrained peatlands in Indonesia have not yet been protected from the risks of conversion. This policy can be supported by carbon trading policy which in turn will show which crops that may give extra profits due to their ability to reduce carbon emissions from peatland uses.

5.6 Conclusions

This study assesses 15 paludiculture food crops that could be used in Indonesia in terms of their sustainability, profitability, scalability of market and the acceptability to the farmers. It is important to identify suitable paludiculture crops for Indonesian peatlands given the high CO_2 emissions and irreversible soil subsidence that are characteristic of current peat management practices. All paludiculture crops can be grown with no or minimum drainage, with CO_2 emissions from these paludiculture ranging from 0 to 49 tonnes CO_2/ha/year. There are, however, major differences in the profitability, with the most promising crops (mangosteen, sago) in principle are able to compete with oil palm, provided that the markets for these crops can be supported and enlarged. Other species, that can be of local interest to farmers are water spinach, *Stenochlaena palustris* edible fern/kelakai, dragon fruit, pineapple and banana, even though some of these crops still require some drainage. These paludiculture crops would contribute to sustainable peatland uses and food security at the regional and national level. The results of this study can be used as inputs for business plans and for value chain development programmes designed for a sustainable peatland management. Critical factors in promoting paludiculture crops are i.e. the development of markets for paludiculture crops; the adaptation and enforcement of the legislation governing peatlands; further improvements to the farming and harvesting technologies, and support to farmers to meet international quality standards.

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CHAPTER 6

Synthesis

6.1 Main findings for each research question

The natural tropical peatlands in Indonesia are experiencing pressure due to land-use changes driven by economic and social developments. Although the important role and contribution of Indonesia's tropical peatlands to both the local and global environments are well recognised, their proper management is not very well–understood or implemented. Until now, the practice of peatland drainage in Indonesia is still common, reflecting that the sustainable peatland management is still poorly understood. A better understanding of the state and impact of the current peatlands' utilisation and management from a socio-ecological point of view is, therefore, very crucial in order to achieve a sustainable peatland management. The core objective of this thesis is to generate relevant data and scientific analysis that are required for a better peatland management in Indonesia by analysing the socio-health-ecological impacts of the peatlands' use and any potential response options. To achieve this objective, four Research Questions (RQs) were formulated and outlined in Section 1.3 of this thesis. In this last chapter, the results presented in chapter 2 to 5 are discussed in the light of those four research questions.

6.1.1 The dynamics of Indonesian peatlands' use and the ecosystem services supplied (RQ1)

Chapter 2 addresses RQ1: 'What are the peatlands' uses and the ecosystem services supplied by the peatlands, the key sustainability issues and the potential response options to move towards sustainable peatland management in Indonesia?' This chapter records the characteristics and the activities taking place in Indonesia's peatlands by identifying the land covers/uses and the ecosystem services they supply over the time.

To address RQ1, I first analysed the peatlands' cover and the their changes in the three main islands (Sumatra, Kalimantan and Papua) during the period of 2000 to 2014 and subsequently linked the changes in the peatlands' cover to the changes in the ecosystem services provided by the peatlands. In this thesis, I classify the land cover into ten types: undisturbed natural forest, disturbed natural forest, plantation forest, estate crop (oil palm), paddy field, dryland agriculture, urban, degraded-land, open water and finally other uses. Based on this peatland cover analysis, I then quantified seven relevant ecosystem services provided by the peatlands: timber production, oil palm production, biomass production for pulp and paddy production (as the provisioning services); carbon sequestration and emissions (as the regulating services); ecotourism/nature watching and biodiversity habitat/protected habitat (as the cultural services).

Finally, I analysed the sustainability issues and the potential response options based on four types of peatland conditions: non-productive or forest use with drainage; non-productive or forest use without drainage; productive (agricultural) use with drainage and productive (agricultural) use without drainage.

The general finding regarding the peatlands' use in Indonesia reveals that the peatland cover has changed considerably during the period of 2000 to 2014. The two key findings:

1) Nationally, the proportion of natural forest cover (both undisturbed and disturbed natural forests) has significantly decreased from 2000 to 2014 (from 61% to 45%), while the proportion of plantation cover (estate crop-oil palm and plantation forest-acacia) and degraded-land cover during the same period had escalated (from 7% to 12% for estate crop cover; from 0.3% to 6% for plantation forest cover and from 23.8% to 27.2% for degraded-land cover). The trend also indicates that half of the total non-forested areas in Indonesia's peatlands are already degraded areas.

2) Among the three main islands (Sumatra, Kalimantan and Papua), the highest conversion of natural peat swamp forests took place in Sumatra and Papua still has a large proportion of the undisturbed natural peat swamp forests. Even though the peatland conversion started later in Kalimantan and some peat swamp forests still remain intact; the island is undergoing a rapid land-use change. The degraded peatlands covered more than 25% of the total peatland areas in Sumatra as well as Kalimantan, while in Papua, the degraded peatland covered about 15% of the total peatland areas.

With regard to the ecosystem services provided by Indonesia's peatlands, the main finding was that the ecosystem services of peat swamp forests in Indonesia, i.e. as carbon sequestration areas and biodiversity habitats, have been replaced by the use for the products of plantation forests and the growing of agricultural commodities (biomass for pulp and oil palm); which in the period of 2000 to 2014:

1) The productions of oil palm and biomass for pulp are the only services provided by the Indonesian peatlands that have increased significantly in the period from 2000 to 2014. This had led to major increases in palm oil production from peatland areas by a factor of nearly of 3 and biomass production for pulp by a factor of 20.

2) The externalities related to CO_2 emission and the loss of protected habitats have been increasing. The CO_2 emissions from peatlands' utilisation in Indonesia were nearly doubled in the period from 2000 to 2014, which was 210 million tonnes CO_2 in the year 2000 to 385 million tonnes CO_2 in the year 2014, with substantial variations between years occur.

3) Timber production, paddy production and biodiversity habitat of Indonesia's peatlands also appear to be declining. About 28% of the total protected areas in peatlands in Sumatra, Kalimantan and Papua have already been converted, with the average loss of 8.6 thousand ha/year of protected habitat.

4) For ecotourism (nature watching), the trend for the total number of visitors to the conservation parks in the peatland areas has increased (21% increase from 2000 to 2014) but this is only 3% of the total number of visitors to all conservation parks in Indonesia.

5) Generally, these findings also indicate that the negative side of peatland conversions in Indonesia overshadows the positive side of such conversions.

The three key findings with regard to the key sustainability issues of Indonesian peatlands were:

1) The drained peatland areas under productive use (plantation and agricultural) and non-productive use will lead to a high risks of fires and health effects from smoke/haze, CO_2 emissions, soil subsidence, habitat loss (from productive uses) and social issues (e.g. loss of access by local people to the forest and land and no income for local people).

2) The non–drained peatland areas under productive use (agricultural use as paludiculture) pose much lower fire risks and CO_2 emissions enabling cropping over the long–term given that there is no or limited soil subsidence. However, in the short–term, they are less financially attractive compared to the current drainage-based agricultural uses such as oil palm and rubber. Their cropping will depend upon policies and regulations that limit the growing of the crops that require peat drainage.

3) The non–drained peatland areas under non-productive or forest use may have well preserved or degraded (but recoverable) ecosystems which provide different ecosystem services, including various non-timber forest products, water regulation, carbon stocks, and biodiversity habitats.

These findings also suggest that the policy priorities for the sustainable peatland use in Indonesia should be based on the water table management (drained and non-drained) and the types of use of the peatlands (productive/agricultural use, non–productive or forest use). The policy priorities should include reforestation and protecting the remaining forests, rehabilitation and rewetting the peatlands by blocking the drainage canals and stopping the digging of new drainage channels, a gradual phasing out of drainage-based crops and replacing them by paludiculture crops, improving the control of fires, the monitoring of the peatland's conditions (including land cover, land use and drainage), and the local implementation of peat policies as well as the enforcement of peat policies.

These findings improved the baseline data from the previous studies (e.g. Murdiyarso et al. 2010; Yule et al 2010; Joosten et al. 2012; Biancalani and Avagyan 2014; Law et al. 2015; World Bank 2016) by linking the economic benefits and sustainability issues of peatlands in Indonesia to the peatland uses' planning and management.

6.1.2 The health impacts of annual peatland fires and smoke (RQ2)

Chapter 3 addresses RQ2: 'What type of health effects are caused by the recurrent annual peatland fires and smoke/haze events in Indonesia and how can the health effects of these be quantified on the local populations?'. The health issues related to the impacts of peatland fires in Indonesia are still given little attention by the local governments and communities (in particular the local populations in the affected areas). This is due to a lack of information about the potential short– and long–term health impacts and the related diseases caused by peatland fires and haze caused by the accumulated smoke at the local scale. The frequent occurrence of peatland fires and haze in Indonesia, in fact, reflects the need to increase public awareness about the negative impacts of the low air quality caused by the prolonged haze. This chapter especially spotted the health consequences of the ongoing peatlands' conversion and degradation in Indonesia, in particular the heatlh consequences of haze from the peatland fires due to drained peatland and slash-and-burn practices.

To address RQ2, I assessed the long-term health impacts of the $PM_{2.5}$ exposure from peat smoke caused by the recurrent annual peatland fires. I took a case study in Central Kalimantan, the province with the largest peatlands in the Indonesian part of Borneo, and quantified the annual mean of the $PM_{2.5}$ concentration from the peat smoke due to peatland fires during the period of 2011 to 2015 and subsequently estimated and analysed the long–term health outcomes and related diseases caused by this annual mean of $PM_{2.5}$ exposure to the local population in Central Kalimantan.

The three key findings were:

1) The estimated annual mean of $PM_{2.5}$ concentrations due to smoke during 2011 – 2015 peatland fires in Central Kalimantan was 26 $\mu g/m^3$ (of which the average annual mean $PM_{2.5}$ concentrations from hotspots in the deep peat and shallow peat were each 13 $\mu g/m^3$), which exceeded the World Health Organisation Air Quality Guidelines of 10 $\mu g/m^3$.
2) The long–term exposure to $PM_{2.5}$ from peat smoke, within the average annual mean $PM_{2.5}$ concentrations of 26 $\mu g/m^3$ as estimated during a 5–year period (2011–2015) causes 648 premature mortality cases per year (equals to 26 mortality cases per 100,000 population), which included 55 mortality cases due to chronic respiratory diseases, 266 mortality cases of cardiovascular diseases and 95 mortality cases of lung cancer. It is noted that the mortality cases due to chronic respiratory diseases include 6 mortality cases of children aged below 5 years (2 mortality cases per 100,000 children aged below 5 years).
3) Based on the sensitivity analysis, the number of all-cases mortality increased with the increasing concentration of $PM_{2.5}$. The premature mortality cases increase by 34% for an increase of 10 $\mu g/m^3$ in the $PM_{2.5}$ concentration, while for a decrease of 10 $\mu g/m^3$ in the $PM_{2.5}$ concentration, the premature mortality will decrease by 45%.

As described in chapter 3, these findings are realised to be distinctive for Central Kalimantan's case, but this can indicate that a large number of fatalities due to peat fires and smoke/haze may have occurred in Indonesia, when taking into account that Sumatra and Kalimantan, as the areas most affected by the smoke from the annual peatland fires, have about 73 million inhabitants (57 million inhabitants in Sumatra and 16 million inhabitants in Kalimantan).

These findings are in line with the previous studies (e.g. Stockwell et al. 2016; Crippa et al. 2016; Koplitz et al. 2016; and Carmenta et al. 2017) and have implications for the public health authority to raise the community awareness about the health risk of the ongoing peatland conversion and degradation in Indonesia. It was also suggested to enforce higher standards for sustainable peatland management, particularly for mitigation policies on fires and drained peatlands' use. The findings also present a new perspective on the quantifying the health outcomes of episodic severe smoke/haze events from peatland fires since the reported government data was an underestimate of the actual health impacts of the peat fires as the government only analysed the short–term health effects of exposure to smoke from peat fire in a specific year. Additionally, these findings also demonstrated the importance of creating robust air quality monitoring stations in the affected areas, such as in Central Kalimantan, for measuring and providing accurate information about the air quality, and also the importance of carrying out proper epidemiological studies to refine the exposure functions, especially for the purpose of evaluating the impacts of episodic severe smoke/haze from landscape fires.

6.1.3 The institutional fit of peatland governance in Indonesia: the creator–adaptor context (RQ3)

Chapter 4 addresses RQ3: 'How is the institutional fit of peatland governance in Indonesia and to what degree do these institutions promote sustainable peatland management?' This chapter presents an integrated appraisal of the technical, political, and cultural interactions between the four main Indonesian peatland regulations and the practices employed by the peatlands' users.

To address RQ3, I assessed the degree of institutional fit between the rule's creators (national regulations and the practices ingrained in the peatland regulations) and the adopters (peatland users that need to comply with the national regulations) with regard to the four main peatland regulations in two provinces in Indonesia, Jambi and Central Kalimantan (both are provinces with large peatland areas). The institutional fit refers to the technical, political, and cultural fit between the practices ingrained in the peatland regulations and the practices used by the peatlands' users (adopters). The four main regulations are: (1) Government Regulation (PP) No. 71/2014 on the Peatland Ecosystems Protection and Management (stating that peatland with more than a 3–m depth is classified as a protected area and its utilisation is prohibited; that setting fires on peatland is banned, and that peatland with a surface water depth of less than 0.4–m is categorised as a damaged area) (Indonesian Government Regulation 2014); (2) Presidential Instructions (Inpres) No. 10/2011, No. 6/2013, and No. 8/2015 on the (Extended) Moratorium of the Granting of New Licences and the Improvement of the Governance of Natural Primary Forest and Peatland (stating that activities relating to the issuing of new permits related to natural forest and peatland conversion are suspended) (Indonesia Presidential Instruction 2015); (3) Government Regulation (PP) No. 4/2001 on the Control of Natural Damage and or Pollution related to Land and Forest Fires (stating that everybody is banned from setting land and forest fires) (Indonesian Government Regulation 2001), and (4) the Minister of Agriculture's Decree (Kepmentan) No. 14/2009 on Guidance for the Utilisation of Peatland for Oil Palm Cultivation (stating that establishing oil palm plantations in peatland is only allowed in peatlands with less than 3–m depth) (Indonesian Minister of Agriculture Decree 2009).

The three key findings were:

1) The degree of institutional fit for the current Indonesian peatland management system is mostly low to moderate for both Jambi and Central Kalimantan. This indicates that the existing practices of peatland users are largely incompatible with the Indonesian national peatland regulation. This also shows that many peatland users are not sufficiently aware of peatland regulations.
2) The leading causes of this low institutional fit were due to: the lack of technical knowledge about the different types of zero burning methods, the lack of availability of technology to extinguish (massive) peatland fires, the lack of information on the actual (accurate) location of the deep peatlands and the groundwater table, unclear land titles, the lack of information sharing between different governmental agencies and with the peatland users and the absence of knowledge and practices on the better alternatives for traditional peat management and land clearing.
3) Among stakeholders, the village governments, farmers groups (associations) and NGOs are the important actors who have the key roles for increasing the degree of fit between the practices ingrained in the peatland regulations and the practices used by the peatlands' users at the local level since many of the land-use decisions are taken at the village level.

While some previous studies focused on the trade-off between peatlands' uses and mitigation policies, in particular for plantations (in particular oil palm and acacia), fires and carbon emissions' issues (e.g. Goldstein 2015; Thorburn & Kull 2015; Carmenta et al. 2017; Urák et al. 2017; Evers et al. 2017), this present study assessed the fit between the practices ingrained in the peatland regulations and the practices used by the peatlands' users that need to comply with the peatland regulations. These present findings suggest that in order to move towards sustainable a peatland management in Indonesia, further work is needed including the establishment of the value chains for paludiculture crops, so that profitable alternatives for phasing out the drained-peatland-based crops (e.g. oil palm, acacia and rubber) can be promoted (e.g. Giesen 2013; Sumarga et al. 2016). Also, it is important to educate people living in and around the peatlands about the regulations governing the peatlands' use, but also of the reasons why such regulations have been established, including the massive health effects that the peatland fires can cause (Herawati & Santoso 2011; Thorburn & Kull 2015; Carmenta et al. 2017). This also involves working with the NGOs and other stakeholders in testing and rolling out a number of alternative peatland uses that generate local incomes (van Beukering et al. 2008; Sumarga et al. 2016).

6.1.4 The alternative development options for Indonesian peatlands: paludiculture food crops (RQ4)

Chapter 5 addresses RQ4: 'What are the alternative development options for Indonesian peatlands by considering four aspects: sustainability, profitability, scalability of the market and the acceptability to the farmers?'. This chapter presents the characteristics of various paludiculture food crops from that can be grown on Indonesian peatlands.

To address RQ4, I took Central Kalimantan, in Indonesian Borneo, as the case study area and I analysed the social-ecological aspects of different alternative crops, which do not require drainage (paludiculture crops) or very minimum drainage of the peatlands. I assessed and compared the potential of various paludiculture crops in the study area (focusing on paludiculture crops that can provide food and are of particular interest to the farmers) by taking into account their sustainability, profitability, the scalability of the market and their acceptability to the farmers.

The key findings were:

1) Based on the aggregated scores in the socio-ecological assessment, the best paludiculture food crops options are mangosteen/manggis (*Garcinia mangostana*), sago (*Metroxylon sagu*), water spinach/kangkong (*Ipomoea aquatic*), kelakai edible fern (*Stenochlaena palustris*), dragon fruit/buah naga (*Hylocereus undatus*), pineapple/nanas (*Ananas como*sus) and banana/pisang (Musa *paradisiaca*). However, some of these species still require drainage (albeit less than the current plantation crops do).
2) In terms of sustainability, the CO_2 emissions from these paludiculture food crops were estimated to range from 0 to 49 tonnes CO_2/ha/year which is much lower than CO_2 emission from oil palm typically (about 78 tonnes CO_2/ha/year based on Hooijer et al. 2012).
3) In terms of profitability, the Net Present Values (NPVs) of those paludiculture food crops range from about 10 thousand euros to 110 thousand euros per hectare for over a 25-year discounting period. Among these paludiculture crops, three crops have NPVs of more than the NPV from oil palm typically (€ 40,000/ha for a 25–year discounting period at a 10% discount rate, based on Sumarga et al. 2015).
4) In terms of the scalability of the market, most of the current paludiculture commodities have limited market access and demand, compared to the current drained-based peatland commodities such as oil palm, rubber, and acacia. While the domestic markets are mostly available at the village level, international markets are not yet available mainly due to

the low quality of the products which often do not meet the standard quality required for export (certification products).

5) In terms of acceptability to the farmers, although the multiplication of the seeds and the harvesting of the products are relatively easy and can be done manually by the farmers, but many potential crops have a long waiting period between planting and the first harvest (e.g. sago and illipenut should wait at least 8 years before the first crop can be harvested), and also most farmers are not connected to the markets so that at present these potential crops are considered to be less profitable.
6) The critical factors in promoting paludiculture crops are i.e. the development of markets for paludiculture crops; the adaptation and enforcement of the legislation governing the peatlands; further improvements to the farming and harvesting technologies, and support to farmers to meet the international quality standards.

These findings complemented the baseline data from previous the studies of paludiculture on Indonesian peatlands (e.g. Limin et al. 2007; Giesen 2013; Noor et al. 2014; Joosten et al. 2016; Tata & Susmianto 2016; Nishimura 2018) and also highlighted that proper peatland management practices should include water management, selection of profitable crops, the farmer acceptance/adaptation to the alternative crops, and market development. The findings demonstrate the trade-off for the 15 selected agro-food paludiculture crops in Central Kalimantan and that the results can be used as inputs for business plans as well as for the value chain development programmes designed for sustainable peatland management particularly in Central Kalimantan (for different parts of Indonesia, the most suitable agro-food paludiculture crops for a sustainable peatland use needs to be investigated by using this assessment approach).

6.2 Reflections on the overall approach: uncertainties and limitations

This thesis covers several methods for addressing the four RQs. For RQ1, the spatial analysis approach and literature review were mainly employed to identify the peatland cover and the trends on peatlands' use in Indonesia. The ecosystem services valuation approach was then applied to quantify the values of each ecosystem service provided by the peatlands. Addressing RQ2 especially required the modelling of smoke dispersion and associated $PM_{2.5}$ concentration in order to quantify the annual mean $PM_{2.5}$ and assessment of the human health risk to quantify the related human health outcomes. RQ3 was addressed by applying the institutional fit concept in order to understand the rule's creators (policy-makers and peatland regulations) and the rule's adopters (peatland users) through a literature review, questionnaires and interviews. Finally, RQ4 was dealt with through a literature review, interviews and questionnaires in order to understand the characterietics of different paludiculture crops in terms of their sustainability, profitability, the scalability of their market and their acceptability to the farmers. Next, I will briefly explain the use of each approach and their uncertainties and limitations.

6.2.1 Literature review

The literature review was a prerequisite for my thesis to find any available information related to the research problem and the RQs in my thesis. The literature review was conducted to analyse the previous research findings, methodologies, concepts and theories, etc. which were collected from various sources through both online and printed sources, including published and unpublished material, e.g. journal articles, various reports, peer–reviews, papers, policy briefs, legal framework documents, national and local regulations, statistical data, thesis, newspapers, etc.

In this thesis, I started my literature study with topics related to the latest peatland conditions in Indonesia, as well as its important role and contribution in global, national and local contexts. The information/data on peatland conditions includes the depth of the peat, hydrological/water level and drainage, vegetation, the peats' distribution (map) at the national and provincial scales, peatland use, ecosystem services, areas of burnt peat and other related matters on Indonesian peatlands (e.g. techniques for measuring carbon, the paludiculture system, peat fires/hotspots, etc.). The social–policy topics were reviewed, particularly in relation to the peat policies/ regulations (at national and provincial levels), population/demography, economic matters, the culture of the people in the peatland areas (e.g. indigenous farmers, transmigrants, etc.). I then narrowed the literature studies for each RQ.

To address RQ2, RQ3, and RQ4, the literature reviews were specifically focused to gather the information related to peatland issues in two case study areas, i.e. in Central Kalimantan Province (RQ2 and RQ4), and Jambi Province (RQ3). I have noted that the information on the topics of peat's distribution and carbon accounting, peat fires and carbon/CO_2 emissions, oil palm and acacia plantations in peatlands, deforestation, and peat policies and regulations were the most available, while the information on the ecosystem accounting, the socio–economic properties of local vegetation above peatlands and epidemiology studies on the diseases caused by the peat smoke/haze in Indonesia (also in specific case study areas) were limited.

6.2.2 Spatial analysis approach

In this thesis, the spatial analysis approach was especially used to address RQ1 and RQ2. This approach has the potential to observe and measure objects on a large scale, while offering an opportunity to overcome or complement the extensive direct measurements/field surveys. In this thesis, the spatial analysis approach, with the help of ArcGIS 10.2 tool, was applied to model the distribution of land cover, peat cover, population, hotspots, burnt areas, smoke dispersion, $PM_{2.5}$ concentrations and the related diseases at the provincial, district and village level boundaries.

The spatial datasets in this thesis were mainly sourced from data owned by Indonesian government, including the Indonesian Land Cover Map produced by the Ministry of Forestry, Republic of Indonesia (MoFRI 2014), the Indonesia Peatland Map Scale 1:250,000, produced by *Balai Besar Sumber Daya Lahan Pertanian/BBSDLP* (Ritung et al. 2011), the Central Kalimantan administration map published by the Central Kalimantan Statistical Bureau (2017) as well as the hotspots, burnt areas, and other spatial data which were provided by the Indonesian Ministry of the Environment and Forestry (MoEFRI), the Ministry of Agriculture, Republic of Indonesia (MoARI), the Indonesian National Institute of Aeronautics and Space (*Lembaga Penerbangan dan Antariksa Nasional/LAPAN*) and the Indonesian Agency for Meteorological Climatological and Geophysics (*Badan Meteorologi Klimatologi dan Geofisika/ BMKG*). Datasets related to the peatlands in Papua are particularly scarce and uncertain; very few remote sensing-based studies can be found and compared with the government's data.

The selection of the map to be used would influence the reliability of the findings in this thesis. The main uncertainty issue on using the spatial approach in this thesis was related to uncertainty of the selected maps/dataset on peat's distribution and land cover as the main input in measuring peatlands' cover/use and all related indicators in this thesis (e.g. ecosystem services). Several Indonesian peatland maps, published between 1952 and 2016 by various sources (see details in Appendix 2.1) have substantial differences in the depth of peat and the total area (the differences vary from 12 Mha to 26.5 Mha). This thesis used the BBSDLP–MoARI peatland map because it is the current official peatlands map in Indonesia, which was also used to provide an indication of the extent of the peatland in the previous study (Warren et al. 2017), although the map may underestimate the peatlands' actual extent and thickness and it has a relatively coarse scale (1: 250,000) (Hooijer and Vernimmen 2013). Also, assuming that the total area and the depth of the peatland remained to be constant over the time, this would lead to uncertainty about the changes to the peatlands' ecosystems (vegetation above peatlands) due to drainage, subsidence and the peat's decomposition. This thesis considered peatlands with at least 50–cm depth of peat; however the lack of data on the peat's depth in many parts of the country means that this boundary is often highly uncertain. The shallow peatlands currently being used may subside and disappear converting themselves into non-peatland areas.

6.2.3 Ecosystem services valuation approach

The Ecosystem Services (ESs) valuation approach is applied in Chapter 2 of this thesis. An ES is defined as the contribution of the ecosystems to the benefits used in economic and other human activities (United Nations et al. 2014). The ES valuation approach was applied to value the contributions of ecosystems (in this thesis, it is focussed on peatland ecosystem) to the economic activities (e.g. agriculture for food production, forestry for raw materials production (e.g. timber and biomass), recreation and tourism, etc.). Knowledge on the effects of peatland development on the ecosystem services supplied by the peatland is essential to make more balanced decisions on the peatland management as well as to develop the sustainable management planning, strategies, and policies in the peatlands (de Groot et al. 2010; Grêt-Regamey et al. 2017).

In this thesis, I only analysed ESs in term of physical units and not in the monetary terms. As pointed out in Chapter 2 of this thesis, the main challenge in applying the ESs approach is particularly related to the differences on the various data inputs, i.e. total areas of peatland per type of uses, number of production, net carbon flux, number of visitors to conservation areas in Indonesian peatlands. Since Indonesia has several peatland maps which lead to different total areas of peatland in Indonesia, this subsequently will reflect the potential uncertainty related to the estimation of the ESs and their spatial distributions. Hence, the selection of the peatland map used would directly influence the reliability of the ESs results. Also, by assuming that the total area and the distribution of peatland areas remained constant, this would lead to uncertainty of the ESs' results.

In the context of limited basic data of the country, although the types of ESs used were only seven, this is the first step towards a comprehensive biophysical analysis of the ESs provided by Indonesian tropical peatlands. Other services which were not included in this thesis (e.g. carbon and water storage, air and water pollution control, genetic resources, production of non-timber forest products, etc.) may have also high values that are relevant for managing (conserving) the peatlands.

6.2.4 Smoke dispersion and associated $PM_{2.5}$ concentration approach

To address the RQ2 of this thesis, the smoke dispersion and the associated $PM_{2.5}$ concentrations produced by each selected (fire) hotspot in the peatland areas were modeled by using the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT version 4.9) model. The HYSPLIT model predicted the atmospheric transport and the dispersion of the pollutants and hazardous materials, as well as the deposition/concentration of these materials from the source to the receptor areas (affected areas). The HYSPLIT model can be used interactively on the Web (the ARL READY system) or a version can be downloaded to a Windows or Mac PC (Stein et al. 2015).

In this thesis, the HYSPLIT model was used to estimate the spatial and temporal evolution of $PM_{2.5}$ from a prescribed burn/hotspot using the location and the burnt area as inputs. The output of the HYSPLIT model shows the dispersion within the direction of the plumes, along with the range of $PM_{2.5}$ concentrations (including the maximum and minimum concentrations). The main limitation of the HYSPLIT model is that this model does not take into account the effect of: chemical reactions, dense gases, by–products from fires, explosions, or chemical reactions or complex terrain – other than what is resolved by the meteorological model's terrain (see https://ready.arl.noaa.gov/ hypub/limitations.html).

The uncertainties are generated from the meteorological inventory datasets and the referenced values used as the inputs in the HYSPLIT model. The various meteorological inventory datasets can be applied in the HYSPLIT model, including the Global Data Assimilation System (GDAS), the NCEP/NCAR Reanalysis project (National Centres for Environmental Prediction/National Centre for Atmospheric Research), Global Forecast System (GFS) and Global Fire Assimilation System (GFAS) which have different spatial resolutions. The differences in the default inputs among these meteorological inventory data cause uncertainty related to the estimation of the plume trajectory, which then affects the estimation of the $PM_{2.5}$ concentrations and their spatial distribution (Khairullah et al. 2017; Koplitz et al. 2016; Crippa et al. 2016). The uncertainties are also generated from several assumptions (referenced values) applied in the HYSPLIT modeling for the runtime and deposition parameters. In this thesis, the assumptions are 24 hours total duration of the transported pollutant material downwind (mostly peatland fires in Central Kalimantan were more than 24 hours), 24–hour pollutant averaging period (output interval of the concentration's release), 100 m AGL (Above–Ground–Level) for the top averaged plume's layer (100 meters AGL is the minimum height to adequately represent the plume and indicate the concentration) and deposition parameters for the dry deposition rate

(0.001 m/s) and for the wet deposition rate (8.0E-05 litter/s). The changes in references values among these assumptions cause uncertainty related to the estimation of the $PM_{2.5}$ deposition.

6.2.5 Human health risk assessment approach

With regards to RQ2, the human health risk assessment approach was applied to quantify the health outcomes due to the long–term exposure to $PM_{2.5}$ from smoke caused by peatland fires.The estimated health impacts associated with the air pollution is an important guide for the policy–makers to indicate the magnitude of the problem and to provide a necessary assessment on the level of effort with regard to the intervention and mitigation strategies in order to improve the public health particularly in the affected areas (Ostro 2004). The health impacts (listed in this study as mortality cases) are determined by multiplying the Attributable Fraction (AF or Impact Fraction, IF) with the baseline mortality risk of the related health case and the number of people in the study area.

The uncertainties and limitations arise mainly from calculating the Relative Risk (RR) used to define the AF. Various RR models have been suggested in the literature (see Burnett et al. 2014), including logarithm functions by Ostro (2004), which was used to calculate the Relative Risk (RR) in this thesis. The use of logarithm functions is recommended by the WHO for estimating the health impacts in the areas with high concentrations of air pollution (Burnett et al. 2014). The uncertainty on the estimation of the RRs is related to the unknown parameters, e.g. the suggested β coefficients for $PM_{2.5}$ in the Ostro's logarithm function model. The parameters of RRs were estimated from the American Cancer Society (ACS) cohort studies (Ostro 2004; WHO 2006) which differ in the air pollution conditions and sources, composition of $PM_{2.5}$ and also the baseline health characteristics (from different populations). This uncertainty can lead to different outcomes when the coefficients are not consistent with the model for the conditions in my study area, Central Kalimantan-Indonesia (Burnet et al. 2014; Héroux et al. 2015). Thus, conducting proper epidemiological studies within the Indonesian peatland areas is recommended in order to refine the exposure functions in this model.

The health impacts can also be quantified in terms of their morbidity impacts. However, the absence of the baseline data on the occurrence of diseases associated with the long–term exposure to $PM_{2.5}$ (such as cardiovascular diseases, chronic respiratory problems, strokes, lung diseases, etc.) limits the assessments of the morbidity impacts in the study area. Thus, conducting health surveys to collect data on the occurrences of these diseases in the affected areas (based on the annual peat fires' smoke) is also suggested.

6.2.6 Interviews and questionnaires

Interviews and questionnaires were specifically used to address RQ3 and RQ4, with targeted respondents including peatland users and policy-makers, as well as experts/researchers from NGOs, academic and other institutions. The interview and questionnaire methods were used to collect data that are mainly related to the practices, incentives, opinions and decision making by the respondents, as well as to find the social-economic background data of the respondents. The uncertainties and limitations of this approach are mainly related to the methods for selecting the respondents, interpreting respondents' answers and the statistical analysis.

In Chapter 4 (RQ3), the respondents were selected by following a classified random sampling method, while in Chapter 5 (RQ4) the respondents were selected based on a purposive sampling method. The two locations for the case study areas (Central Kalimantan and Jambi) were selected due to high occurences of annual fires, land cover changes and greenhouse emissions from their extensively converted forest peatlands, which that has attracted global attention (Miettinen et al. 2016). The villages of the respondents were selected based on the consultations with the local governments and peatland experts in the peatland areas, which have diverse utilisation of the peatland and different types of inhabitants (including indigenous people and transmigrants). In total, about 250 respondents were selected, including respondents from three villages in Jambi and ten villages in Central Kalimantan. The number of selected villages and respondents was limited due to time and budget constraints. Nevertheless, this study has greatly benefited from the intensive consultations held with the experts and local governments in selecting the villages. The uncertainty is then related to the statistical analysis which is affected by the scoring and relative share (percentages) of the answers of the respondents. The different boundaries for classification scores, for instance, will lead to the uncertainty on the performance of the results as described in chapters 4 and 5 of this thesis.

6.2.7 Institutional fit approach

The concept of institutional fit is used in this thesis (Chapter 4) to assess the degree of fit between the creator (the national regulations and the practices engrained in the peat regulations) and the adopters (peatland users). Institutional fit is defined as the process of diagnostic analysis whereby the attributes of a problem are examined to identify the governance arrangements that generate a desirable outcome (Young 2002; Cox 2012).

In this thesis, the concept of institutional fit is used for assessing the adoption of proposed sustainable peatland management policies as well as to gain a better understanding of whether and how the national policies and regulations are adopted by local actors and incorporated into their strategies and practices (Ansari et al. 2010). A new practice that is prescribed by a policy or regulation is not automatically accepted and adopted in all localities. The adoption may vary across the actors, organisations and locations and may occur through phases of conflict and cooperation (Ansari et al. 2010; Schouten et al. 2016; Slade and Carter 2016). Thus, the concept of fit is crucial for understanding the diffusion processes of new practices that are ingrained in the policies and regulations.

The analysis of institutional fit requires analysing both the characteristics of the rule creators (in this thesis, the national regulations and the practices ingrained in the regulations) and the rule adopters (in this thesis, the local peatland users who need to comply with the national regulations). The uncertainties and limitations are related to defining the characteristics of the practices embedded in the technical, cultural and political fit and the scoring for the degree of fitness of each practice. Applying the "fitness" model is a sound approach, and one that is easily comprehended by the policy–makers. However, the limitations are related mainly to the implications of the findings, which are very distinctive for the case study areas. This means that the findings are not recommended to be used to generalise the conditions of peatland management in Indonesia.

6.3 Conclusions

6.3.1 Baseline for the thesis

The previous studies have revealed the important role and contribution of Indonesian tropical peatlands to local, national and global environments (e.g. Yule 2010; Page et al. 2011; Posa et al. 2011; Jauhiainen et al. 2016; Evers et al. 2017). Some studies provided information on the problems and general impacts (including the health impacts due to the massive smoke and peat fires in 2015) caused by peatlands' use in Indonesia over the time (e.g. Hooijer et al. 2012; Law et al. 2015; Goldstein 2015; Thorburn & Kull 2015; Koplitz et al. 2016; Crippa et al. 2016; World Bank Group 2016; Carmenta et al. 2017; Urák et al. 2017). On the other hand, several policies and regulations have been published by the Indonesian Government in order to better manage its vast amount of tropical peatland, including e.g. the Government Regulation (PP) 57/2016 (the emendation of PP No. 71/2014) on the Protection and Management of

Peatland Ecosystems (stating that peatland with more than a 3–m depth is classified as a protected area and its use is prohibited; that setting fires in peatlands is banned, and that peatland with a ground water depth of less than 0.4–m is categorised as a damaged area) (Indonesian Government Regulation 2014); Presidential Instructions (Inpres) No. 10/2011, No. 6/2013, and No. 8/2015 on the (Extended) Moratorium of the Granting of New Licences and the Improvement of Governance of Natural Primary Forest and Peatland (stating that activities relating to the issuing of new permits related to natural forest and peatland conversion are suspended) (Indonesian Presidential Instruction 2015); Government Regulation (PP) No. 4/2001 on the Control of Natural Damage and or Pollution related to Land and Forest Fire (stating that everybody is banned from setting land and forest fires) (Indonesian Government Regulation 2001) and the Minister of Agriculture's Decree (Kepmentan) No. 14/2009 on Guidance for the Utilisation of Peatland for Oil Palm Cultivation (stating that establishing oil palm plantations in peatland is only allowed in peatlands with less than 3–m depth) (Indonesian Minister of Agriculture's Decree 2009). Some studies have recommended that various potential paludiculture crops be used to prevent any further degradation of Indonesia's peatlands (e.g. Giesen 2013; Noor et al. 2014; Joosten et al. 2016; Tata & Susmianto 2016; Nishimura 2018). However, there are still some knowledge gaps with regard to the proper peatland management in Indonesia which are addressed in this thesis.

6.3.2 New insights brought by this thesis

This thesis shows the important part performed by the socio-ecological dynamics of tropical peatland management. Trends in peatland uses and the ecosystem services supplied by the peatland show the dynamics of peatland ecosystems. This information is useful for monitoring peatland uses and for drawing policy priorities based on the peatland conditions and the type of uses. The assessment of long-term human health impacts caused by exposure to ambient fine particle air pollution ($PM_{2.5}$) in the smoke produced by the peat fires indicates a large number of fatalities due to peat fires and smoke/haze occurring on a large scale in many peatland areas in Indonesia. This includes premature mortality cases and mortality cases due to cardiovascular disease, chronic respiratory problems, and lung cancer. The institutional fit assessment provides information that many peatland users in Indonesia are insufficiently aware of the peatland regulations hence the existing practices by the peatland users are largely incompatible with the national peatland regulations. The ongoing process of fitting driven by village governments, farmers groups (associations) and NGOs may increase the degree of fit between the rules creators (national peatland regulations and the practices ingrained in the peatland regulations) and the adopters (peatland users who need to comply with the peatland national regulations). To prevent further peatland degradation in Indonesia, paludiculture food crops are highly recommended as the alternative development options for the sustainable use and management of peatland areas. The successful implementation of paludiculture will greatly depend on a number of factors, i.e. the development of markets for paludiculture crops; the adaptation and enforcement of the peatland legislation; further improvements to the farming and harvesting technologies (including plant breeding to get superior plant seeds with a short waiting time between planting and first harvesting), and support to farmers to meet the international quality standards. This thesis will be an important resource in addressing the sustainability issues and alternative of the peatland uses as well as assessing the policy priorities for better peatland management in Indonesia. The functions of the peatland for the well-being of all the people (peatland users and stakeholders) and to control CO_2 emissions and peat subsidence without compromising the ability of future generations to meet their needs can hence be optimised. The sustainable peatland management models should not only consider ecological sustainability but also the profitability and fairness (benefit sharing) among stakeholders. Here, transparency and cooperation among stakeholders are needed to create a synergy in the use of peatlands in a sustainable way.

6.4 Outlook for further research

The main functions of the peatland ecosystems in Indonesia are related to its ESs (carbon, water, and biodiversity storage) and ability to produce agricultural commodities that can support the livelihood of the local farmers. For this reason, further research into how to find a balance between conservation and agricultural functions is needed, with regard to reducing the externalities on peatland uses, supporting the local economies and human welfare as well as supporting wildlife and the environment. An approach that can better integrate social–economic–ecological dynamics is needed to explain why most peatland uses remain unsustainable at this phase of human history. As the findings show in this thesis, the research and development for Indonesian peatlands need to focus on sustainable peatland management efforts which will minimise the environmental impacts through better land and water management, thereby reducing the fire risk and related human health impacts. This needs a further assessment of how the benefits from and the damage to peatlands are distributed among the stakeholders, at all levels and under various scenarios, so that the stakeholders might be able to design the necessary policies, programmes, and activities that not only favour the conservation of peatlands but also promote their socio-economical equity.

6.5 Recommendations for better peatland management

Peatlands are typically developed to improve their direct economic value to society. However, the development plans for peatlands typically fail due to the very limited consideration given to the socio–ecological attributes of the peatland in its natural state as well as to the high risk of widespread environmental degradation from the poor management of peatland. In this thesis, I highlight some recommendations for better peatland management in Indonesia based on the technical, political, and social-cultural aspects as summarised below.

6.5.1 Technical aspects

- Monitoring peatland condition and ecosystem services with a comprehensive system. This should include monitoring the land cover/use, hydrology (drainage and water tables), peat depth, peat subsidence, vegetation composition and ecosystem services in both physical and monetary terms. Specifically in Chapter 2, this thesis showed that the evaluations of the peatlands' uses and ecosystem's services would allow us to monitor the economic benefits generated by the peatlands at the local and national scales, under different management options (this can be extended to the international scale). Satellite images combined with ground checks can assist this comprehensive monitoring system of the peat condition and uses, and also the fire occurrences (as shown in chapters 2 and 3). Providing online links will be an effective way to share the information to the key stakeholders, including the information on the real-time conditions (e.g. ground water table depth, hotspots, air quality, etc.) as well as future predictions. These will also assist the peatlands users/owners to closely monitor their peatland areas (as suggested in Chapter 4 of this thesis).

- Introducing different types of zero burning methods and technology to extinguish the (sometimes massive) peat fires particularly for the areas under drained-based peatland management. Chapters 3 and 4 show that the main cause of peatland fires in Indonesia is due to human activities by burning the drained–peatlands. The lack of zero burning methods which are easy, quick and cheap to implement causes many peatland users to still use slash-and-burn practices for cleaning their lands. Compensation and adequate incentives for applying zero burning for land preparation should be provided, especially for smallholders/middle–low farmers (e.g. using the cost margin between burning and zero burning techniques for preparing peatland as a standard for the incentive). The zero burning programme should be implemented gradually through the establishment of demonstration plots (demonstration activities) at the village level, starting with the preparation or preconditioning of the farmers, training and technical guidance, supplying lightweight peatland processing tools and subsidised production (NPK fertiliser, herbicides, pesticides, etc.). Hence, the commitment from the government and investors to allocate the fundings for implementing zero burning peatland preparation is crucial.

- Developing alternative cropping technologies to be used in peatland that do not require drainage and assisting the land users in moving towards such new crop systems as well as establishing trials with the most promising paludiculture crops such as sago, mangosteen, illipenuts, etc. particularly under fully rewetting condition. Chapter 5 demonstrates the potential alternative options for agro-food paludiculture commodities. As highlighted in Chapter 5, it is important to initiate trials using modern breeding techniques to enhance the yields and reduce the time between planting and the first yield, as well as using modern harvesting techniques to improve the products' quality and post-harvest technologies for paludiculture crops.

- Providing up-to-date baseline data, including a national peatland map (as part of the One–Map Policy) which can adequately and precisely reflect the boundaries of peat areas, the depth of the peat and the water table in the peat areas. The baseline data should be made available to all stakeholders in particular to the decision-makers and peatland users at the village level. The location, land cover and tenure status of peatland areas should be transparently and rigorously communicated to all stakeholders, including any protected areas under the moratorium and areas targeted for restoration and rehabilitation programmes. Chapters 2, 3, 4 and 5 of this thesis reveal that, to date, the information on peatlands, i.e. the actual (accurate) location of deep peatlands and the ground water table depth within the key stakeholders jurisdictions are still often incomplete creating uncertainty about the implementation of peat policies by the stakeholders.

6.5.2 Political aspects

- Sharing, communicating, and enforcing the existing and new regulations on the peatland to all relevant government agencies and key stakeholders particularly in the province, district, and village levels. Chapters 3 and 4 reveal that the information related to peatland matters e.g. the One-Map Policy and its programmes, land titles, the results from socio–ecological assessments, mitigation policies and strategies on (new) drainage and using fires in peatland areas, etc., should be shared and communicated among the peatland users and decision-makers. Local government officials should communicate the (new) regulations to all the stakeholders, including people living in villages and the companies operating on the peatlands. It is also important that the implementation of the policies at the local level is regularly controlled by the responsible government officials (e.g. at least once per year by MoEFRI and other related government institutions) or by independent teams. Satellite imaging can be used to assist identifying the offenders (e.g. in land burning activities, illegal logging/encroachment in the protected forests, etc.). It is important to make it clear that the people/companies who do not comply with the regulations are liable and the punishments are serious enough to deter such actions. These punishments should be communicated upfront to all the stakeholders in a way that ensures that the stakeholders receive and understand this information.

- Translating the national policy on the peatland management into sub-national regulations (*Peraturan Daerah/ PERDA*) to move to sustainable land–use (wise use) practices. Chapters 2 and 4 remark that the national peat policy is often not effective because it has not yet been widely translated into sub-national regulations at the level where many of the land-use decisions are taken, i.e. at the provincial, district and village levels.

- The current permanent moratorium policy on activities relating to the issuing of new permits related to natural forest and peatland conversion should be implemented and translated into sub-national regulations. Chapter 2 reveals that most of natural peat swamp forests in Indonesia were rapidly converted and degraded. Meanwhile, Chapter 4 shows that the degree of fit between the regulations on moratorium of the granting new licences on converting peatlands and natural primary forests (Inpres 10/2011, No. 6/2013, No. 8/2015) and the practices by the peatland users is rated as moderate. This indicates that stopping the issuance of permits on converting natural forests and peatland areas and restoring degraded/drained forest and peatlands is the key to tackle further degradation and fires in forests and peatland areas in Indonesia.

- Setting the standards for sustainable peatland management based on the land use characteristics (e.g. productive use and non-productive/forest uses) and water management (e.g. with drainage and without drainage) and by taking into account the ecosystem services valuation, institutional fit and health risk impact assessments (short– and long–term) as the basic information/data for monitoring the peatland ecosystem states and its contribution to the communities. The standards should also include the criteria for carbon emissions' reductions and carbon trading. The standards and their assessments could be integrated into the national, provincial and local land-use plannings. The information/data on the assessment results should be easily accessed by the public (open and transparent) and could be included in the annual (environmental) statistics data report (e.g. by BPS) at the national, provincial and local levels. Chapters 2, 3 and 4 explicitly suggest the importance of setting higher standards for sustainable peatland management.

- Setting the market development for the paludiculture crops and creating greater market access and demand for the paludiculture commodities. Chapter 5 demonstrated that the main bottleneck in the implementation of paludiculture is the limited access to the markets and the poor demand for paludiculture products (the international markets are still not available yet). This also should be coupled with further improvements to the farming and harvesting technologies, the products quality and production chains and the socialisation and training at the community level as well as the plantation level. Also the policy banning the export of some potential paludiculture commodities, e.g. illipenuts and rattan should be revoked so the use of the peatlands without–drainage will be more profitable. This in turn will create jobs for local people and reduce the pressure to clear the forests and drain the peat.

- Supporting business developments where local communities are offered business opportunities that can be started in undrained peatlands (e.g. edu–ecotourism, aquaculture, rattan/purun products, etc.). This includes providing easier access to credit for sustainable businesses on the peatlands (e.g. credit for paludiculture crops) while making no credit available for crops that require the drainage of peatlands, such as oil palm, hevea rubber, acacia, etc.). Chapters 4 and 5 reveal that the current business development opportunities for local communities in undrained peatlands and the promotion of products from these areas on the international markets are still very limited.

- Rewarding the communities who are succesful managing their peatlands well and acknowledge their contribution maintaining Indonesian peatlands and for not causing health problems to public. Chapter 4 suggested giving financial reward to the communities who are not draining any peatlands/not constructing a single drainage canal; not starting fires on their peatland or in the forest; and not converting any forests sited on peatland. This could be part of the regular government budget provided to the local community (village–based or farmers associations). Chapter 5 highlighted that the districts that manage to control the number of fires and ensure no new drainage in the peatlands could be rewarded while the damaged peatland areas should be taken over by the government. This chapter also pointed out that a fiscal policy which integrates the ecological and social aspects into the intergovernmental fiscal transfer instruments should be implemented to promote and support sustainable development in peatland areas, for example providing general-purpose transfer (*Dana Alokasi Umum, DAU*), specific-purpose fund (*Dana Alokasi Khusus, DAK*), and/or shared revenue fund from taxes, non-taxes and/or natural resources (*Dana Bagi Hasil, DBH*)).

- Establishing air pollution and health information system centers, particularly at the sub-district level *(kecamatan*) and creating sufficient air quality monitoring stations and health centers to monitor public health, particularly in the areas with a higher risk of peat fires and peat smoke exposure. Chapter 3 demonstrates the uncertainty in estimating the level of air pollution and its associated health impacts, which is caused by the limited air quality data available in the study areas (there is only one air monitoring station in Central Kalimantan), and the lack of baseline data for the occurrence of related health diseases (such as cardiovascular diseases, lung diseases, and lost working days) as no epidemiological studies on the health effects caused by peat smoke exposure have been conducted in the affected areas.

6.5.3 Social-cultural aspects

- Communicating the existing and new peat regulations (in particular the reasons why the regulations were made and the related sanctions) to the (local) governments. Chapter 4 reveals that most of the peatland users stated they have limited knowledge of the content of the regulations, although they show a willingness to comply with the regulations for a better management of their peatlands. It is also beneficial for the communities to formulate social sanctions together with the other stakeholders (government, businessmen, etc.) as well as to agree to comply with the regulations and (social) sanctions. The social sanctions could be based on the culture/customs/ traditions of the local community in the peatland areas, which should be shared and agreed among the inhabitants and the local government.

- Local government officials and communities need to be made aware of the impacts of unsustainable peatland use, i.e. burning and draining the peatlands. Chapter 3 provides information on the health risks caused by the poor air quality and that the peat smoke/haze caused by the (recurrent) peatland fires will influence local people health in the long–term (chronic effects of peat smoke/PM exposure lead to health problems for every person). The findings in the Chapter 3 assert the need for public health authority to raise the community awareness on the health impacts of the haze and the need for tackling the ongoing peatland conversions and degradation in Indonesia. Planning for the necessary emergency/health care services during and after the forest and peatland fire seasons is also important especially for the vulnerable groups like infants, people with chronic illness and the elderly. Chapter 2 provides the information that draining peatland leads to subsidence and also the high risk of floodings in the wet season and fires in the dry season. Mapping (both the spatial and temporal approaches) can be an effective way to illustrate the distribution of the flood and fire risks, as well as their related impacts, so that the communities and local governments can know and be aware so regular health check-ups on the local people or affected areas can be initiated.

- Developing community-based monitoring for controlling the peatland use and its fire and water management. Chapter 4 highlights that the communities (peatland users) should be actively involved in the monitoring of the peatland' conditions in their areas. Peatland users could learn techniques to measure the conditions of their lands (peat depth, ground water level, peat acidity, etc.) and the ESs' supplied by the peatlands in their areas. The local knowledge (wise-use) practices can be shared among the communities/villages in order to control the peatland fires in their villages and communities. Chapters 2, 3 and 4 highlighted the fire control measures as most peatland users in Indonesia still prepare their peatlands before farming by draining the peat and then employing slash-and-burn practices. It is important that the villages and communities that have expressed an interest in controlling the fires and farming the paludiculture crops are facilitated in setting up a fire control unit and an information unit for farming the paludiculture crops. For fire control, this involves receiving training on fire control, being provided with equipment and establishing a water source in the communities (e.g. a bore well, but not a canal). For farming paludiculture crops, this involves receiving training to increase the farmer (traditional) knowledge on the breeding and harvesting the potential commodities, post-harvesting technologies and information on the domestic and export markets.

- Starting/developing community-based businesses such as edu-ecotourism, aquaculture, rattan/purun products, etc. Chapters 4 and 5 reveal that the business development is important to support the livelihood of the local communities so that they are motivated to use the peatland in a sustainable way. For edu-ecotourism, this will require community efforts to provide clean, green and healthy villages as well as to promote their unique cultures and traditions to tourists. This, however, will involve infrastructure developments to support the business. Peatland users (farmers) should change their farming orientation to "peat without drainage commodities (paludiculture)" in which the government and the communities should provide incentives to the peatland users for their sustainable use of peatland (including incentives for no-drainage and no-fires on peatlands' use).

In summary, the successful transformation of Indonesian peatlands to sustainable uses requires comprehensive and consistent implementation of these technical, political and social-cultural aspects. A strong commitment and synergy of all stakeholders to balance between conservation and development functions on the peatlands is needed in order to achieve the sustainable peatland management.

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Appendices

Appendix 2.1. Comparison data of peatland distribution in Indonesia as reported by various sources.

Source (year)	Peat distribution based on region					Highlight
	Sumatra	Kalimantan	Papua	Others	Total	
Polak (1952)*	n.a.	n.a.	n.a.	n.a.	16.5	Unit: Mha
Driessen (1978)*	9.7	6.3	0.1	n.a.	16.1	Unit: Mha
Pusat penelitian tanah (1981)*	8.9	6.5	10.9	0.2	26.5	Unit: Mha
Euroconsult (1984)*	6.84	4.93	5.46	0	17.2	Unit: Mha
Sukardi and Hidayat (1988)*	4.5	9.3	4.6	<0.1	18.4	Unit: Mha
Deptrans (1988)*	8.2	6.8	4.6	0.4	20.1	Unit: Mha
Subagyo et al (1990)*	6.4	5.4	3.1	n.a.	14.9	Unit: Mha
Deptrans (1990)*	6.9	6.4	4.2	0.3	17.8	Unit: Mha
Nugroho et al. (1992)*	4.8	6.1	2.5	0.1	13.5	Unit: Mha
Radjagukguk (1993)*	8.25	6.79	4.62	0.4	20.1	Unit: Mha
Dwiyono and Racman (1996)*	7.16	4.34	8.40	0.1	20.0	Unit: Mha
Wetlands International (2002-2006)*	7.21	5.83	7.8	n.a.	20.8	Unit: Mha
Koh et al. (2011)	5,572,443	6,668,629	n.a.	n.a.	12,241,072	Unit: Ha
BBSDLP MoARI - Ritung et al. (2011)	6,436,649	4,778,004	3,690,921	n.a.	14,905,574	Unit: Ha
Miettinen et al. (2012)	7,234,069	5,769,036	n.a.	n.a.	13,003,105	Unit: Ha
Kementerian Lingkungan Hidup dan Kehutanan/MoERI (2015)	9,646,459	8,786,009	7,997,038	48,214	26,477,720	Unit: Ha (Kesatuan Hidrologi Gambut/ Peat Hydrological Unit)
Miettinen et al. (2016)	7,230,230	5,781,720	n.a	n.a.	13,011,950	Unit: Ha

n.a not available; * data are taken from Wahyunto and Suryadiputra (2008)

Appendix 2.2. Comparison data of palm oil plantation distribution in Indonesian peatland since 2000 as reported by various sources.

Year	Assumed peat area	Palm oil plantation areas in peatlands (Ha)				Source	Limitation
		Sumatra	Kalimantan	Papua	Indonesia		
1990	Indonesia: 20.8 Mha Sumatra 7.21 Mha Kalimantan: 5.83 Mha Papua: 7.8 Mha	250,000	821	0	250,821	Gunarso et al. 2013	Exclude most independent smallholders
	Indonesia: 13,003,105 Ha Sumatra: 7,234,069 Ha Kalimantan: 5,769,036 Ha Papua: n.a	17,985	0	n.a	17,985	Miettinen et al. 2012	Except Papua. Resolution: 250-m.
2000	Indonesia: 20.8 Mha Sumatra 7.21 Mha Kalimantan: 5.83 Mha Papua: 7.8 Mha	438,864	16,415	0	455,279	Tropenbos 2011	Assumed that in 1990 there was no palm oil on peatlands. Not published document.
	Indonesia: 20.8 Mha Sumatra 7.21 Mha Kalimantan: 5.83 Mha Papua: 7.8 Mha	700,000	1,000	0	701,000	Gunarso et al. 2013	Exclude most independent smallholders
	Indonesia: 13,003,105 Ha Sumatra: 7,234,069 Ha Kalimantan: 5,769,036 Ha Papua: n.a	512,341	15,982	n.a	528,323	Miettinen et al. 2012	Except Papua. Resolution: 250-m.
2005	Indonesia: 20.8 Mha Sumatra 7.21 Mha Kalimantan: 5.83 Mha Papua: 7.8 Mha	1,447,158	35,776	1,278	1,484,212	Tropenbos 2011	Assumed that in 1990 there was no palm oil on peatlands. Not published document.
	Indonesia: 20.8 Mha Sumatra 7.21 Mha Kalimantan: 5.83 Mha Papua: 7.8 Mha	1,200,000	50,000	1,500	1,251,500	Gunarso et al. 2013	Exclude most independent smallholders
2007	Indonesia: 13,003,105 Ha Sumatra: 7,234,069 Ha Kalimantan: 5,769,036 Ha Papua: n.a	821,949	111,414	n.a	933,363	Miettinen et al. 2012	Except Papua. - Resolution: 250-m.
2010	Indonesia: 20.8 Mha Sumatra 7.21 Mha Kalimantan: 5.83 Mha Papua: 7.8 Mha	2,842,196	304,537	1,726	3,148,459	Tropenbos 2011	- Assumed that in 1990 there was no palm oil on peatlands. - Not published document.
	Indonesia: 20.8 Mha Sumatra 7.21 Mha Kalimantan: 5.83 Mha Papua: 7.8 Mha	1,400,000	308,000	1,700	1,709,700	Gunarso et al. 2013	- Exclude most independent smallholders
	Indonesia: 13,003,105 Ha Sumatra: 7,234,069 Ha Kalimantan: 5,769,036 Ha Papua: n.a	1,026,922	258,299	n.a	1,285,221	Miettinen et al. 2012	- Except Papua. - Resolution: 250-m.
2011	Indonesia: 12,241,072 Ha Sumatra: 5,572,443 Ha Kalimantan: 6,668,629 Ha Papua: n.a	464,553	43,184	n.a	507,737	Koh et al. 2011	- Only closed canopy oil palm plantations included. - Resolution: 250-m. - Except Papua.
2015	Indonesia: 13,011,950 Ha Sumatra: 7,230,230 Ha Kalimantan: 5,781,720 Ha Papua: n.a	1,315,830	730,750	n.a	2,046,580	Miettinen et al. 2016	- Only industrial plantations - Exclude smallholders - Except Papua. - Resolution: 30-m.

n.a : not available

Appendix 2.3. Comparison data of plantation forest areas for biomass production (pulp and other derivate) provided by Indonesian peatland since 2000 based on government data and other sources.

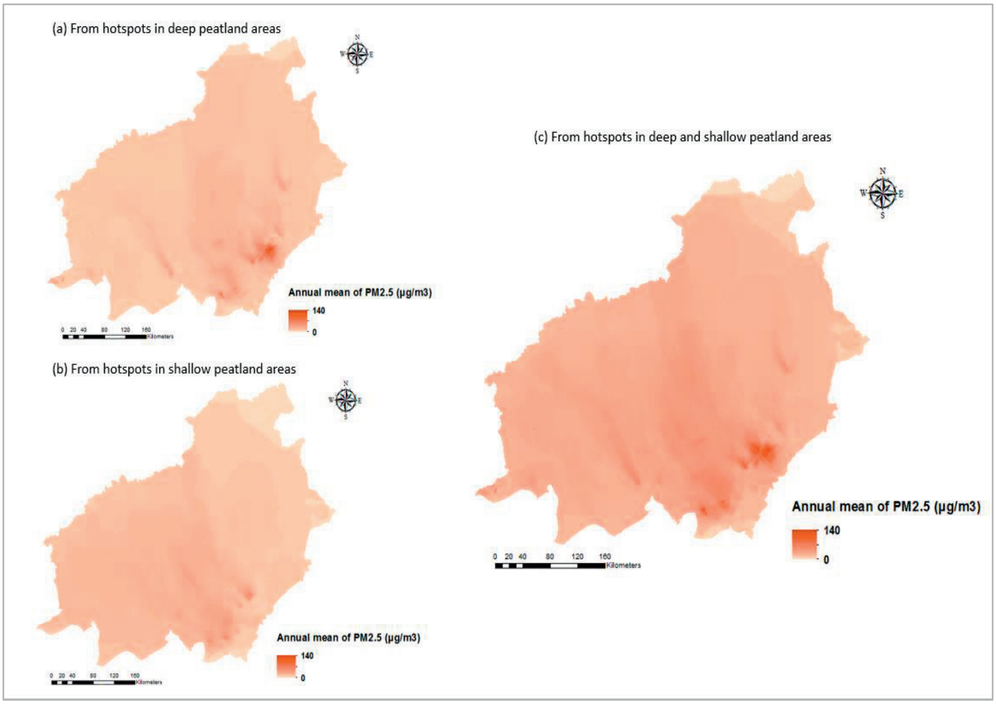
Year	Assumed peat area	Plantation forest areas for biomass production in peatlands (Ha)				Source	Limitation
		Sumatra	Kalimantan	Papua	Indonesia		
1990	Indonesia: 13,003,105 Ha Sumatra:7,234,069 Ha Kalimantan: 5,769,036 Ha Papua: n.a	306	0	n.a	306	Miettinen et al. 2012	Resolution: 250-m. Only closed Acacia plantations included. Except Papua.
2000	Indonesia: 13,003,105 Ha Sumatra: 7,234,069 Ha Kalimantan: 5,769,036 Ha Papua: n.a	80,176	250	n.a	80,426	Miettinen et al. 2012	Resolution: 250-m. Only closed Acacia plantations included. Except Papua.
	Indonesia: 14,915,135 Ha Sumatra: 6,457,740 Ha Kalimantan: 4,777,398 Ha Papua: 3,679,998 Ha	48,342	0	453	48,796	Indonesian Government data: Land cover from MoFRI (2014) Peat areas from MoARI (2011)	Without specific type of plant plantation. Resolution: 250-m
2003	Indonesia: 14,915,135 Ha Sumatra: 6,457,740 Ha Kalimantan: 4,777,398 Ha Papua: 3,679,998 Ha	67,490	13	453	67,956	Indonesian Government data: Land cover from MoFRI (2014) Peat areas from MoARI (2011)	Without specific type of plant plantation. Resolution: 250-m.
2007	Indonesia: 13,003,105 Ha Sumatra: 7,234,069 Ha Kalimantan: 5,769,036 Ha Papua: n.a	671,919	9,780	n.a	681,699	Miettinen et al. 2012	Resolution: 250-m. Only closed Acacia plantations included. Except Papua.
2009	Indonesia: 14,915,135 Ha Sumatra: 6,457,740 Ha Kalimantan: 4,777,398 Ha Papua: 3,679,998 Ha	423,112	1131	453	424,697	Indonesian Government data: Land cover from MoFRI (2014) Peat areas from MoARI (2011)	Without specific type of plant plantation. Resolution: 250-m.
2010	Indonesia: 13,003,105 Ha Sumatra: 7,234,069 Ha Kalimantan: 5,769,036 Ha Papua: n.a	874,921	22,797	n.a	897,718	Miettinen et al. 2012	Resolution: 250-m. Only closed Acacia plantations included. Except Papua.
2012	Indonesia: 14,915,135 Ha Sumatra: 6,457,740 Ha Kalimantan: 4,777,398 Ha Papua: 3,679,998 Ha	790,475	12,082	453	803,010	Indonesian Government data: Land cover from MoFRI (2014) Peat areas from MoARI (2011)	Without specific type of plant plantation. Resolution: 250-m.
2014	Indonesia: 14,915,135 Ha Sumatra: 6,457,740 Ha Kalimantan: 4,777,398 Ha Papua: 3,679,998 Ha	871,753	29,793	453	901,999	Indonesian Government data: Land cover from MoFRI (2014) Peat areas from MoARI (2011)	Without specific type of plant plantation. Resolution: 250-m.
2014	Sumatra	610,000 + 427,000 (948,000 *0.45) = 1,037,000	50,000	n.a	1,087,000	Industry data: APP (Sustainability Report) 2014. PM.Haze (April Tour Report) 2015.	Only total number. Except Papua.
2015	Indonesia: 13,011,950 Ha Sumatra: 7,230,230 Ha Kalimantan: 5,781,720 Ha Papua: n.a	1,074,230	53,320	n.a	1,127,550	Miettinen et al. 2016	Pulp wood plantations (*Acacia sp.*). Except Papua. Resolution: 30-m.

n.a : not available

Appendix 2.4. Peatland use in Sumatra, Kalimantan and Papua, Indonesia since 2000.

Region/ Year	Land cover type on the peatland area (Ha)										
	Natural Forest	Undisturbed natural forest	Disturbed natural forest	Plantation forest	Estate crop	Dryland agriculture	Paddy field	Urban	Open water	Other uses	Degraded land
Sumatra											
2000	3,055,246	381,325	2,673,921	48,342	950,264	425,034	236,550	41,561	5,290	15,807	1,679,644
2003	3,008,868	425,212	2,583,655	67,490	967,069	420,901	236,553	41,214	5,290	16,751	1,693,604
2006	2,501,669	405,830	2,095,838	263,319	1,016,857	424,109	238,230	41,214	5,241	16,329	1,950,772
2009	1,939,979	283,719	1,656,260	423,112	1,213,379	480,455	238,892	41,297	5,241	14,233	2,101,150
2012	1,605,173	246,909	1,358,263	790,475	1,303,976	497,840	237,909	41,172	5,242	14,145	1,961,808
2014	1,497,636	227,785	1,269,851	871,753	1,402,394	614,578	216,004	41,172	5,242	14,224	1,794,736
Kalimantan											
2000	2,940,546	65,179	2,875,368	-	86,743	248,236	132,183	20,449	5,138	1,195	1,342,908
2003	2,904,605	62,492	2,842,114	13	95,183	251,806	135,659	20,468	5,138	1,304	1,363,221
2006	2,757,350	58,980	2,698,370	97	134,533	268,086	134,419	20,468	5,138	1,400	1,455,906
2009	2,523,231	58,234	2,464,997	1,131	260,502	269,930	144,782	20,468	5,138	1,803	1,550,412
2012	2,381,463	55,454	2,326,009	12,082	304,008	273,903	145,489	20,468	5,142	2,504	1,632,339
2014	2,259,313	50,793	2,208,520	29,793	340,579	283,878	144,987	20,468	5,200	2,671	1,690,509
Papua											
2000	3,059,485	2,631,028	428,457	453	1,768	17,752	354	5,266	59,357	2,022	533,540
2003	3,047,248	2,598,671	448,577	453	1,768	18,002	354	5,276	59,357	2,022	545,517
2006	3,034,808	2,532,900	501,908	453	2,007	20,150	354	5,276	59,366	2,129	555,454
2009	3,022,510	2,486,968	535,542	453	2,037	23,877	354	5,519	59,366	2,137	563,744
2012	3,021,222	2,480,720	540,503	453	2,745	25,421	644	5,620	59,366	758	563,768
2014	3,020,631	2,466,087	554,544	453	2,828	25,421	644	5,620	59,366	758	564,276
Indonesia											
2000	9,055,278	3,077,532	5,977,746	48,796	1,038,775	691,021	369,087	67,276	69,786	19,025	3,556,092
2003	8,960,721	3,086,375	5,874,346	67,956	1,064,019	690,709	372,566	66,959	69,786	20,077	3,602,342
2006	8,293,826	2,997,710	5,296,117	263,869	1,153,397	712,345	373,003	66,959	69,746	19,858	3,962,132
2009	7,485,720	2,828,920	4,656,799	424,697	1,475,918	774,262	384,028	67,285	69,746	18,174	4,215,306
2012	7,007,858	2,783,083	4,224,774	803,010	1,610,729	797,164	384,043	67,260	69,750	17,407	4,157,914
2014	6,777,580	2,744,665	4,032,915	901,999	1,745,801	923,877	361,636	67,260	69,807	17,654	4,049,521

Appendix 3.1. Smoke dispersion and associated annual average concentration of $PM_{2.5}$ ($\mu g/m^3$) in Central Kalimantan, Indonesia from hotspots 2011-2015 in: (a) deep peatland areas; (b) shallow peatland areas; (c) deep and shallow peatland areas combined.



Appendix 3.2. The health impacts due to exposure to $PM_{2.5}$ emissions from peat smoke in Central Kalimantan, Indonesia during a 5 years period (2011-2015) (sensitivity analysis, showing impacts of 10 µg/m^3 increase and decrease in $PM_{2.5}$ concentrations, as well as double the $PM_{2.5}$ concentration).

Health case categories	X [a] (µg/m^3 $PM_{2.5}$)	X_o [a] (µg/m^3 $PM_{2.5}$)	Shape of exposure function, RR and Attributable Fraction for $PM_{2.5}$	Number of deaths from exposure to $PM_{2.5}$ for all ages
Premature mortality (all-cause)	26	4	Linear; 1.04; 0.04	648
	26	5.8	Linear; 1.04; 0.04	598
	26	8	Linear; 1.03 ; 0.03	514
	26	10	Linear; 1.03; 0.03	463
	36	4	Linear; 1.06; 0.06	871
	16	4	Linear; 1.02; 0.02	359
	52	4	Linear; 1.09; 0.09	1303
	26	4	Log-linear; 1.00; 0.003	46
	26	5.8	Log-linear; 1.00; 0.002	37
	26	8	Log-linear; 1.00; 0.002	30
	26	10	Log-linear; 1.00; 0.002	25
	36	4	Log-linear; 1.00; 0.004	54
	16	4	Log-linear; 1.00; 0.002	32
	52	4	Log-linear; 1.00; 0.004	63
Chronic respiratory	26	4	Linear; 1.09; 0.09	55
	26	5.8	Linear; 1.08; 0.08	51
	26	8	Linear; 1.07; 0.07	42
	26	10	Linear; 1.06; 0.06	38
	36	4	Linear; 1.13; 0.12	70
	16	4	Linear; 1.05; 0.05	29
	52	4	Linear; 1.21; 0.17	102
	26	4	Log-linear; 1.01; 0.01	4
	26	5.8	Log-linear; 1.01; 0.01	3
	26	8	Log-linear; 1.00; 0.004	2
	26	10	Log-linear; 1.00; 0.003	2
	36	4	Log-linear; 1.01; 0.01	4
	16	4	Log-linear; 1.00; 0.004	3
	52	4	Log-linear; 1.01; 0.01	5

Cardiovascular [b]	26	4	Linear; 1.23; 0.23	1151
	26	5.8	Linear; 1.21; 0.21	1056
	26	8	Linear; 1.18; 0.15	766
	26	10	Linear; 1.16; 0.13	693
	36	4	Linear; 1.34; 0.25	1242
	16	4	Linear; 1.12; 0.1	543
	52	4	Linear; 1.57; 0.35	1741
	26	4	Log-linear; 1.3; 0.05	266
	26	5.8	Log-linear; 1.24; 0.08	386
	26	8	Log-linear; 1.18; 0.15	765
	26	10	Log-linear; 1.15; 0.13	637
	36	4	Log-linear; 1.36; 0.11	553
	16	4	Log-linear; 1.2; 0.04	194
	52	4	Log-linear; 1.44; 0.19	930
Lung cancer [b]	26	4	Linear; 1.34; 0.34	104
	26	5.8	Linear; 1.31; 0.31	95
	26	8	Linear; 1.27; 0.2	63
	26	10	Linear; 1.24; 0.18	57
	36	4	Linear; 1.52; 0.33	100
	16	4	Linear; 1.18; 0.14	45
	52	4	Linear; 1.91; 0.45	137
	26	4	Log-linear; 1.47; 0.32	95
	26	5.8	Log-linear; 1.37; 0.27	81
	26	8	Log-linear; 1.29; 0.22	66
	26	10	Log-linear; 1.23; 0.18	57
	36	4	Log-linear; 1.59; 0.37	109
	16	4	Log-linear; 1.31; 0.23	70
	52	4	Log-linear; 1.72; 0.42	124

[a] X is the observed concentration of $PM_{2.5}$ (in μg/m^3) and X_o is the background concentration (μg/m^3, as the lowest effect level)

[b] The suggested β coefficients for measuring cardiovascular case and lung cancer case in the linear exposure function approach are 0.00893 and 0.01267 respectively, based on Ostro (2004).

Appendices

Appendix 4.1. List of respondents

Location	Respondents
CENTRAL KALIMANTAN	
Peatland users	• 120 randomly selected peatland users/owners: individual farmers, small-scale company, medium-scale company, large-scale company.
Policy makers	• Provincial Government (Provincial Secretary). • Provincial House of Representative members (DPRD/Dewan Perwakilan Rakyat Daerah Propinsi). • Regency House of Representative members (DPRD/Dewan Perwakilan Rakyat Daerah Kabupaten: Pulang Pisau, Kapuas, and Palangka Raya). • Regional Development and Planning Agency (BAPPEDA/Badan Perencanaan dan Pembangunan Daerah: Propinsi, Kab. Pulang Pisau, Kab. Kapuas, Kota Palangka Raya). • Regional Environmental Agency (BLHD/Badan Lingkungan Hidup Daerah: Propinsi). • Forestry Department (Dinas Kehutanan: Propinsi, Kab. Pulang Pisau, Kab. Kapuas, Kota Palangka Raya). • Regional Land Agency (BPN/Badan Pertanahan Daerah: Propinsi). • Head of Buntoi village. • Head of Gohong village. • Head of Dadahup village. • Head of Kalampangan village.
Informants (Institution leaders/experts)	• Global Green Growth Institute (GGGI) – Indonesia. • University of Palangka Raya – Palangka Raya Institute for Land-use and Agricultural Research (UPR-PILAR). • NGOs Gerakan Anti Asap (GAAs).
JAMBI	
Peatland users	• 90 randomly selected peatland users/owners: individual farmers, small-scale company, medium-scale company, large-scale company.
Policy makers	• Provincial House of Representative members (DPRD/Dewan Perwakilan Rakyat Daerah Propinsi). • Regency House of Representative members (DPRD/Dewan Perwakilan Rakyat Daerah Kabupaten: Muaro Jambi). • Regional Development and Planning Agency (BAPPEDA/Badan Perencanaan dan Pembangunan Daerah: Propinsi, Kab. Muaro Jambi). • Regional Environmental Agency (BLHD/Badan Lingkungan Hidup Daerah: Propinsi, Kab. Muaro Jambi). • Forestry Department (Dinas Kehutanan: Propinsi, Kab. Muaro Jambi). • Regional Land Agency (BPN/Badan Pertanahan Daerah: Propinsi, Kab. Muaro Jambi). • Head of Gedong Karya village. • Head of Delima village. • Head of Sungai Beras village.
Informants (Institution leaders/experts)	• University of Jambi, Agriculture Faculty (UNJA). • NGO WARSI.
NATIONAL	
Policy makers	• Ministry of Environment and Forestry (MoEF), Directorate of Peat Degradation Control (KLHK/Kementerian Lingkungan Hidup dan Kehutanan, Direktorat Pengendalian Kerusakan Gambut). • Ministry of Environment and Forestry (MoEF), Forest Fire Unit (KLHK/Kementerian Lingkungan Hidup dan Kehutanan, Unit Kebakaran Hutan). • Peatland Restoration Agency (BRG/Badan Restorasi Gambut).
Informants (Experts, Institution leaders)	• Center for International Forestry Research (CIFOR). • Central Agency on Statistics (BPS/Badan Pusat Statistik).

Appendix 4.2. The national legal framework related to peatland management in Indonesia

Type of legal document	Title	Regulated aspect	Content related to peatland use
Act (*Undang-Undang or UU*)			
	Act No. 5 year 1990	Conservation of Natural Resources and their Ecosystems	Not use of the phrase "peatland" or "peatland ecosystem" in the text. This act regulates the basic rules on conservation of natural resources and their ecosystems that also can be applied to peatland.
	Act No. 5 year 1994	The endorsement of the United Nations Convention on Biological Diversity	No use of the phrase "peatland" or "peatland ecosystem" in the text. Relates to peatland when peatland is available in managed areas of environmental protection, biodiversity resources, and ecosystem. This act just relates to the ratification by Indonesia of the UN Convention on Biological Diversity.
	Act No. 12 year 1992	Cultivation system	No use of the phrase "peatland" or "peatland ecosystem" in the text. Relates to peatland when peatland is available inside cultivation areas, and should be managed to prevent environmental damage.
	Act No. 6 year 1994	The endorsement of the United Nations Framework Convention on Climate Change	No use of the phrase "peatland" or "peatland ecosystem" in the text. Relates to peatland when peatland is available in managed areas and should be managed to prevent GHGs emissions.
	Act No. 41 year 1999	Forestry	No use of the phrase "peatland" or "peatland ecosystem" in the text. Relates to peatland when peatland is available inside forest areas and relate to environmental protection, biodiversity resources, and ecosystem.
	Act No. 7 year 2004	Water Resources	No use of the phrase "peatland" or "peatland ecosystem" in the text. Relates to peatland when peatland is available in wetland areas and in managed areas for environmental protection, biodiversity resources, and ecosystem.
	Act No. 32 year 2004	Decentralisation	No use of the phrase "peatland" or "peatland ecosystem" in the text. Relates to peatland when peatland is available in the territory of a province or regency.
	Act No. 17 year 2004	Ratification of the Kyoto Protocol	No use of the phrase "peatland" or "peatland ecosystem" in the text. Relate to peatland when peatland is available in utilization areas for carbon trading and carbon emissions reduction.

	Act No. 26 year 2007	National Spatial Plan	Directly uses the phrase "peatland" or "peatland ecosystem" in the text. Article 5, paragraph (2) letter "a" categorises peatland areas as Protected Areas (an Area gives protection to its subordinates areas).
	Act No. 32 year 2009	Protection and Environmental management	Directly uses the phrase "peatland" or "peatland ecosystem" in the text. Standard criteria for peatland damage are needed as one of the indicators of environmental damage (Article 21 letter f). As part of the preservation of natural resources peatland ecosystems need to be conserved (Article 57 paragraph 1 and Explanations Article 57 paragraph 1 letter a).
	Act No. 41 year 2009	Sustainable Protection of Agricultural Land	No use of the phrase "peatland" or "peatland ecosystem" in the text. Relates to peatland when peatland is available in agricultural areas. Every farmer has the right to determine his/her own agricultural plant species. Relates to control of the food agricultural system where communities who grow their crops in peatland, must be safeguarded.
	Act No. 6 year 2014	Village	No use of the phrase "peatland" or "peatland ecosystem" in the text. Relates to peatland when peatland is available in the village area.
Government Regulation (*Peraturan Pemerintah or PP*)			
	Government Regulation No. 27 year 1991	Wetland management	No use of the phrase "peatland" or "peatland ecosystem" in the text. Relates to peatland when peatland is available in wetland areas, for their protection, conservation, and preservation, and also for controlling environmental damage in wetland areas. Authority of Wetland management is under MoPWPH (*PU*).
	Government Regulation No. 150 year 2000	Land degradation Control for Biomass Production	Relates to peatland when peatland is available in managed areas for protection, conservation, and preservation, and also for controlling environmental damage related to forest fires and peatland. It governs the standard criteria for preventing environmental damage in wetlands including those containing peatland.

	Government Regulation No. 4 year 2001	Environmental Damage and or Environmental Pollution Control related to Forest and land Fire	Forbids all forest and land fires. No use of the phrase "peatland" or "peatland ecosystem" in the text. Relates to peatland when peatland is available in managed areas, for protection, conservation, and preservation, and also for controlling environmental/ ecosystem damage due to forest and land fires.
	Government Regulation No. 44 year 2004	Forestry Planning	No use of the phrase "peatland" or "peatland ecosystem" in the text. Relates to peatland when peatland is available in forest areas.
	Government Regulation No. 45 year 2004	Forest Protection	No use of the phrase "peatland or peatland ecosystem " in the text. Relates to peatland when peatland is available in protected forest areas.
	Government Regulation No. 6 year 2007	Forest Governance and the Development of Forest Management and Utilisation Plans	No use of the phrase "peatland" or "peatland ecosystem" in the text. Relates to peatland when peatland is available in a forest area.
	Government Regulation No. 26 year 2008	National Spatial Planning (*RTRWN*)	Included peatland as related-criteria adopted from the Presidential Decree No.32/1990.
	Government Regulation No. 37 year 2012	Watershed Management	No use of the phrase "peatland" or "peatland ecosystem" in the text. Relates to peatland when peatland is available in lowland areas, for protection, conservation, and preservation, and also for controlling environmental damage.
	Government Regulation No. 71 year 2014	Protection and Management of Peatland Ecosystems	Peatland with more than a three meter depth is classified as a Protected Area and its use is prohibited. Peatland ecosystems under "development status" are categorized as damaged (*rusak*) when the groundwater table decreases to more than 0.4-m depth from the peat surface in peat deeper than 1 meter. If peat is less than 1-meter thick, its degradation or damage status is regulated under environment permits (*ijin lingkungan* according to Art 24). To set fires in peatlands is banned.
	Government Regulation No. 1 year 2016	Peatland Restoration Agency	Peatland Restoration Agency (PRA or called BRG) has responsibility for peatland restoration in 2 million hectares in 7 selected provinces for a 5 year period (until 2020).

	Government Regulation No. 57 year 2016	Amendment PP 71/2014 on Protection and Management of Peatland Ecosystems	Amendment PP 71/2014. The core of this revision is to regulate a permanent moratorium on peatland utilization, to ensure peatland protection areas, to reinforce the power of government to take over damaged peatland areas (due to fires) particularly in the concession areas, and to impose sanctions on offenders.
Presidential Regulation (*Peraturan Presiden or Perpres*), Presidential Instruction (*Instruksi Presiden or Inpres*), Presidential Decree (*Keputusan Presiden or Keppres*)			
	Presidential Decree No. 32 year 1990	Management of Protected Areas	Defines the threshold of peatland depth for peatland to be used or developed. Defines a peatland area as an area with a peat soil depth of 3-meters or more, both upstream and in a swamp (Article 10). 3-meters peat depth is the threshold peatland depth for peatland that may be used, cultivated, or mined.
	Presidential Decree No. 48 year 1991	Ratification of the Convention Ramsar	Peatland is classified as one of areas in a Wetland Ecosystem. An inventory of wetlands is needed for planning and implementation of the regional conservation of wetland and water birds.
	Presidential Decree No. 80 year 1999	General Guidelines for Planning and Development Area Management Peatland district in Central Kalimantan	Peatland with a depth of less than 3-meters is for cultivation while peatland with depth of more than 3-meters is for conservation.
	Presidential Regulation No. 5 year 2006	National Energy Policy	Uses the phrase "peatland" in the text. Peat is included as one type of energy source.
	Presidential Instruction No. 10 year 2011	Moratorium on the Granting of New Licences and the Improvement of Governance of Natural Primary Forest and Peatland	A suspension on granting of new concession licences related to forest (logging) and peatland conversion.
	Presidential Instruction No. 6 year 2013	Extends for another 2 years the Moratorium on the Granting of New Licences and the Improvement of Governance of Natural Primary Forest and Peatland	Extends the two-year suspension of new licences related to forest (logging) and peatland conversion.

	Presidential Regulation No. 62 year 2013	REDD Management Agency	Relates to peatland when peatland is available in peat swamp forests and other utilisation areas, for reducing emissions.
	Presidential Instruction No. 8 year 2015	Extends for another 2 years the Moratorium on the Granting of New Licences and the Improvement of Governance of Natural Primary Forest and Peatland	Extends the two-year suspension of new permits related to forest (logging) and peatland conversion.
	Presidential Regulation No. 9 year 2016	Accelerating the Implementation of the Map Policy on scale 1: 50,000	Mapping soil, peatland and land suitability with scale 1: 50,000 for national development planning.
Ministerial Regulations: Ministerial Regulation (*Peraturan Menteri or Permen*), Ministerial Decree (*Keputusan Menteri or Kepmen*), Director General Decree (*Keputusan Direktur Jenderal or Kepdirjen*)			
	Minister of Mines Decree No. 507K /20/M.Pe year 1989	Classification and Exploitation of Peatland as Vital Mineral Material	Classifies peat as a vital mineral material (Group B) that can be mined.
	Minister of Forestry Decree Kepmen No. 260/Kep-II year 1995	Guidelines for Prevention and Control of Forest Fires, supplemented with implementation guidelines.	No use of the phrase "peatland" or "peatland ecosystem" in the text. Relates to peatland when peatland is available in utilization areas. Everybody is banned from setting land and forest fires.
	Director General of Forest Protection and Nature Conservation (PHPA) Decree No. 243/Kpts/DJ.VI year 1995	Technical Guidelines for Forest Fire Prevention and Control in concession areas and other land use areas.	Regulates technical criteria for Forest Fire Prevention and Control in concession areas and other land use areas including peatland.
	Director General of Estate Crops Decree No. 38/KB.110/DJ.BUN/05 year 1995	Technical Guidelines for Land Clearance without Burning to Develop Plantations	Regulates technical criteria for land clearance for plantations without burning including in peatland.
	Minister of Environment Decree No. 5 year 2001	Environmental Impact Assessment (EIA) Guidelines for Development in Wetlands	An Environmental Impact Assessment or EIA should be done before carrying out development in a peatland ecosystem area.
	Minister of Environment Regulation No.7/Kepmen LH year 2006	Procedures for assessing soil degradation and setting standard criteria for potential biomass production	Peatland soil is included in standard criteria for assessing soil degradation for potential biomass production. Sets the standard criteria relating to environmental damage in wetlands.

	Minister of Forestry Decree Kepmen No.55 /Kep-II year 2008	Master Plan for Rehabilitation and Conservation in Peatland development Zone of Central Kalimantan.	Forming of Protected Forest Management Area (*KPHL*)-plan in the Mega Rice Project (MRP) area.
	Minister of Forestry Regulation No. P.61/Menhut-II year 2008	Provisions and Procedures for the Granting of Business Licences for Ecosystem Restoration in Production Forest	Relates to peatland when peatland is available in areas designated for restoration in production forests.
	Minister of Forestry Regulation No.P.28/Menhut-II year 2009	Approval Procedure for Forest Planning within Regional Spatial Plans	No use of the phrase "peatland" or "peatland ecosystem" in the text. Relates to peatland when peatland is available in forest and or utilization areas.
	Minister of Forestry Regulation No.P.30/Menhut-II year 2009	Reducing Emissions from Deforestation and Forest Degradation	Relates to peatland when peatland is available in peatland swamp forests, and other utilisation areas, for reducing emissions.
	Minister of Forestry Regulation No. P.36/Menhut-II year 2009	Procedures for Licensing of Commercial Utilisation of Carbon Sequestration and/or Storage in Production and Protection Forests	Includes regulating peatland utilization in production and protection forest areas.
	Minister of Agriculture Regulation No.14/Permentan/PL.110/2 year 2009	The Guidance for the Utilization of Peatland for Oil Palm Cultivation	Regulates peatland utilization for oil palm cultivation including technical criteria for designating agricultural areas, and for construction of canals around the boundary of cultivated area. Utilization is only allowed in peatlands with less than 3-meters depth.
	Minister of Environment Regulation No. 5 year 2012	Types of Business Plan and or Activity that should be equipped with Environmental Impact Analysis	Mentions peatland in the attachments. Environmental Impact Assessment or EIA are required before mining coal or peat or constructing Peat power plants, or any other utilization in peatland ecosystems.

	Minister of Environmental and Forestry Instruction No.S661/Menlhk-Setjen/Rokum year 2015	Instructions in Relation to Peatlands	• Peatland areas under protection functions but unopened with existing permits immediately will be stated to be protection function areas which should not be opened. • Timber and plantation concessions in peatlands with protection functions, can operate until the first harvest (1 cycle) and then there will be an adjustment of permits (*RKU* and *CTR*) after the harvest. • The company must immediately make a recovery of protection functions in its locations within a certain period. If it does not comply the Government will take over the lands and ask for a third-party to do the work based on the company's costs through the legal/law mechanisms. • Concession license holders having an area above or equal to 40 percent of a peat ecosystem with protection function, can propose a land swap area.

Appendix 4.3. Interview results of peatland users in Jambi, Sumatra

Description		Number of respondents (N = 90)	Relative share (%)
Type of peatland uses			
Land uses type:	1. Farming (agriculture)	10	11
	2. Planting trees (Plantation)	80	89
	3. Unproductive land	-	-
	4. (Eco)Tourist area	-	-
	5. Conservation area	-	-
Type of planting:	1. Paddy/Rice	3	3
	2. Vegetables	10	11
	3. Oil palm	43	48
	4. Acacia	2	2
	5. Rubber	3	3
	6. Fruits	0	0
	7. Others (e.g. jelutung, areca nut, sago, rattan, etc.)	29	33
Ownership type:	1. Certificate	26	29
	2. Lease (Rent)	-	-
	3. Owner, no certificate (saprodik, SKT)	72	69
	4. Don't know	2	2
Peatland type:	1. Deep peat (>3m)	1	1
	2. Shallow peat (< 3m)	64	71
	3. Peat, unsure if it is deep or shallow	9	10
	4. No peat	13	15
	5. Don't know	2	3
Area (ha):	1. < 2	45	50
	2. 2 - 10	43	48
	3. ≥ 10	2	2
Type of cultivation:	1. Shifting cultivation	11	12
	2. Permanent cultivation	51	57
	3. Agro-forestry	28	31
Management of peatlands			
Land management type:	1. Drained (with the drainage 0.6 – 2 m depth)	75	83
	2. Not drained	15	17
Reason to grow plants:	1. High market price	17	19
	2. Low maintenance cost	17	19
	3. Short–time harvested	13	14
	4. Inherited land and plants	3	3
	5. Self-consumption	6	7
	6. Other (following neighbours)	34	38
Production (ton/ha/year) per crop	1. < 2	2	8
	2. 2 - 10	26	29
	3. ≥ 10	26	29
	4. Don't know	36	40
Income (IDR million/ha/year)	1. < 2	11	12
	2. 2 - 10	32	36
	3. ≥ 10	12	13
	4. Don't know	35	39

Main problem:	1. Fire	1	1
	2. Water supply	9	10
	3. Fertilizer	61	68
	4. Seedling	2	2
	5. Pests and weeds	4	5
	6. Price at market	3	3
	7. Soil subsidence (plants collapse)	10	11
Future plan:	1. No willing to switch crop (land use)	14	16
	2. Willing to switch crop to other crops (land use)	31	34
	3. No planning/ Don't know	45	50
Opinions on peatland regulations			
PP 4/2001: Control of Natural Damage and or Pollutions related to Land and Forest Fires (Fire banned on forest and (peat) land).	1. Know the regulation	39	43
	2. Possible to comply	35	90
	3. Comply	28	72
	4. Checked for compliance	17	44
	5. Know the sanction	31	34
Kepmentan 14/2009: Guidance for the Utilisation of Peatland for Oil Palm Cultivation.	1. Know the regulation	6	7
	2. Possible to comply	6	100
	3. Comply	2	33
	4. Checked for compliance	0	0
	5. Know the sanction	3	50
Inpres 10/2011, No. 6/2013, No. 8/2015: (Extended)Moratorium on the Granting of New Licences and the Improvement of Governance of Natural Primary Forest and Peatland.	1. Know the regulation	14	16
	2. Possible to comply	13	93
	3. Comply	14	100
	4. Checked for compliance	11	79
	5. Know the sanction	9	64
PP 71/2014: Protection and Management of Peatland Ecosystems.	1. Know the regulation	6	7
	2. Possible to comply	6	100
	3. Comply	3	50
	4. Checked for compliance	0	0
	5. Know the sanction	1	17
Impression of peatland use			
Main utilization of peatland:	1. Forest area	11	12
	2. Timber logging	-	-
	3. Oil palm plantation	27	30
	4. Acacia forest plantation	5	6
	5. Paddy field	5	5
	6. Production of fish	-	-
	7. Ecotourism area	-	-
	8. Forest Biodiversity conservation area	42	47
	9. Rubber	-	-
Trends in peatland use	1. More/larger areas used	12	14
	2. More fires	6	7
	3. Changes in hydrology	11	12
	4. More canals	9	10
	5. More canals blocked	3	3
	6. More degraded land	3	3
	7. More reforestation	13	15
	8. More flooding	9	10
	9. More soil subsidence	15	17
	10. More peat used as mineral soil	8	9

Problems related to peatland use:	1.	Fire	6	7
	2.	Water management	10	11
	3.	Drought	2	2
	4.	Flooding	2	2
	5.	Low productivity	46	51
	6.	Pests and weeds	1	1
	7.	Marketing of product	2	2
	8.	None	3	4
	9.	Don't know	18	20
What should be improved:	1.	Facility (infrastructure, equipment, etc.)	7	8
	2.	Policy and regulation	11	12
	3.	Financial support	14	16
	4.	Education	1	1
	5.	Communication/information	11	12
	6.	Research and development	4	4
	7.	Law enforcement	4	4
	8.	Marketing of product	2	2
	9.	Don't know	36	41
Interaction with stakeholders				
Stakeholders with good relationship with peatland users	1.	House of Representatives member	1	1
	2.	Civil Servant National Government	3	3
	3.	Civil Servant Provincial Government	6	7
	4.	Civil Servant Regency Government	10	11
	5.	Civil Servant District/ village Government	25	27
	6.	Investor and Businessman Large Company	1	1
	7.	Investor and Businessman Medium Company	1	1
	8.	Owner or Private worker Smallholder Company	4	5
	9.	Individual Farmer	20	22
	10.	Researcher (Scientist/ Teacher/Lecturer) of University/Research Centre	2	2
	11.	International/National NGO	1	1
	12.	Local NGO	17	19
How government interacts with peatland users:	1.	Informal meeting/discussion	14	16
	2.	Formal meeting (workshop, training, etc.)	17	19
	3.	Field visit	7	8
	4.	Research visit (Census and survey)	5	6
	5.	During political campaigns	3	3
	6.	During environmental campaigns	4	4
	7.	Never interact	40	44
What should be improved:	1.	Training and workshop	26	29
	2.	Assistance	18	20
	3.	Extension worker	7	8
	4.	Frequency of visits	22	24
	5.	Coordination and communication facilities	17	19

Appendix 4.4. Interview results of peatland users in Central Kalimantan

Description		Number of respondents (N = 120)	Relative share (%)
Type of peatland uses			
Land uses type:	1. Farming (agriculture)	42	35
	2. Planting trees (Plantation)	73	61
	3. Unproductive land	5	4
	4. (Eco)Tourist area	-	-
	5. Conservation area	-	-
Type of planting:	1. Paddy/Rice	23	20
	2. Vegetables	18	15
	3. Oil palm	6	5
	4. Acacia	2	1
	5. Rubber	60	50
	6. Fruits	8	6
	7. Others (e.g. jelutung, areca nut, sago, rattan, etc.)	3	3
Ownership type:	1. Certificate	53	44
	2. Lease (Rent)	-	-
	3. Owner, no certificate (saprodik, SKT)	67	56
	4. Don't know	-	-
Peatland type:	1. Deep peat (>3m)	46	38
	2. Shallow peat (< 3m)	26	22
	3. Peat, unsure if it is deep or shallow	43	36
	4. No peat	5	4
	5. Don't know	-	-
Area (ha):	1. < 2	37	31
	2. 2 - 10	78	65
	3. ≥ 10	5	4
Type of cultivation:	1. Shifting cultivation	20	16
	2. Permanent cultivation	89	74
	3. Agro-forestry	11	10
Management of peatlands			
Land management type:	1. Drained (with the drainage 0.5 – 5 m depth)	103	86
	2. Not drained	17	14
Reason to grow plants:	1. High market price	22	19
	2. Low maintenance cost	17	14
	3. Short–time harvested	17	14
	4. Inherited land and plants	28	23
	5. Self-consumption	11	9
	6. Other (following neighbours)	25	21
Production (ton/ha/year) per crop	1. < 2	18	15
	2. 2 - 10	41	34
	3. ≥ 10	17	14
	4. Don't know	44	37
Income (IDR million/ha/year)	1. < 2	13	11
	2. 2 - 10	33	28
	3. ≥ 10	46	38
	4. Don't know	28	23
Main problem:	1. Fires	73	61
	2. Water supply	19	16
	3. Fertilizer	12	10
	4. Seedlings	5	4
	5. Pests and weeds	8	7
	6. Price at market	3	2

Future plan:	1. No willing to switch crop (land use)	89	74
	2. Willing to switch crop to other crops (land use)	29	24
	3. No planning/ Don't know	2	2
Opinions on peatland regulations			
PP 4/2001: Control of Natural Damage and or Pollutions related to Land and Forest Fires. (Fire banned on forest and (peat) land)	1. Know the regulation	73	61
	2. Possible to comply	70	96
	3. Comply	64	88
	4. Checked for compliance	17	27
	5. Know the sanction	66	90
Kepmentan 14/2009: Guidance for the Utilisation of Peatland for Oil Palm Cultivation.	1. Know the regulation	24	20
	2. Possible to comply	14	58
	3. Comply	5	21
	4. Checked for compliance	6	25
	5. Know the sanction	12	50
Inpres 10/2011, No. 6/2013, No. 8/2015: (Extended) Moratorium on the Granting of New Licences and the Improvement of Governance of Natural Primary Forest and Peatland.	1. Know the regulation	15	13
	2. Possible to comply	13	87
	3. Comply	9	60
	4. Checked for compliance	6	40
	5. Know the sanction	10	67
PP 71/2014: Protection and Management of Peatland Ecosystems.	1. Know the regulation	17	14
	2. Possible to comply	15	88
	3. Comply	15	88
	4. Checked for compliance	7	41
	5. Know the sanction	9	53
Impression of peatland use			
Main utilization of peatland:	1. Forest area	5	4
	2. Timber logging	-	-
	3. Oil palm plantation	12	10
	4. Acacia forest plantation	-	-
	5. Paddy field	23	19
	6. Production of fish	1	1
	7. Ecotourism area	3	3
	8. Forest Biodiversity conservation area	4	3
	9. Rubber	72	60
Trends in peatland use	1. More/larger areas used	17	14
	2. More fires	24	20
	3. Changes in hydrology	11	9
	4. More canals	14	12
	5. More canals blocked	2	2
	6. More degraded land	15	13
	7. More reforestation	9	7
	8. More flooding	8	6
	9. More soil subsidence	13	11
	10. More peat used as mineral soil	7	6
Problems related to peatland use:	1. Fire	46	38
	2. Water management	13	11
	3. Drought	14	12
	4. Flooding	14	12
	5. Low productivity	19	17
	6. Pests and weeds	5	4
	7. Marketing of product	4	3
	8. None	3	2
	9. Don't know	2	1

What should be improved:	1.	Facility (infrastructure, equipment, etc.)	70	58
	2.	Policy and regulation	17	14
	3.	Financial support	8	7
	4.	Education	-	-
	5.	Communication/information	8	7
	6.	Research and development	-	-
	7.	Law enforcement	-	-
	8.	Marketing of product	17	14
	9.	Don't know	-	-
Interaction with stakeholders				
Stakeholders with good relationship with peatland users	1.	House of Representative member	2	2
	2.	Civil Servant National Government	1	1
	3.	Civil Servant Provincial Government	2	1
	4.	Civil Servant Regency Government	13	11
	5.	Civil Servant District/ village Government	22	19
	6.	Investor and Businessman Large Company	0	0
	7.	Investor and Businessman Medium Company	1	1
	8.	Owner or Private worker Smallholder Company	2	1
	9.	Individual Farmers	47	39
	10.	Researcher (Scientist/ Teacher/Lecturer) of University/Research Centre	1	1
	11.	International/National NGO	2	2
	12.	Local NGO	27	22
How government interacts with peatland users:	1.	Informal meeting/discussion	17	14
	2.	Formal meeting (workshop, training, etc.)	17	14
	3.	Field visit	10	8
	4.	Research visit (Census and survey)	6	5
	5.	During political campaigns	7	6
	6.	During environmental campaigns	9	8
	7.	Never interact	54	45
What should be improved:	1.	Training and workshop	56	47
	2.	Assistance	17	14
	3.	Extension worker	20	17
	4.	Frequency of visits	14	11
	5.	Coordination and communication facilities	13	11

Appendix 4.5. Interview results with policy makers in Indonesia

Description		National	Jambi	Central Kalimantan
Impression of peatland use	Main utilization of peatland:	Forest Biodiversity conservation area (due to moratorium).	Plantations (oil palm, and acacia).	Farming and plantations (paddy, rubber, and oil palm).
	Main owner(s) of used peatlands	Individual farmers (smallholders) and companies.	Companies and individual farmers (smallholders).	Individual farmers (smallholders) and government.
	Problems of peatland use:	• Difficult to monitor peatland use due to absence of information on locations of deep peat and measurement of water levels. • Uncertainty of peatland information due to there being many differing maps of peatland distribution (the One-Map Policy is not completed yet). • Forest and peatlands are managed based on provincial and or regency administrative boundaries, whereas peatland dome systems spread across regencies. This makes peatlands difficult to manage due to the decentralization rule's limiting the authority of national government. • Fire is used by peatland users due to slash and burn practice for clearing land particularly during dry seasons & El Niño. • Zero burning alternatives (e.g. manual slash, mechanical slash) are costly, not quick nor easy. • Limited budget (or no new budget) for fire prevention (including budget for building pumps, blocking canals (dams), irrigation, etc.). • Blocking canals is difficult to apply in some peatland areas because some local	• Fire, due to slash and burning practices, particularly during dry season & El Niño. • Methods for zero burning (e.g. manual slash, mechanical slash) are costly, not quick nor easy. • Forest and peatlands are managed based on regency administrative boundaries, whereas peatland dome systems spread across regencies. This makes peatlands difficult to manage due to different interests and priorities of peatland use in each regency, and the authority of provincial government is limited by the decentralization rule. • Increasing expansion of land use to peatland areas due to other mineral lands being limited while people need land for agriculture. • Land grabbing and overlapping landownership due to unclear land boundaries and the variety of maps. • Limited budget (or no new budget) for fire prevention (including budget for building pumps, blocking canals (dams), irrigation, etc.). • Planning budget for peatland development and management has macro direction (no detail for peatland users) with partial legislative and executive decision. • Blocking canals is difficult to apply in some peatland areas because some local	• Fire, due to slash and burning practices, particularly during dry season & El Niño. • Methods for zero burning (e.g. manual slash, mechanical slash) are costly, not quick nor easy. • Blocking canals is difficult to apply in some peatland areas because some local communities still use the canals for transportation of products (timber, rubber, oil palm, rattan, etc.) and of people. • Forest and peatlands are managed based on regency administrative boundaries, whereas peatland dome systems spread across regencies. This makes peatlands difficult to manage due to different interests and priorities of peatland use in each province and or regency, and the authority of provincial government is limited by the decentralization rule. • Increasing expansion of land use to peatland areas due to other mineral lands being limited while people need land for agriculture. • Land grabbing and overlapping landownership due to unclear land boundaries and the variety of maps. • Limited budget (or no new budget) for fire prevention (including budget for building pumps, blocking canals (dams), irrigation, etc.).

		communities still use the canals for transportation of products (timber, rubber, coconut, oil palm, etc.) and of people. • In some cases there are overlapping landownerships (government, local community and companies), including customary lands. • Many deep peatlands were already under concession permits and used before the peat regulations were issued . • Lack of markets for paludiculture products (e.g. jelutung, sago, illipenut/tengkawang, etc.), also price of the product is relatively lower than oil palm or acacia.	communities still use the canals for transportation of products (coconut, oil palm, acacia, etc.) and of people. • Many deep peatlands were already under concession permits and used before the peat regulations were issued. • Lack of markets for paludiculture products (e.g. jelutung, coffee, etc.), also price of the product is relatively lower than oil palm or acacia. • Low productivity due to limited water supply to the lands particularly during dry season, soil subsidence (number of plant collapse is increase), decreasing water catchment and water quality, smoke & haze causing harm to plants. • Peatland users (farmers) need subsidies for fertilizers, seedlings, and pesticides. • Social problems due to smoke and haze that usually cause schools to close (fewer schooldays) and increase health problems.	• In some cases there are overlapping landownerships (government, local community and companies), including customary lands. • Many deep peatlands were already under concession permits and used before the peat regulations were issued . • Lack of markets for paludiculture products (e.g. jelutung, sago, illipenut/tengkawang, etc.), also price of the product is relatively lower than oil palm or rubber. • Low productivity due to soil subsidence (number of plant collapses is increasing), decreasing water catchment and water quality, smoke & haze causing harm to plants. • Peatland users (farmers) need subsidies for fertilizers, seedlings, and pesticides. • Social problems due to smoke and haze that usually cause schools to close (fewer schooldays) and increase health problems.
	What should be improved	• Consensus about knowledge and values resulting in a common vision for setting priority of actions. • Having similar vision and perception on sustainable peatland uses, cross-sectoral and at all levels. • Completing One-Map Policy and harmonizing peatland data from all sources to establish clear guidelines on peatland governance (including authority to publish peatland data/information to public). • Financial support and planning on peatland issues (financial policy	• Using peatlands for community benefit with more for food crops instead of industrial crops, also forest conversion is only for food crop development so increasing the income of local people. • Socialization of best practice for sustainable peatland management. • Involving local communities in mapping and planning peatland management. • Management of natural peatland resources for long term public welfare/benefits. • Consensus about knowledge and values resulting in a common vision for setting priority	• Combining Dayak concepts with modern concepts (e.g. blocking canals/water management). • Socialization of best practice for sustainable peatland management. • Management of natural peatland resources for long term public welfare/benefits. • Involving local communities in mapping and planning peatland management. • Consensus about knowledge and values resulting in a common vision for setting priority of actions. • Having similar vision and perception on

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		and making specific budgets for peatland issues). • Technology innovation on peatland use (intensification of farming), zero burning methods, water management (irrigation, dams, water level monitoring, etc.). • Consolidation of diverse information streams (e.g. formal (science) vs informal (traditional customs), deficit model vs engagement model). • Education and socialisation of peatland owners and the local community concerning peatland regulations, guidance on responsible/wise use approach, and the best practices of sustainable peatland management. • Monitoring, field control, and law enforcement.	of actions. • Having similar vision and perception on sustainable peatland uses, cross-sectoral and at all levels. • Financial support and planning on peatland issues (financial policy and making specific budgets for peatland issues). • Technology innovation on peatland use (intensification of farming), zero burning methods, water management (irrigation, dams, water level monitoring, etc.). • Consolidation of diverse information streams (e.g. formal (science) vs informal (traditional customs). • Education and socialisation of peatland owners and the local community concerning peatland regulations, guidance on responsible/wise use approach, and the best practices of sustainable peatland management. • Monitoring, field control, and law enforcement.	sustainable peatland use, cross-sectoral and at all levels. • Financial support and planning on peatland issues (financial policy and making specific budgets for peatland issues). • Technology innovation on peatland use(intensification of farming), zero burning methods, water management (irrigation, dams, water level monitoring, etc.). • Consolidation of diverse information streams (e.g. formal (science) vs informal (traditional customs). • Education and socialisation of peatland owners and the local community concerning peatland regulations, guidance on responsible/wise use approach, and the best practices of sustainable peatland management. • Monitoring, field control, and law enforcement.
Opinions on peatland regulations	How is information on the laws and regulations shared:	• Direct sending of formal material (hard copy) to related institutions at all levels. • Direct provision of material through institutional websites. • Formal meetings (workshop, training, forum, group discussion, etc.). • Informal meetings and discussions through field and research visits (Census and survey), during political and or environmental campaigns. • Through social media (press release).	• Receiving formal material (hard copy) from national government. • Direct sending of formal material (hard copy) to related institutions at regency level. • Direct provision of material through institutional websites. • Through coordination among provincial and regency institutions. • Formal meetings (workshop, training, forum group discussion, etc.). • Informal meetings and discussions through field and research visits (Census and survey), during political and or environmental	• Receiving formal material (hard copy) from national government. • Direct sending of formal material (hard copy) to related institutions at regency level. • Direct provision of material through institutional websites. • Through coordination among provincial and regency institutions, also heads of villages and heads of ethnic groups (*kepala adat*). • Formal meetings (workshop, training, forum group discussion, etc.). • Informal meetings and discussions through field and research visits

			campaigns. • Through social media (press releases).	(Census and survey), during political and or environmental campaigns. • Through social media (press releases).
	How is it checked that people comply with all regulations:	• Direct coordination of national level with provincial level. • Field and research visits (including combined with satellite image reports of land use change).	• Field (mostly by extension agents) and research visits (including based on reports). • Direct coordination of provincial level with regency level, then regency level to district level and village level.	• Field (mostly by extension agents) and research visits (including based on reports). • Direct coordination of provincial level with regency level, then regency level to district level and village level.
Sustainable peatland management	Program/ Priority:	• Mapping peatland ecosystem distribution and zoning all Peatland Hydrology Unit(s) into Protection and Utilization Zones. • Monitoring average water level in drained peatland uses. • Integrated management actions to deal with the externalities of peatland use (fire and smoke, carbon emission, peat subsidence, deforestation, loss of biodiversity, social issue, etc.). • Community livelihood in context of Sustainable Peatland Management with technical facilitators for peatland users (farmers) and incentives for different stakeholders. • Restoration of peatlands, promoting paludiculture and markets. • Consolidation at all cross sectoral levels, sharing knowledge, updated information, and regulations.	• Initiated by provincial or regency House of Representative institution (*DPRD*), to make sub- regulations, based on the national peatland regulations, and to implement them in provincial/regency spatial planning (*RTRWP/K*). • Consolidation at all cross-sectoral levels, sharing knowledge, updated information, regulations, etc. • Integrated management actions to deal with the externalities of peatland use (fire and smoke, carbon emission, peat subsidence, deforestation, loss of biodiversity, social issue, etc.). • Community livelihood in context of Sustainable Peatland Management with technical facilitators for peatland users (farmers) and incentives for different stakeholders. • Restoration of degraded peatlands, promoting paludiculture and its markets. • Building model and pilot projects for sustainable peatland development.	• Initiated by provincial or regency House of Representative institution (*DPRD*) to make sub- regulations, based on the national peatland regulations, and to implement them in provincial/regency spatial planning (*RTRWP/K*). • Consolidation at all cross-sectoral levels, sharing knowledge, updated information, regulations, etc. • Integrated management actions to deal with the externalities of peatland use (fire and smoke, carbon emission, peat subsidence, deforestation, loss of biodiversity, social issue, etc.). • Community livelihood in context of Sustainable Peatland Management with technical facilitators for peatland users (farmers) and incentives for different stakeholders. • Restoration of degraded peatlands, promoting paludiculture and its markets. • Building model and pilot projects for sustainable peatland development.
Interaction with stakeholders	Problems:	• Limited interface domain (only national - provincial level). • The person in charge	• Lack of sharing of detailed information among institutions about their concerns	• Lack of sharing of detailed information among institutions about their concerns

	is always changing. • Lack of sharing among institutions about their concerns about maintaining peatlands (e.g. Ministry of Agriculture and Ministry of Public Work and Public Housing (PUPH) are not sharing their concerns about maintaining peatlands in undrained and forested state). • No direct line of command for forest fire management in normal daily activities: a range of legislation in response to large fires only emphasizes fire control and suppression rather than addressing the underlying causes.	about maintaining peatlands. • Sometimes national government brings in its programs without consultation with local governments. • Limited interface domain (only provincial – regency level; then regency – district – village level). • Person in charge is always changing. • No direct line of command for forest fire management in normal daily activities: a range of legislation in response to large fires only emphasizes fire control and suppression rather than addressing the underlying causes. • Lack of direct interaction among related stakeholders (e.g. *DPRD* with local communities, NGOs, companies) about their concerns about peatland issues. • Due to distrust by local people of individuals from government, *DPRD*, companies, and NGOs, local people deny them access to communication.	about maintaining peatlands. • Sometimes national government brings in its programs without consultation with local governments. • Limited interface domain (only provincial – regency level; then regency – district – village level). • Person in charge is always changing. • No direct line of command for forest fire management in normal daily activities: a range of legislation in response to large fires only emphasizes fire control and suppression rather than addressing the underlying causes. • Lack of direct interaction among related stakeholders (e.g. *DPRD* with local communities, NGOs, companies) about their concerns about peatland issues. • Due to distrust by local people of individuals from government, *DPRD*, companies, and NGOs, local people deny them access to communication. • There are provincial regulations on controlled burning but it is uncontrolled in the field (regency level) where some of peatlands are not protected areas (not conservation areas). • Controlling, investigating, listening and meetings between the government and *DPRD* with companies/investors are only done when there is a problem/conflict with the local community (e.g. overlapping landownerships, land grabbing in protected areas, etc.).

	What should be done:	• Consolidation of cross-sectoral, all levels sharing of knowledge, updated information, regulations, etc. • Involving local communities in implementation of regulations, programs, and actions and on making peatland development plans (bottom-up system). • Public engagement initiatives (e.g. participatory approach) to increase legitimacy and acceptability of regulations, policy, and sustainable management options. • Building an independent (or cross-sectoral) institution for peatland governance.	• Consolidation of cross-sectoral, all levels drafting of sub-regulations for peatland management (*DPRD* and government). • Consolidation of cross sectoral, all levels sharing of knowledge, updated information, regulations, etc. • Sharing and discussion among stakeholders (government, NGOs, farmers, indigenous community, academic community, businessmen) on peatland issues. • Involving local communities in implementation of regulations, programs, and actions and on making peatland development plans (bottom-up system). • Public engagement initiatives (e.g. participatory approach, Forest community) to increase legitimacy and acceptability of regulations, policy, and sustainable management options.	• Consolidation of cross-sectoral, all levels drafting of sub-regulations for peatland management (*DPRD* and government). • Consolidation of cross sectoral, all levels sharing of knowledge, updated information, regulations, etc. • Sharing and discussion among stakeholders (government, NGOs, farmers, indigenous community, academic community, businessmen) on peatland issues. • Involving local communities in implementation of regulations, programs, and actions and on making peatland development plans (bottom-up system). • Public engagement initiatives (e.g. participatory approach, Forest community) to increase legitimacy and acceptability of regulations, policy, and sustainable management options. • Strengthening coordination among provincial, regency, and village government, also with heads of indigenous communities (*kepala adat*).

Appendix 4.6. Institutional fit of Indonesian peatland management

Regulation	Rule Regulation (content)	Dimension	Rule Creator (national regulator supplemented with provincial policies)	Rule Adopter (peatland users)	Fit degree	Causes of misfit
1. Government Regulation (PP) No. 4/2001 regarding Control of Natural Damage and/or Pollutions related to Land and Forest Fires.	i. Everybody is banned from setting land and forest fires.	Technical - technological standards - infrastructure - educational and financial institutions	i. The National regulation prescribes zero burning, but some provinces allow controlled burning (e.g. Local Government in Central Kalimantan issued controlled burning regulation particularly for local farmers/ smallholders). ii. Establish fire management systems (Fire early warning system) for forest and or land fires suppression. iii. Remote sensing monitoring by reporting to the local authority at least every 6 months. iv. Establish standard operating procedures to prevent and combat forest and land fires; and the organisation responsible for preventing and combating the forest and land fires; v. Provide regular forest and land fire prevention training as every person is obliged to combat forest and land fires on his own lands.	**Jambi:** i. Most local farmers and landowners clear their lands not only to prepare the land for farming but also to indicate ownership because most individual farmers/smallholders do not have the highest level of land ownership certificate, sometime only letters from heads of the villages acknowledging the land right or the letters acknowledging the customary land right from the customary heads. ii. Use manual land clearing (slash) and herbicides for zero burning, but if zero-burning is impossible, burning takes place on each piece of land in turn (usually only in shallow peatland). iii. Create canals to block fires and wildfires (fire wall; but this will make drain the peat). iv. Build wells for water sources to extinguish fires. v. Establish fire management systems for community-based (village), company-based.	Low (1 out of 5) (establish fire management system)	i. Never know who exactly causes or sets the fire. ii. At the moment there is no effective technology to extinguish (massive) peatland fires. Local people only wait for heavy rain (especially during El Niño). iii. Fires and wildfire cannot be controlled, even when remote sensing monitoring is available. iv. Lack of technical knowledge about other types of land clearing method without burning (zero burning) on peatlands.
				Central Kalimantan: i. Most local farmers and landowners clear their lands not only to prepare the land for farming but also to indicate ownership because most individual farmers/smallholders	Low (1 out of 5) (establish fire management system)	

do not have the highest level of land ownership certificate, sometime only letters from heads of the villages acknowledging the land right or the letters acknowled-ging the customary land right from the customary heads.

ii. Indigenous peoples rely on slash-and-burn farming techniques for subsistence farming.
iii. Use manual land clearing (slash) and herbicides for zero burning, but if zero-burning is not possible, burning takes place on each piece of land in turn (usually only in shallow peatland).
iv. Burning permits are allowed only to local inhabitants who are not members of a corporate body/ business entity, with the land area must not exceed 1-2 ha, but if zero-burning is impossible, burning takes place on each piece of land in turn (usually only in shallow peatland).
v. Create canals to block fires and wildfires (fire walls).
vi. Build wells for water sources to extinguish fires.
vii. No fire means creating different types of land clearing methods, pest control methods, and fire combat methods.
viii. Every landowner is obliged to use his land based on land use permit where a cleared land indicates ownership of the property.
ix. Establish fire management systems for community-based (village), company-based.

Political - Interests - power structures - agendas	i. Normative claims: protected forest and land including protection of peatland ecosystem. ii. Zero burning, although national regulation prescribes zero burning, some provinces allow controlled burning method. iii. Reducing CO_2 emissions from forest and peat fires with the high interest on emerging payment for environmental services (PES) like REDD+. iv. In Central Kalimantan, the local government issued a controlled burning regulation particularly only for local farmers (smallholders), with fires permit issued by the village head.	**Jambi:** i. Landowners burn their lands with the main purposes to do land (vegetation) clearing, land conversion, or stake land claims following the customary law (land tenure right). ii. Slash-and-burn method is still used, as it is the easiest, fastest, and cheapest way to land clearing. Most local farmers and landowners clear their lands not only to prepare the land for farming but also to indicate ownership because most individual farmers/smallholders do not have the highest level of land ownership certificate, sometime only letters from heads of the villages acknowledging the land right or the letters acknowledging the customary land right from the customary heads. iii. Land clearing indicates landownership, where non-cleared lands (vegetation) will be taken back by the government. iv. Establishing a village fire combat community for fire prevention and firefighting as well as interest on REDD+ project.	Low (1 out of 4) (interest on REDD+)	i. The authorities seldom involve relevant stakeholders in the formulation of the legislation such as the prohibition of fire for land clearing. ii. Slash-and-burn method is still used, as it is the easiest, fastest, and cheapest method for land clearing.
		Central Kalimantan: i. The slash-and-burn method is still used, as it is the easiest, fastest, and cheapest way to land clearing. Most local farmers and landowners clear their lands not only to prepare the land for farming but also to indicate ownership because most individual farmers/small-holders do not have	Low (1 out of 4) (interest on REDD+)	

		the highest level of land ownership certificate, sometime only letters from heads of the villages acknowledging the land right or the letters acknowled-ging the customary land right from the customary heads. ii. Land clearing indicates landownership, where non-cleared lands (vegetation) will be taken back by the government. iii. Local inhabitants, who are not members of a corporate body or business entity, with a land area of no more than 2 ha, are allowed to have controlled burning permit. iv. Landowners burn their vegetation land with the main purposes for land clearing, land conversion, or stake land claims following the customary law (land tenure right). v. Fire management follows controlled burning regulation. vi. Establishing a village fire combat community for fire prevention and firefighting. vii. Some villages are involved in the REDD+ project.		
Cultural - Structure - cultural values - beliefs - practices - roles and responsibilities	i. Every person is obliged to combat forest and land fires on site land or his activities. ii. Non-fired land clearing method does not applied to indigenous or traditional land clearing for fields and gardens. Burning is done deliberately in order to prepare the fields.	**Jambi:** i. Land clearing (vegetation burning) is applied when land users (mostly farmers) begin to open new lands/ areas or during preparation of land before the rain season begins. ii. The agricultural land users believe that burning land can improve the fertility of peat soil and is effective for killing pests, the knowledge that they get from generation to generation.	Low (1 out of 3) (Fire prevention)	i. Cleared land is a sign of land-ownership. ii. Local communities have not been consulted, traditional knowledge on the use of fire in agriculture are adopted, and

	iii. Providing alternative for land clearing methods using zero burning technology.	iii. Burning land (vegetation) is mostly applied for seasonal farming types such as horticulture, agricultural food, etc. iv. Some farmers still carry out a controlled burning system to clear their lands within *Manduk* system (a tradition that involving communities in working together to clean up lands by burning). **Central Kalimantan:** i. Indigenous peoples rely on slash and burning method for subsistence agriculture (farming). ii. Land clearing (burning) is mostly applied when land users start to open new lands/areas or during preparation of land before the rain season begins. iii. The agricultural peatland users believe that burning land can improve peat soil fertility and is useful for killing pests, a wisdom that they pass from generation to generation. iv. Some indigenous farmers are still doing shifting cultivation under a controlled burning system to clear their lands within *Handep* (hand in hand tradition) system (a rotating community collaboration) which local people believe it as good practices to have good relationship among communities. v. Only burning the land with the permission of the village head based on controlled burning regulation, is applied.	Low (1 out of 3) (Fire prevention)	provision of incentives for local communities and other stakeholders for not using the fire was not considered resulting in the failure of implementation of fire management regulations. iii. Alternative types of zero burning technology are not known yet (can only be done by expensive mechanical tools).

				vi. Burning (vegetation) land is mostly used for seasonal farming types such as horticulture, agricultural food, etc. vii. Dayak people create wells in the middle of the forest, so they have a source of water to extinguish fire.		
2. Minister of Agriculture Decree (Kepmentan) No. 14/2009 on the Guidance for the Utilisation of Peatland for Oil Palm Cultivation	i. Oil palm cultivation/ plantation in peatlands is only allowed in peatland with peat depth less than 3 meters, and the proportion of peatland with a thickness of less than 3 meters is at least 70% (seventy percent) of the total cultivation area.	Technical - technological standards - infrastructure - educational and financial institutions	i. Peat layer deeper than 3 meters, with a total peatland area of more than 30% of the total cultivated area, cannot be converted into oil palm plantation. ii. Oil palm can be cultivated on peatlands that are located on community land and in cultivation area (not in forested areas); iii. Soil substratum under peat is not quartz sand or not acid sulphate soil (ASS); iv. The peat maturity level is sapric (mature) or hemic (half-mature); and v. The peat fertility level is eutrophic.	**Jambi:** i. Landowners use their lands based on permits and maps from the local authorities. ii. Manually measure their peatland depth by using rods, making pore water and checking the water content of leaves to suggest their peat types (mostly by local farmers). iii. Peat with thickness > 3 m still gives good results for oil palm cultivation, without significant environmental impact (with proper management). iv. Some large oil palm companies use satellite and radar sensing technology to measure peat depth in their peatlands; others, however, continue to use their lands based on the given permits.	Low (1 out of 5) (no cultivated oil palm in forested areas)	i. Lack of detailed information on actual locations of deep peat. ii. Land users hardly ever (almost never) measure the peat depth of their peatlands.
				Central Kalimantan: i. Landowners use their lands based on permits and maps from the local authorities; some of them have hardly ever (almost never) measured the depth of their peatlands in the field. ii. Local farmers/smallholders manually measure (suggest) their peat depth and peat type by using rods, making pore water and also checking the water content of leaves.	Low (1 out of 5) (no cultivated oil palm in forested areas)	

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		iii. Peat with thickness > 3-m still gives good results for oil palm cultivation, without significant environmental impact (with proper management). iv. Some large oil palm companies use satellite and radar sensing technology to measure peat depth in their peatlands; others, however, continue to use their lands based on the given permits.		
Political - Interests - power structures - agendas	i. Oil palm plantations become one significant source to supply foreign exchange income (national income) and to increase public welfare. ii. National government wants to protect deep peat areas/peat ecosystem protection, but also wants to improve service on the development of oil palm cultivation in peatland areas (shallow peatlands). iii. This regulation is the legal basis for provincial/regency governments to use peatlands for oil palm cultivation. iv. Facilitate the development of oil palm cultivation in peatlands and provide certainty for oil palm cultivation business in peatlands. v. Companies that have already practiced oil palm cultivations on their peatland areas and have	**Jambi:** i. Oil palm plantations have become one significant source for domestic income supply and increase public welfare because of their easily available markets so that many local farmers want to replace their plants (crops) with oil palm. ii. Many large areas of oil palm cultivation are owned by companies. Landowners (especially companies) must use their lands based on the type of permits (HGU). If not, the government will take the lands back and give the lands to another company(s). iii. Some landowners (including some oil palm companies) have already planted their lands before this regulation is issued. iv. Companies are given permits by the local government based on Spatial Planning map (*RTRWP*). v. Establishing a village farmer community for smallholder farmers, within proposed areas (plasma) for oil palm cultivation.	Moderate (3 out of 6) (cultivation oil palm; companies with prior issued licences can continue their cultivation activities; applying water management)	i. Due to limited mineral lands, the land expansions go to peatland areas coupled with food security and income-generating issues, and increase international oil palm demand and market. ii. The market demand for oil palm is higher than the other crops in peatlands.

	received licenses, are allowed to continue their cultivation activities. Companies must adapt their practices with this new guideline. Ongoing requests or registrations regarding oil palm cultivation activities should follow this new guideline. vi. Promote Eco-hydro water management in peatlands.	vi. Water management is individually managed by using flap gate (one follow system) or by following eco- hydro water management.	
		Central Kalimantan: i. Oil palm plantations have become one significant source for domestic income supply and increase public welfare because of their easily available markets so that many local farmers want to replace their plants (crops) with oil palm. ii. Many large areas of oil palm cultivation are owned by companies. Landowners (especially companies) must use their lands based on the type of permits (HGU). If not used then the government will take the lands back and give the lands to another company(s). iii. Some landowners (including companies) have already planted their lands before this regulation is issued. iv. Many of the lands are inherited; and indigenous peoples received the land use right through *Dayak Misik* program (5 ha/household). v. Establishing a village farmer community for smallholder farmers, and propose areas (plasma) for oil palm cultivation. vi. Water management is based on customary rules (e.g. *Handil* system); which the *Handil* organisers have the power to govern water in the field.	Moderate (3 out of 6) (cultivation oil palm; companies with prior issued licences can continue their cultivation activities; applying eco-hydro water management)

Cultural - Structure - cultural values - beliefs - practices - roles and responsibilities	i. Oil palm plantation is primarily done in the mineral lands but because the mineral lands are lacking, the oil palm cultivation can be done on peatlands, but must be in accordance with the rules for peatland sustainability: (a) done only on community land farming area, (b) on peatland with depth less than 3 meters, (c) the subsoil under the peatland is not quartz sand or not acid sulphate soil (ASS); (d) the maturity of the soil is sapric (the most decomposed) or hemic (somewhat decomposed); and (e) eutrophic peatlands. ii. Peatland is widely distributed across Indonesia, mostly in coastal and lowland areas. So far, people have cultivated plants (e.g. pineapples, coconut, oil palm, etc.) on peatlands based on land characteristic (e.g. peat depth, water level) iii. Guidelines for cultivation on peatlands are needed in order to maintain the functions of peatlands.	**Jambi:** i. Landowners have the right to determine their land use type, and only companies must use their lands based on given permits and this regulation. ii. Some farmers believe that oil palm is the most profitable and suitable plant for peatland areas (including degraded peatland) compared to other types of agricultural plants (e.g. paddy, areca nut, rubber, etc.). iii. Some landowners have inherited areas with areca nut, paddy, and other uses, and also eager to convert their plants to oil palm. iv. Decisions on the kind of plant/land use are based largely on following neighbour's successful story/practice of high-benefit yield crops (currently oil palm) with lack of knowledge about these guidelines. v. Oil palm companies encourage local farmers to plant oil palm trees by providing cultivation training as well as buying their Fresh Fruit Bunch (FFB). vi. Farmer groups have been established in order to improve and develop farmers' welfare collectively.	Moderate (2 out of 3) (planting oil palm based on land characteristic; cultivating oil palm only in community lands)	i. Some landowners have already planted their lands with oil palm trees before this regulation is issued. ii. The market drives changes in the types of crops previously cultivated by local farmers into oil palm trees.
		Central Kalimantan: i. Landowners have the right to decide on their land use type, and only companies must use their lands based on given permits and this regulation. ii. Some landowners have had inherited areas with rubber, paddy, and other	Moderate (2 out of 3) (planting oil palm based on land characteristic; cultivating oil palm only in	

				uses; and also eager to convert their plants to oil palm. iii. Some farmers believe that oil palm is the most profitable and suitable plant for peatlands (including degraded peatlands) compared to other types of agricultural plants (e.g. paddy, rubber, etc.). iv. Decisions on the kind of plant/land use are based largely on neighbour's successful story/practice of high-benefit yield crops (currently oil palm, rubber) with a lack of knowledge on these guidelines. v. Oil palm companies encourage local farmers to plant oil palm trees by providing cultivation training as well as buying their Fresh Fruit Bunch (FFB). vi. Farmer groups have been established in order to improve and develop collective farmers' welfare.	community lands)	
3. Presidential Instruction (Inpres) No.10/2011, No.6/2013, and No.8/2015 on (Extended) Moratorium on the Granting of New Licences and the Improvement of Governance of Natural Primary Forest and Peatland	i. A two-year suspension of new permits related to forest conversion. ii. Instructions to certain government agencies to suspend the activities of issuing new permits related to the conversion of natural forests and peatlands. iii. Exemptions to existing legal	Technical - technological standards - infrastructure - educational and financial institutions	i. No new permit for conversion of natural forests and peatlands. ii. Develop a better process for land use planning and licensing during the moratorium period. iii. The location of the moratorium is based on an Indicative Map of Moratorium New Licences Issuance i.e. in conservation forest, protected forest, production forest (limited production forest, regular production forest, or	**Jambi:** i. Landowners still use their lands based on permits given by provincial, or district, or village government based on spatial planning (RTRWP) map, or and customary forest laws. ii. The local community(s)/villagers create and use their village maps to describe the boundaries of land ownership, under the supervision of the village government in which they work based on agreed boundaries. iii. Local people/communities have an understanding that the lands with a distance of 5-km from the village can be used as productive lands.	Moderate (2 out of 4) (Moratorium of new licenses; following the Indicative maps of moratorium new licences Issuance)	i. There is still a difference in interpretation of the peatland categories between local governments (provincial/ regency) and technical implementation units at the Ministry of Environment and Forestry which causes some areas that

permits and activities for national purposes (e.g. energy generation). iv. Reference to one map that will guide the implementation and is updated on a regular basis.		permanent production forest which can be converted), revised every 6 months. iv. The moratorium of new licenses is applied to the uses of natural primary forest and peatland areas, with the exception is given to: a) Application, which has received principle approval from Minister of Forestry; b) Implementation of vital national development, i.e. geothermal, oil and gas, electricity, lands for rice and sugar cane; c) Extension of forest utilisation permit and or use of forest area that has applied permit in the field; and d) Ecosystem restoration.	iv. Local communities and or new companies planted ex-burnt areas and then submitted their requests to government to own the lands as their lands (restoration peatlands). **Central Kalimantan:** i. Landowners still use their lands based on permits granted by provincial, or district, or village government based on spatial planning (RTRWP) map, or and customary forest laws. ii. Local community(s) /villagers create and use their village maps to describe the boundaries of land ownership, under the supervision of the village government in which they work based on agreed boundaries. iii. Local people/communities have an understanding that the lands with a distance of 5-km from the village can be used as productive lands. iv. Local communities and or new companies planted ex-burnt areas and then submitted their requests to the government to own the lands as their lands (restoration peatlands).	Moderate (2 out of 4) (Moratorium of new licenses; following the Indicative maps of moratorium new licences Issuance)	should be in the moratorium area not available in the next revision of the Indicative map of moratorium on granting of new licences (*PIPPIB*). ii. Lack of detailed information about the actual boundaries between forest and non-forest areas at the village level. iii. Overlapping landownership. iv. Government information on boundaries between forest and non-forest areas is only on paper document (map), no clear boundaries at the village level.
	Political - Interests - power structures - agendas	i. The National government wants to protect the remaining forest and ecosystem protection areas (no deforestation). ii. Complete improvements in ongoing governance of forests and peatland management for	**Jambi:** i. Landowners use their lands based on licences given by provincial, or district, or village government as well as spatial planning (*RTRWP*) maps and or customary forest laws. ii. Landownership and type of land uses are mostly continued from inherited/ traditional uses and also through	Moderate (3 out of 5) (Moratorium of new licenses; coordinating with local government on	i. In many areas, the non-forested land is legally classified as "forest" and therefore not available for agricultural expansion,

	reducing emissions from deforestation and forest degradation. iii. The Ministry of Forestry has the primary authority in the implementation of moratorium regulations and is responsible for making Indicative maps of moratorium new licences Issuance (*PIPPIB*) and its revision; the Ministry of Environment is responsible for efforts to reduce carbon emissions in the areas of the Indicative Moratorium maps; the Ministry of Home Affair is responsible for assisting and monitoring Governor and Regency Mayor for the implementation of the regulation; the National Land Agency is responsible for continuing the suspension the issuance of property rights including land use rights based on the new indicative moratorium map; the National Spatial Planning Coordinating Board is responsible for accelerating the consolidation of the new indicative moratorium map into the revision of the regional/provincial maps; Governors and	the purchase of land; some peatlands tend to be replanted with paludiculture by local farmers. iii. Most of local farmers/smallholders have no licenses on their land uses (no certificate yet), only based on customary rights and or tenure rights granted by the local government (2 ha/household). iv. Farmers, with informal licences or customary rights, continue to use their land even though there is no clear boundary between their land and protected forests. v. The areas of social forestry (village forest and community forestry) are mostly included in the moratorium which needs permits from the government for its utilisations.	land use; REDD+)	whereas forest land is legally classified as "non-forest" and therefore at risk of conversion. ii. There is no transparency of land status. iii. Due to lack of markets for paludiculture products it is therefore not attractive for local farmers or companies.
		Central Kalimantan: i. Most local farmers/smallholders do not have their land use permits (no certificate yet), but only based on customary rights or land use rights given by local government before they acquire a title property right certificates; still they can use the land to farm. ii. Indigenous peoples/community (Dayaks) can have the right to use land through the Dayak *Misik* program (the program was established by the provincial government for indigenous peoples). iii. Landowners are entitled to use their land based on permits granted by provincial and district government as well as spatial planning (*RTRW*) map and or and customary forest laws.	Moderate (3 out of 5) (Moratorium of new licenses; coordinating with local government on land use; REDD+)	

	Regency/city Mayors are responsible for suspending the issuance of the recommendation and permits/licences of new locations in forest areas, peatlands and other uses based on the new indicative moratorium map. iv. Provincial and district governments grant licences to use their lands based on spatial planning (*RTRW*) map including moratorium map, and customary forest laws that can be changed every 5 years or if there is a new national policy or internal required by the province or district. v. Establish REDD+ task force; promote paludiculture for peatlands.	iv. Land tenure and type of land use are largely continued from the inherited uses and land purchase; some peatlands tend to be replanted with paludiculture by local farmers. v. The areas of social forestry (village forests and community forestry) are mostly included in the moratorium requiring government permission for its utilisation. vi. Several protected forest areas and peatlands in Kapuas Regency were established for REDD+ pilot projects where several villages were involved in supporting the program, while others still used their lands as business as usual.		
Cultural - Structure - cultural values - beliefs - practices - roles and responsibilities	i. Develop and manage forested areas for Non-Timber Forest Productions (NTFPs). ii. Develop a transparent and participatory process for reviewing, revoking, reissuing, or relocating illegal permits or in areas not suitable for development.	**Jambi:** i. Most of the forest area is believed to be an unowned land, and cleared area shows landownership. ii. Access to forest use is based on customary forest laws in some customary forests and only for non-timber forest products. iii. Local people/communities have an understanding that the lands within 5 km of their village can be used as productive lands.	Moderate (2 out of 3) (managing forested areas for Non-Timber Forest Productions; developing a transparent and participatory process)	i. Local people/ communities have not been consulted, nor landowners were involved in the formulation of legislation and mapping. ii. Unclear landownership, also considering forest as

	iii. Incorporate stakeholder engagement best practices and include informed consent from relevant communities.	iv. Some farmers have already established community/village forest (*Hutan Desa*) for managing forest without damaging the forest ecosystem, but only based on consultation with the village head. v. The village head has ultimate authority to regulate land use and can grant land use rights at the site/village location. Local people/communities have an understanding that the lands within 5 km of their village can be used as productive lands.		unowned land and inheritance land trigger (peatland) encroachment.
		Central Kalimantan: i. Most of the forest area is believed to be an inherited area especially for indigenous peoples (Dayak). ii. Access to forest use is based on customary forest laws in some customary forests, and only for non-timber forest products. iii. Some farmers have already established community/village forests (*Hutan Desa*) to manage forests without damaging the forest ecosystem, but only in consultation with the village head. iv. The village head has the ultimate authority to regulate land use and can grant land use rights at the site/village location. Local people/communities have an understanding that the lands within 5-km of their village can be used as productive areas.	Moderate (2 out of 3) (managing forested areas for Non-Timber Forest Productions; developing a transparent and participatory process)	

4. Government Regulation (PP) No.71/2014 on the Protection and Management of Peatland Ecosystems.	i. Peatland with more than a 3 meters depth is classified as a protected area, and its use is prohibited. ii. Peatland ecosystem under "development status", with the groundwater table decline for more than 0.4 meters of peat surface, on the peatland with peat depth more than 1 meter, are classified as "damaged peatland". But if the peatland are less than 1 meter depth, their degradation status or damage is regulated by environmental permit (*ijin lingkungan* according to Article 24). iii. Setting fires on peatlands is banned.	Technical - technological standards - infrastructure - educational and financial institutions	i. Peat layer deeper than 3 meters cannot be converted. ii. No drainage with water level deeper than 0.4 meters is allowed. iii. National regulation prescribes zero burning but some provinces allow controlled burning (e.g. Local Government in Central Kalimantan had issued controlled burning regulation particularly for local farmers/ smallholders).	**Jambi:** i. No use or limited use of peatland with peat depth than 3-meters by some local farmers and companies. ii. Use selected plant species based on land suitability where shallow peatlands are planted for tidal rice fields, deep peatlands are for coconuts. iii. Make a lot of ditches to drain peat water so that peat layer thickness decreases rapidly. Make water stop-log/dam overflow (*tabat system*) to maintain ground water levels and peat layer thickness in peatlands. iv. Use manual land clearance (slash) and herbicides for zero burning, but if zero-burning is not possible, burning takes place on each piece of land in turn (usually only in shallow peatlands). **Central Kalimantan** i. No use or limited use of peatland with peat depth more than 3-meters by some indigenous farmers and companies. ii. Peat with a thickness of > 3-m still provide good results, mainly for annual cultivation crops, with no significant environmental impacts (with proper management). iii. Drainage and burning (deep) peat are applied by local farmers to reduce peat depth until 2-meters in 3 years, but the peat layer is left up to a thickness of about 15 cm for humus. iv. Groundwater table 0.5-meters and 0.6-meters, respectively, for oil palm	Low (1 out of 3) (No use or limited use of peatland with peat depth more than 3-meters) Low (1 out of 3) (No use or limited use of peatland with peat depth more than 3-meters)	i. Lack of information on where the deep peat is while rough maps are only available to the national government and research organisations, but not at the level of the provincial or district governments. ii. Water table depth is hardly ever measured, varies throughout the year, and is difficult to control (can only be done by expensive water control systems). The water table is not controlled according to the regulations, and there is no monitoring or enforcement by the government. Canals were built not only for drainage but also for transporting products and people. Tertiary

		and acacia, are required for this commodity (according to the private sector operations of most palm oil and pulp and paper industries). Make ditches with water stop-log/dam overflow (*tabat system*) to maintain groundwater levels and peat layer thickness in peatlands. v. Use fire only for certain purposes and on a limited scale where fire can be controlled by canal blocking. The burning permission is only for local inhabitants who are not members of a corporate body/business entity, with the land area must not exceed 1-2 ha, but if zero-burning is not possible, burning takes place on each piece of land in turn (usually only in shallow peatlands).		canals are provided by the government (PU/Public Work Department) with the proposals from the community without measuring drainage depth. iii. Fires and wildfire are not controlled, although there is monitoring based on remote sensing. There is no strict line of command for the forest fire management in normal daily activities.
Political - Interests - power structures - agendas	i. Permanently moratorium on conversion of peatlands to support carbon emission reduction and carbon trading. ii. Reinforcement power of government to take over damaged areas of peatlands, particularly in concession areas. iii. Agendas: a) within a maximum of 2 years (i.e. in September 2016),	**Jambi:** i. Land expansion is allowed on peatlands under local government permits due to limited mineral lands for farming and plantations, also increasing demand for oil palm products (food and biofuel) and rubber (latex), given the high economic benefits. ii. Landowners, who have already planted their peatlands before the regulation was issued, have right and responsible for managing and rehabilitating their damaged	Low (1 out of 3) (Agenda to rehabilitate damaged peatlands)	i. Lack of information sharing and control within MoEF and between different government agencies; lack of monitoring and enforcement makes peatland users insufficiently

	all peatland areas in Indonesia are mapped in Peatland Hydrological Units (PHU) including all peat soil areas and land adjacent to the respective rivers and coastal areas over Indonesia (covers more than 26 million Ha); b) within a maximum of four years (i.e. in September 2018), all PHUs are surveyed and enable to prepare maps of peat depth and to undertake the functional classification of the PHU(s); c) Establish the zoning of all PHUs into Protection and Utilisation Zones with a minimum of 30 percent for protected areas of the total PHU area, including the centre of the peat dome and its surroundings. Additional protection area is also given outside the core 30 percent of the PHU area if the following indicators are found:	peatlands. Otherwise the government is entitled to take over their land. However, the taking over areas by the government is mainly applied to the companies. iii. Landowners have the right to decide their land use type(s) and type(s) of cultivated plants for having benefit as much as possible. iv. Forests and lands are managed based on 8 peat dome systems which are cross regencies and have various interests and priority on the peatland utilisation. v. Slash-and-burn method is still used because it is the easiest, fastest, and cheapest way for land clearing. **Central Kalimantan:** i. Land expansion is allowed on peatlands under local government permits due to limited mineral lands for farming and plantation, also increasing demand for oil palm products (food and biofuel) and rubber (latex), given the high economic benefits. ii. Landowners, who have already planted their peatlands before this regulation was issued, have right and responsible for managing and rehabilitating their damaged peatlands. Otherwise, the government is entitled to take over their land. However, the taking over areas by the government is mainly applied to the companies. iii. Landowners have the right to determine their land use type(s) and	Low (1 out of 3) (Agenda to rehabilitate damaged peatlands)	incentivised to use peatlands according to the regulations; the Ministry of Agriculture and the Ministry of Public Work/PU do not share concerns about maintaining peatlands in undrained, forested state, while conflict of interest with landowners is due to increase demand for food security (agriculture lands). At the district level, the representatives of the MoEF are functioning in a local government system facing multiple incentives including incentives promoting giving licenses on peatland use to local farmers and companies.

	- Peat with a 3 meters depth or more; - Specific or endemic genetic resources; - Species protected under applicable laws; and - Protected peatland in existing spatial plans and conservation areas. d) Require the development and implementation of the Integrated Protection and Management Plan for each PHU; and e) Require average water levels to be maintained no more than 0.4 m below the surface in the use zones to minimise subsidence and reduce fire risk.	type(s) of cultivated plant for having benefit as much as possible. iv. The slash-and-burn method is still used because it is the easiest, fastest, and cheapest method for land clearing.		ii. No strict line of command for forest fire management in normal daily activities and that a range of legislation in response to large fires only emphasise fire control and suppression rather than address the underlying cause. iii. Forest and land are managed based on regency administrative boundaries while government seldom involve peatland users/landowners to formulate legislations such as prohibiting the use of fire for land clearing.
Cultural - cultural values - beliefs - practices - roles and responsibilities	i. No peat layer deeper than 3 meters can be used. ii. Water level should be managed with no deeper than 0.4 metres is allowed. iii. Zero burning means requiring another	**Jambi:** i. Land uses are mostly continued from inherited area, in which peatlands have been already cultivated before the regulation is issued. ii. Decision on the type of plant/land use is based mostly on following neighbour's successful story/practice	None	i. Local communities have not been consulted, nor traditional knowledge on the peatland use (e.g. fire use in

	alternative for land clearing. iv. Government can take over the damaged peatland areas.	that shows the high benefits of their land (currently oil palm plantation). iii. Farmers believe that peat water is toxic for plants and should be disposed of/run-off, making a lot of ditches will drain peat water so that thickness of the peat layer will decrease rapidly. Make dam overflow/water stop-log to maintain ground water levels and peat layer thickness in peatlands. iv. The agricultural peatland users believe that burning land can increase the fertility of their soil and is also useful for killing pests; the knowledge they pass from generation to generation. v. Some local farmers use traditional tools such as hand trowel for minimum tillage to avoid the exposure of the pyrite layers which can lead to increased soil acidity.		agriculture), or provision of incentives for local communities and other stakeholders for non-use of peat (or fire) have not been considered. ii. Regarding investment decisions on peatland use and type of crop/plant, companies and local people/communities often choose options with shorter time spans than long-time sustainability.
		Central Kalimantan: i. Indigenous farmers do not use deep peat for farming, only shallow peat will be managed with local wisdom such as fish pond, wet agriculture, and burning land control. ii. Land uses are mostly continued from inherited uses that peatlands have been already cultivated before the regulation is issued. iii. Farmers believe that peat water is toxic for plants and should be disposed of/run-off, by making canals (> 2.5-m) when opening peatlands; the canal is closed after the rain, so that the plants can use rain water (non-toxic water).	Low (1 out of 4) (No use deep peat)	iii. The expansion of peatland use is caused by limited availability of mineral land and increased demand for agricultural land. iv. Lack of knowledge on the practices and management of sustainable peatlands for

	iv. The agricultural peatland users believe that burning land can increase their soil fertility as well as useful for killing pests; the knowledge that they pass from generation to generation. v. Some indigenous farmers still do shifting cultivation under a controlled burning system to clear their lands with *Handep* (hand in hand tradition) system (a rotating community collaboration work) where local people believe that it is a good practice for having a good community relationship. vi. Decision on the type of plant/land uses is based largely on following neighbour's successful story/practice that shows the high benefits of their land (currently rubber and oil palm plantation). vii. Water management is based on customary rules (*Handil* system) where canal blockings must be under the Handel system management. viii. Some local farmers use traditional tools such as hand trowel (*tajak*) for minimum tillage to avoid the exposure of the pyrite layers which can lead to an increase in soil acidity.	peatland users. For example, most transmigrants treat peatlands that are similar to mineral lands because they do not come from peatland areas (mostly Java, Bali, Nusa Tenggara, etc.), the paludiculture commodities are less well known. v. Only limited number of transmigrants from Banjar (Kalimantan) started to treat peatland based on their experience; they experience difficulties in marketing their products (e.g. jelutung, vegetables, etc.) with less rigid buyers/clients.

Appendix 5.1. Interview results of peatland users in Central Kalimantan Province, Indonesia

Attribute and type of paludiculture crop	Number of responses (farmer groups) and Relative share of groups growing the crop (%)					
A. Time period until the first harvest (year)	< 1	1 - 2	3 - 5	6 - 10	> 10	Total
1. Banana/pisang	2 (40%)	3 (60%)	-	-	-	5
2. Bitter gourd/pare	1 (100%)	-	-	-	-	1
3. Candlenut/kemiri	-	-	1 (100%)	-	-	1
4. Durian/durian	-	-	1 (33%)	2 (67%)	-	3
5. Dragon fruit/buah naga	-	2 (100%)	-	-	-	2
6. Illipenut/tengkawang	-	-	-	4 (100%)	-	4
7. Kelakai edible fern/kelakai	3 (100%)	-	-	-	-	3
8. Liberica coffee/kopi liberika	-	-	1 (100%)	-	-	1
9. Mangosteen/manggis	-	-	-	1 (100%)	-	1
10. Pineapple/nanas	2 (33%)	4 (67%)	-	-	-	6
11. Rambutan/rambutan	-	-	3 (75%)	1 (25%)	-	4
12. Sago/sagu	-	-	-	1 (50%)	1 (50%)	2
13. Snake fruit/salak	-	-	1 (100%)	-	-	1
14. Sweet-melon/melon	3 (100%)	-	-	-	-	3
15. Water spinach/kangkong	1 (100%)	-	-	-	-	1
B. Number of harvest (times/year)	1	2	3	4	≥ 5	Total
1. Banana/pisang	-	3 (60%)	1 (20%)	-	1 (20%)	5
2. Bitter gourd/pare	-	-	1 (100%)	-	-	1
3. Candlenut/kemiri	-	1 (100%)	-	-	-	1
4. Durian/durian	2 (67%)	1 (33%)	-	-	-	3
5. Dragon fruit/buah naga	-	1 (50%)	-	-	1 (50%)	2
6. Illipenut/tengkawang (once/4 years)	4 (100%)	-	-	-	-	4
7. Kelakai edible fern/kelakai	-	-	-	-	3 (100%)	3
8. Liberica coffee/kopi liberika	-	1 (100%)	-	-	-	1
9. Mangosteen/manggis	1 (100%)	-	-	-	-	1
10. Pineapple/nanas	-	2 (33%)	4 (67%)	-	-	6
11. Rambutan/rambutan	3 (75%)	1 (25%)	-	-	-	4
12. Sago/sagu	-	2 (100%)	-	-	-	2
13. Snake fruit/salak	-	1 (100%)	-	-	-	1

14. Sweet-melon/melon	-	-	2 (67%)	1 (33%)	-	3
15. Water spinach/kangkong	-	-	-	1 (100%)	-	1
C. Production (tonne/ha/year)	< 1	1 - 2	3 - 5	6 - 10	> 10	Total
1. Banana/pisang	-	-	-	-	5 (100%)	5
2. Bitter gourd/pare	-	-	-	-	1 (100%)	1
3. Candlenut/kemiri	-	-	-	-	1 (100%)	1
4. Durian/durian	-	-	-	-	3 (100%)	3
5. Dragon fruit/buah naga	-	-	-	-	2 (100%)	2
6. Illipenut/tengkawang	-	-	-	-	4 (100%)	4
7. Kelakai edible fern/kelakai	-	-	3 (100%)	-	-	3
8. Liberica coffee/kopi liberika	-	-	-	1 (100%)	-	1
9. Mangosteen/manggis	-	-	-	-	1 (100%)	1
10. Pineapple/nanas	-	-	-	-	6 (100%)	6
11. Rambutan/rambutan	-	-	-	-	4 (100%)	4
12. Sago/sagu	-	-	-	-	2 (100%)	2
13. Snake fruit/salak	-	-	-	-	1 (100%)	1
14. Sweet-melon/melon	-	-	-	-	3 (100%)	3
15. Water spinach/kangkong	-	-	-	1 (100%)	-	1
D. Total price of commodity (millions IDR/ha/year)	< 1	1 - 5	6 - 10	11 - 20	> 20	Total
1. Banana/pisang	-	-	-	-	5 (100%)	5
2. Bitter gourd/pare	-	-	-	-	1 (100%)	1
3. Candlenut/kemiri	-	-	-	-	1 (100%)	1
4. Durian/durian	-	-	-	-	3 (100%)	3
5. Dragon fruit/buah naga	-	-	-	-	2 (100%)	2
6. Illipenut/tengkawang	-	-	-	-	4 (100%)	4
7. Kelakai edible fern/kelakai	-	-	-	-	3 (100%)	3
8. Liberica coffee/kopi liberika	-	-	-	-	1 (100%)	1
9. Mangosteen/manggis	-	-	-	-	1 (100%)	1
10. Pineapple/nanas	-	-	-	-	6 (100%)	6
11. Rambutan/rambutan	-	-	-	-	4 (100%)	4
12. Sago/sagu	-	-	-	-	2 (100%)	2
13. Snake fruit/salak	-	-	-	-	1 (100%)	1
14. Sweet-melon/melon	-	-	-	-	3 (100%)	3
15. Water spinach/kangkong	-	-	-	-	1 (100%)	1

E.	Total production cost of commodity (millions IDR/ha/year)	< 1	1 - 5	6 - 10	11 - 20	> 20	Total
1.	Banana/pisang	-	-	-	5 (100%)	-	5
2.	Bitter gourd/pare	-	-	-	1 (100%)	-	1
3.	Candlenut/kemiri	-	-	-	1 (100%)	-	1
4.	Durian/durian	-	-	-	3 (100%)	-	3
5.	Dragon fruit/buah naga	-	-	-	-	2 (100%)	2
6.	Illipenut/tengkawang	-	4 (100%)	-	-	-	4
7.	Kelakai edible fern/kelakai	-	-	3 (100%)	-	-	3
8.	Liberica coffee/kopi liberika	-	1 (100%)	-	-	-	1
9.	Mangosteen/manggis	-	-	1 (100%)	-	-	1
10.	Pineapple/nanas	-	-	4 (67%)	2 (33%)	-	6
11.	Rambutan/rambutan	-	-	-	4 (100%)	-	4
12.	Sago/sagu	-	-	2 (100%)	-	-	2
13.	Snake fruit/salak	-	-	1 (100%)	-	-	1
14.	Sweet-melon/melon	-	-	-	-	3 (100%)	3
15.	Water spinach/kangkong	-	-	1 (100%)	-	-	1

F. Type of the highest cost in the production cost:
1. *Seedlings*
2. *Fertilisers*
3. *Pesticides & herbicides*
4. *Water supply/irrigation & water quality*
5. *Farming tools*
6. *Labour(s)*
7. *Transportation of commodities*
8. *Don't know*

		a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*Total*
1.	Banana/pisang	-	1 (20%)	1 (20%)	1 (20%)	1 (20%)	-	1 (20%)	-	5
2.	Bitter gourd/pare	-	1 (100%)	-	-	-	-	-	-	1
3.	Candlenut/kemiri	-	1 (100%)	-	-	-	-	-	-	1
4.	Durian/durian	1 (33%)	1 (33%)	-	-	1 (33%)	-	-	-	3
5.	Dragon fruit/buah naga	1 (50%)	1 (50%)	-	-	-	-	-	-	2
6.	Illipenut/tengkawang	-	2 (50%)	1 (25%)	-	1 (25%)	-	-	-	4
7.	Kelakai edible fern/kelakai	-	-	-	-	-	-	3 (100%)	-	3
8.	Liberica coffee/kopi liberika	1 (100%)	-	-	-	-	-	-	-	1
9.	Mangosteen/manggis	-	-	1 (100%)	-	-	-	-	-	1
10.	Pineapple/nanas	-	3 (50%)	2 (33%)	-	1 (17%)	-	-	-	6

11.	Rambutan/rambutan	1 (25%)	1 (25%)	1 (25%)	-	-	1 (25%)	-	-	4
12.	Sago/sagu	-	-	-	-	-	1 (50%)	1 (50%)	-	2
13.	Snake fruit/salak	-	1 (100%)	-	-	-	-	-	-	1
14.	Sweet-melon/melon	-	2 (67%)	1 (33%)	-	-	-	-	-	3
15.	Water spinach/kangkong	-	-	-	1 (100%)	-	-	-	-	1
G.	*Total benefit of commodity (millions IDR/ha/year)*	< 1	1 - 5		6 - 10		11 - 20		> 20	Total
1.	Banana/pisang	-	-		-		-		5 (100%)	5
2.	Bitter gourd/pare	-	-		-		-		1 (100%)	1
3.	Candlenut/kemiri	-	-		-		-		1 (100%)	1
4.	Durian/durian	-	-		-		-		3 (100%)	3
5.	Dragon fruit/buah naga	-	-		-		-		2 (100%)	2
6.	Illipenut/tengkawang	-	-		-		-		4 (100%)	4
7.	Kelakai edible fern/kelakai	-	-		-		-		3 (100%)	3
8.	Liberica coffee/kopi liberika	-	-		-		-		1 (100%)	1
9.	Mangosteen/manggis	-	-		-		-		1 (100%)	1
10.	Pineapple/nanas	-	-		-		-		6 (100%)	6
11.	Rambutan/rambutan	-	-		-		-		4 (100%)	4
12.	Sago/sagu	-	-		-		-		2 (100%)	2
13.	Snake fruit/salak	-	-		-		-		1 (100%)	1
14.	Sweet-melon/melon	-	-		-		-		3 (100%)	3
15.	Water spinach/kangkong	-	-		-		-		1 (100%)	1
H.	*The ease of obtaining seedlings*	Easy	Difficult	Reason						Total
1.	Banana/pisang	5 (100%)	-	Self-seedlings.						5
2.	Bitter gourd/pare	1 (100%)	-	Self-seedlings.						1
3.	Candlenut/kemiri	-	1 (100%)	Should buy the high quality of seedlings.						1
4.	Durian/durian	2 (67%)	1 (33%)	Self-seedlings or buy the high quality of seedlings.						3
5.	Dragon fruit/buah naga	-	2 (100%)	Should buy the high quality of seedlings.						2
6.	Illipenut/tengkawang	4 (100%)	-	Self-seedlings.						4
7.	Kelakai edible fern/kelakai	3 (100%)	-	Wildly grown.						3
8.	Liberica coffee/kopi liberika	-	1 (100%)	Should buy the high quality of seedlings.						1
9.	Mangosteen/manggis	1 (100%)	-	Self-seedlings.						1
10.	Pineapple/nanas	5 (83%)	1 (17%)	Self-seedlings or buy the high quality of seedlings.						6
11.	Rambutan/rambutan	3 (75%)	1 (25%)	Self-seedlings or buy the high quality of seedlings.						4

12.	Sago/sagu	2 (100%)	-	Wildly grown.	2
13.	Snake fruit/salak	1 (100%)	-	Self-seedlings.	1
14.	Sweet-melon/melon	3 (100%)	-	Self-seedlings.	3
15.	Water spinach/kangkong	1 (100%)	-	Self-seedlings.	1

I.	*The ease of maintaining and harvesting*	Easy	Difficult	Reason	Total
1.	Banana/pisang	4 (80%)	1 (20%)	Easy to harvest manually; difficult due to pest & weeds.	5
2.	Bitter gourd/pare	1 (100%)	-	Easy to harvest manually.	1
3.	Candlenut/kemiri	1 (100%)	-	Easy to harvest manually.	1
4.	Durian/durian	1 (33%)	2 (67%)	Difficult to reach fruits with the manual technique (need tools and labours).	3
5.	Dragon fruit/buah naga	2 (100%)	-	Easy to harvest manually.	2
6.	Illipenut/tengkawang	3 (75%)	1 (25%)	Easy to harvest manually; only can be harvested once per 4 years.	4
7.	Kelakai edible fern/kelakai	2 (67%)	1 (33%)	Easy to harvest manually; cannot be stored (only fresh product).	3
8.	Liberica coffee/kopi liberika	1 (100%)	-	Easy to harvest manually.	1
9.	Mangosteen/manggis	1 (100%)	-	Easy to harvest manually.	1
10.	Pineapple/nanas	6 (100%)	-	Easy to harvest manually.	6
11.	Rambutan/rambutan	3 (75%)	1 (25%)	Easy to harvest manually; need tools.	4
12.	Sago/sagu	-	2 (100%)	Difficult to harvest manually; long and laborious starch extraction process.	2
13.	Snake fruit/salak	1 (100%)	-	Easy to harvest manually.	1
14.	Sweet-melon/melon	3 (100%)	-	Easy to harvest manually.	3
15.	Water spinach/kangkong	1 (100%)	-	Easy to harvest manually.	1

J. Number of locations for directly marketing of product in the Village scale:

a. None, only for self & family-consumption
b. Only in own village
c. 1 other village
d. 2 other villages
e. 3 other villages
f. ≥ 3 other villages

		a	b	c	d	e	f	Total
1.	Banana/pisang (fruit)	-	-	2 (40%)	-	-	3 (60%)	5
2.	Bitter gourd/pare	-	-	-	-	-	1 (100%)	1
3.	Candlenut/kemiri	-	-	-	1 (100%)	-	-	1
4.	Durian/durian	-	-	1 (33%)	-	-	2 (67%)	3
5.	Dragon fruit/buah naga	-	-	1 (50%)	-	-	1 (50%)	2

6.	Illipenut/tengkawang	-	-	3 (75%)	-	-	1 (25%)	4
7.	Kelakai edible fern/kelakai	1 (33%)	-	-	-	-	2 (67%)	3
8.	Liberica coffee/kopi liberika	-	-	-	1 (100%)	-	-	1
9.	Mangosteen/manggis	-	-	-	-	-	1 (100%)	1
10.	Pineapple/nanas	-	-	3 (50%)	-	-	3 (50%)	6
11.	Rambutan/rambutan	-	-	1 (25%)	-	-	3 (75%)	4
12.	Sago/sagu	1 (50%)	-	-	-	-	1 (50%)	2
13.	Snake fruit/salak	-	-	-	-	-	1 (100%)	1
14.	Sweet-melon/melon	-	1 (33%)	-	-	-	2 (67%)	3
15.	Water spinach/kangkong	-	-	-	-	-	1 (100%)	1

K. Number of locations for directly marketing of product in the Provincial scale:

a. None
b. 1 other regency/city
c. 2 other regencies
d. 3 other regencies
e. ≥ 3 other regencies

		a	b	c	d	e	Total
1.	Banana/pisang (fruit)	-	-	1 (20%)	-	4 (80%)	5
2.	Bitter gourd/pare	-	-	1 (100%)	-	-	1
3.	Candlenut/kemiri	-	-	1 (100%)	-	-	1
4.	Durian/durian	-	-	1 (33%)	-	2 (67%)	3
5.	Dragon fruit/buah naga	-	-	1 (50%)	-	1 (50%)	2
6.	Illipenut/tengkawang	-	-	4 (100%)	-	-	4
7.	Kelakai edible fern/kelakai	3 (100%)	-	-	-	-	3
8.	Liberica coffee/kopi liberika	-	-	1 (100%)	-	-	1
9.	Mangosteen/manggis	-	-	-	-	1 (100%)	1
10.	Pineapple/nanas	-	-	-	-	6 (100%)	6
11.	Rambutan/rambutan	-	-	2 (50%)	-	2 (50%)	4
12.	Sago/sagu	-	-	2 (100%)	-	-	2
13.	Snake fruit/salak	-	-	1 (100%)	-	-	1
14.	Sweet-melon/melon	-	-	-	-	3 (100%)	3
15.	Water spinach/kangkong	-	-	1 (100%)	-	-	1

L. Number of locations for directly marketing of product in the National scale:

a. None
b. 1 other province
c. 2 other provinces
d. 3 other provinces
e. ≥ 3 other provinces

		a	b	c	d	e	Total
1.	Banana/pisang (fruit)	-	4 (80%)	1 (20%)	-	-	5
2.	Bitter gourd/pare	1 (100%)	-	-	-	-	1
3.	Candlenut/kemiri	1 (100%)	-	-	-	-	1
4.	Durian/durian	-	3 (100%)	-	-	-	3
5.	Dragon fruit/buah naga	-	2 (100%)	-	-	-	2
6.	Illipenut/tengkawang	-	4 (100%)	-	-	-	4
7.	Kelakai edible fern/kelakai	3 (100%)	-	-	-	-	3
8.	Liberica coffee/kopi liberika	-	1 (100%)	-	-	-	1
9.	Mangosteen/manggis	-	1 (100%)	-	-	-	1
10.	Pineapple/nanas	-	5 (83%)	1 (17%)	-	-	6
11.	Rambutan/rambutan	-	4 (100%)	-	-	-	4
12.	Sago/sagu	-	2 (100%)	-	-	-	2
13.	Snake fruit/salak	-	1 (100%)	-	-	-	1
14.	Sweet-melon/melon	-	1 (33%)	-	2 (67%)	-	3
15.	Water spinach/kangkong	1 (100%)	-	-	-	-	1

M. Number of locations for directly marketing of product in the International scale (export):

a. None
b. 1 other country
c. 2 other countries
d. 3 other countries
e. ≥ 3 other countries

		a	b	c	d	e	Total
1.	Banana/pisang (fruit)	-	-	-	-	-	-
2.	Bitter gourd/pare	-	-	-	-	-	-
3.	Candlenut/kemiri	-	-	-	-	-	-
4.	Durian/durian	-	-	-	-	-	-
5.	Dragon fruit/buah naga	-	-	-	-	-	-
6.	Illipenut/tengkawang	-	-	-	-	-	-

7.	Kelakai edible fern/kelakai	-	-	-	-	-	-
8.	Liberica coffee/kopi liberika	-	-	-	-	-	-
9.	Mangosteen/manggis	-	-	-	-	-	-
10.	Pineapple/nanas	-	-	-	-	-	-
11.	Rambutan/rambutan	-	-	-	-	-	-
12.	Sago/sagu	-	-	-	-	-	-
13.	Snake fruit/salak	-	-	-	-	-	-
14.	Sweet-melon/melon	-	-	-	-	-	-
15.	Water spinach/kangkong	-	-	-	-	-	-

N. What should be improved:

a. Seedling technique
b. Maintaining & harvesting technique
c. Post-harvest processing technology
d. Product quality (certification product)
e. Policy and regulation related to trading of product

		a	b	c	d	e	Total
1.	Banana/pisang (fruit)	-	1 (100%)	1 (100%)	3 (100%)	-	5
2.	Bitter gourd/pare	-	-	-	1 (100%)	-	1
3.	Candlenut/kemiri	-	-	-	1 (100%)	-	1
4.	Durian/durian	1 (33%)	-	1 (33%)	1 (33%)	-	3
5.	Dragon fruit/buah naga	-	-	1 (50%)	1 (50%)	-	2
6.	Illipenut/tengkawang	-	-	1 (25%)	-	3 (75%)	4
7.	Kelakai edible fern/kelakai	-	-	3 (100%)	-	-	3
8.	Liberica coffee/kopi liberika	1 (100%)	-	-	-	-	1
9.	Mangosteen/manggis	-	-	-	3 (50%)	-	1
10.	Pineapple/nanas	-	-	3 (50%)	2 (50%)	-	6
11.	Rambutan/rambutan	1 (25%)	-	1 (25%)	-	-	4
12.	Sago/sagu	-	1 (50%)	1 (50%)	-	-	2
13.	Snake fruit/salak	-	-	1 (100%)	2 (67%)	-	1
14.	Sweet-melon/melon	-	-	1 (33%)	1 (100%)	-	3
15.	Water spinach/kangkong	-	1 (100%)	-	-	-	1

Appendix 5.2. The ecological attributes of various paludiculture crops in Central Kalimantan

Product	Crop	Life form and life span	Assumed water table depth or WTD (m)	Density of the plants per hectare (minimum-maximum individual/ha)	Tolerated Soil pH	Tolerated peat depth	Tolerant to inundation	Propagation	Companion species	Sources
Fruit	Pineapple/nanas (*Ananas comosus*)	Herb; perennial	0.3 – 0.6	20,000 – 40,000 (21,500)	4.5 – 6.5	Shallow - medium (<150cm)	No (die after 1 day inundation)	Crowns, slips, suckers.	Jackfruit/ nangka/ cempedak (*Artocarpus spp.*), rambutan, cashew, as a ground cover in a mass planting: areca palm, oil palm, oconuts, etc.	PROSEA 2018; Ecocrop FAO 2018; World Agroforestry ICRAF 2018; Ken Fern 2018; Noor et al. 2015; Najiyati et al. 2005; Chotimah 2002.
	Sweet melon/melon (*Cucumis melo*)	Herb/vine; annual	0.3 – 0.6	12,000 – 16,000	5 - 8.7	Shallow - medium (<150cm)	No (die after 1 day inundation).	Seed	Corn, eggplant, lemongrass.	PROSEA 2018; Ecocrop FAO 2018; Ken Fern 2018; Noor et al. 2015; Najiyati et al. 2005.
	Liberica coffee/ kopi liberika (*Coffea liberica*)	Tree/shrub; perennial	0.5 – 0.75	800 – 1,000 (880)	4.3 – 6.5	Shallow - medium (<150cm)	No (die after 10 days inundation)	Seed, grafted tree.	Bananas, areca palm, coconut, oil palm, ginger, gourds, chili peppers, long beans, etc.	PROSEA 2018; Ecocrop FAO 2018; World Agroforestry ICRAF 2018; Ken Fern 2018.
	Durian (*Durio zibethinus*)	Tree; perennial	0.3 – 0.7	156 – 160 70 - 100	4.3 – 7.5	Shallow - medium (<200cm)	No tolerant to a long time period of inundation; requires a lot of water after harvest.	Seed, grafted tree.	Rambutan, mangosteen, langsat/lanzon es, coffee, etc.	PROSEA 2018; Ecocrop FAO 2018; World Agroforestry ICRAF 2018; Ken Fern 2018; Giesen and Nirmala 2018; Noor et al. 2015.

Mangosteen/manggis (*Garcinia mangostana*)	Tree; perennial	0.3 – 0.7	100 – 125 100	4.3 – 7.5	Shallow - medium-deep (<300cm)	Yes	Seed	Banana, papaya, durian, rambutan, coconuts, langsat/ lanzones, etc.	PROSEA 2018; Ecocrop FAO 2018; World Agroforestry ICRAF 2018; Ken Fern 2018; Giesen and Nirmala 2018; Noor et al. 2015; Wösten et al. 2008.
Dragon fruit/buah naga (*Hylocereus sp*.)	Shrub/vine; perennial	0.3 – 0.6	730 – 1,100	5 – 7.5	Shallow - medium- (<200cm)	No (die after 4 days inundation)	Seed, stem cuttings.	Ananas, papaya, guava, longan, rambutan.	PROSEA 2018; Ecocrop FAO 2018; Ken Fern 2018.
Banana/pisang (*Musa paradisiaca*)	Herb; perennial	0.3 – 1.0	900 – 1,000	4.5 – 7.5	Shallow - medium-deep (<300cm)	Yes	Suckers, seed, offshoots from the base of the plant.	Coffee, oil palm, areca palm, coconut, etc.	PROSEA 2018; Ecocrop FAO 2018; Ken Fern 2018.
Rambutan (*Nephelium lappaceum*)	Tree; perennial	0.3 – 0.7	69 – 100 70 - 84	5.5 – 6.7	Shallow - medium (20-230cm)	No tolerant to a long time period of inundation.	Seed, grafted tree	Legumes (Canavalia, Crotalaria, Vigna), mangosteen, coconuts, mango, etc.	PROSEA 2018; Ecocrop FAO 2018; Ken Fern 2018; Giesen and Nirmala 2018; Noor et al. 2015; Wösten et al. 2008; Limin et al. 2007.
Snake fruit/salak (*Salacca/Eleiodoxa* spp.)	Shrub/tree; perennial	0.2 – 0.75	833 – 1,250	4.5 – 7.5	Shallow - medium (<200cm)	Yes	Seed, suckers division	Bitter bean/ petai, kelakai (edible swamp fern).	PROSEA 2018; Ecocrop FAO 2018; World Agroforestry ICRAF 2018; Ken Fern 2018; Noor et al. 2015; Najiyati et al. 2005.

Vegetable	Water spinach/ kangkong (*Ipomoea aquatica*)	Herb/vine; Short–lived perennial, sometimes annual	0 – 0.3	20,000 – 25,000	4.3 – 7.5	Shallow - medium - deep	Yes	Stem/ shoots cuttings/ plant fragment, seed.	Paddy, edible corm taro/talas (*Colocasia esculenta*).	PROSEA 2018; Ecocrop FAO 2018; Ken Fern 2018; Giesen and Nirmala 2018; Nasrul 2010; Najiyati et al. 2005; Chotimah 2002.
	Bitter gourd/pare (*Momordica charantia*)	Herb/vine; Short–lived perennial	0.3 – 0.6	11,000 – 40,000 4000 - 13.000	5 – 6.7	Shallow - medium (50-200cm)	No (dies after 4 days inundation)	Seed	Chili, eggplant, cucumber, lemongrass, etc.	PROSEA 2018; Ecocrop FAO 2018; Ken Fern 2018; Nasrul 2010; Palada and Chang 2003; Najiyati et al. 2005; Chotimah 2002.
	Edible swamp fern/ kelakai/midin (*Stenochlaena palustris*)	Herb/vine / fern; perennial	0 – 0.13	10,000 – 13,000	3.5 – 4	Shallow - medium- deep (50-200cm)	Yes	Spores, rhizome division.	As a groundcover in a mass planting of all type of perennial crops.	PROSEA 2018; Ecocrop FAO 2018; Ken Fern 2018; Giesen and Nirmala 2018; Nion et al. 2018; Tata and Susmianto 2016.
Starch	Sago palm/sagu/rumbia (*Metroxylon sagu*)	Tree; perennial	0 – 0.4	60 – 140 (124-136)	3.5 – 6.5	Shallow - medium- deep (<300cm)	Yes	Suckers, shoot, seed	Edible swamp ferns (e.g. kelakai), rattan, nypa palm (*Nypa fruticans*), illipe nut/ tengkawang, etc.	PROSEA 2018; Ecocrop FAO 2018; Ken Fern 2018; Giesen and Nirmala 2018; Tata and Susmianto 2016; Noor et al 2015; TECA (2015a); Biancalani and Avagyan 2014; Chotimah 2002.

Spices; Edible nut	Candlenut/kemiri (*Aleurites moluccana*)	Tree; perennial	0.5 – 0.7	100 – 150	5 – 8	Shallow - medium-deep (50-200cm)	No tolerant to a long time period of inundation.	Seed, cuttings, grafted tree.	Ananas, lemongrass, Malay apple/ jambu bol (*Syzygium malaccense*)	PROSEA 2018; Ecocrop FAO 2018; World Agroforestry ICRAF 2018; Giesen and Nirmala 2018; Krisnawati et al. 2011.
Edible oil & fats	Illipenut/tengkawang (*Shorea* spp.)	Tree; perennial	0 – 0.5	100 – 400	3.4 – 4	Shallow - medium-deep	Yes	Seed, wilding, stem/shoot cuttings.	Coffee, kelakai (edible swamp fern), galangal.	PROSEA 2018; Ecocrop FAO 2018; Ken Fern 2014; Giesen and Nirmala 2018; Winarni et al. 2017; Tata and Susmianto 2016; TECA (2015b); Bianca-lani and Avagyan 2014.

Appendix 5.3. The socio-economical attributes of various paludiculture crops in Central Kalimantan

Product Category	Crop	Rotation cycle	First harvesting	Harvest cycle	Productivity (ton/ha/year)	Market price (IDR/unit)	Investment cost for 25 years (IDR/ha)	Maintenance & Harvest cost for 25 years (IDR/ha)	Food products	Other uses	Domestic market (Local & National)	Potential international market (Regional & Global)	Sources
Fruit	Pineapple/ nanas *(Ananas comosus*)	2–3 years	9–12 months	7–12 month (3 times/28 months)	28 (15–40)	5000/fruit	84,224,000	106,522,000	Fresh/raw fruit, canning fruit, juice, jam, vinegar	Cattle feed, fibres (from leaves), enzyme bromelain (extract derivate from steam and fruit)	Regencies: Kapuas, East Kotawaringin, South Barito. Provinces: Lampung, North Sumatra, (West) Java.	South-East Asia Region: Singapore, Malaysia, Thailand. Global: China, Japan, Korea, Europe, USA, Middle East, Asia.	BRG 2019; PROSEA 2018; Ecocrop FAO 2018; BRG 2019; MoARI 2018; BPS 2018a, 2018b; BPS Central Kalimantan 2018a, 2018b; Ken Fern 2018; ; JICA 2017; Limin et al. 2017; Noor et al. 2014; survey data and analysis in this study.
	Sweet melon/ melon (*Cucumis melo*)	3–4 months	2 months	2-4 months (3 times/ year)	20 (11–30)	6000/kg	502,648,000	222,300,000	Fresh/raw fruit, canning fruit, juice, edible nut and oil (seed).	Medicinal herbal (root, leaves); seed oil for commercial cosmetic preparations (humectant, skir conditioner, etc.	Regencies: Palangka Raya (e.g. Kalampa-ngan village), West Kotawa-ringin, East Kotawaringin Provinces: Java (East Java, Central Java, Jakarta), South Kali-mantan, West Kalimantan.	South-East Asia Region: Malaysia, Singapore, Thailand Global: China, South Korea, Japan.	BRG 2019; PROSEA 2018; Ecocrop FAO 2018; Ken Fern 2018; MoARI 2018; BPS 2018a, 2018b; BRG 2019; BPS Central Kalimantan 2018a, 2018b; survey data and analysis in this study.
	Liberica coffee/ kopi liberika (*Coffea liberica*)	25–30 years	3–4 years	10–12 months (1–2 times/ year)	8 (2–10)	10,000/kg (dried-peeled-coffee beans) 5000/kg (coffee berries)	26,835,000	88,175,000	Coffee powder	Medicinal uses (leaves)	Regencies: Pulang Pisau, West Kotawa-ringin, East Kotawaringin, Murung Raya. Provinces: Jambi, Lampung, South Sumatra, Jakarta, Central Java.	South-East Asia Region: Malaysia, Singapore. Global: Germany, USA, Japan.	BRG 2019; PROSEA 2018; Ecocrop FAO 2018; Ken Fern 2018; BPS 2018a, 2018b; MoARI 2018; BRG 2018; BPS Central Kalimantan 2018a, 2018b; JICA 2017; survey data and analysis in this study.
	Durian (*Durio zibethinus*)	25–30 years	7 years	9–12 months (once/year)	16 (12–18)	8000/kg	67,500,000	296,661,250	Fresh/raw fruit, juice, cake, ice	Wood, fuel (dried rind of the fruit),	Regencies: Katingan, Pulang Pisau,	South-East Asia Region: Malaysia, Singapore.	BRG 2019; PROSEA 2018; Ecocrop FAO 2018;

		(4–5 years for grafted trees)						cream, boiled & roasted seed	medicinal uses (fruit, root, leaves, flower petals)	Kapuas East Barito. Murung Raya. Provinces: Java, East Kalimantan, West Kalimantan, South Kalimantan.	Global: China, Japan, Canada, Saudi Arabia, Uni Arab Emirates, Netherlands, Australia.	Ken Fern 2018; BPS 2018a, 2018b; MoARI 2018; BRG 2019; BPS Central Kalimantan 2018a, 2018b; survey data and analysis in this study.
Mangosteen/ manggis (*Garcinia mangostana*)	25 – 30 years	6 (6–8) years	12 months (once/year)	19 (16–20)	8000/kg	15,228,000	219,560,000	Fresh/raw fruit	medicinal uses (rind of the fruit, leaves)	Regencies: Kapuas (e.g. Sei Dusun village), Murung Raya, Pulang Pisau, North Barito, South Barito. Provinces: Bali, Java, West Sumatra.	South-East Asia Region: Thailand, Malaysia, Singapore. Global: China, Taiwan, Hongkong, Saudi Arabia, Uni Arab Emirates, Europe.	BRG 2019; PROSEA 2018; Ecocrop FAO 2018; Ken Fern 2018; BPS 2018a, 2018b; MoARI 2018; BPS Central Kalimantan 2018a, 2018b; Wösten et al. 2008; survey data and analysis in this study.
Dragon fruit/buah naga (*Hylocereus undatus*)	20 years	18-24 months	5–7 months (twice/year)	18 (10–20)	7000/kg	36,057,036	1,823,897,653	Fresh/raw fruit pulp, juice, jam, syrup, wine, ice cream, yogurt, jelly, sherbet, candy, preserve, pastries,	Medicinal uses (fruit), raw material for food coloring agent, flower used in soup or tea, ornamental flowers, fragrant.	Regencies: Pulang Pisau, Palangka Raya, West Kotawaringin. Provinces: East Java	South-East Asia Region: Singapore, Malaysia Global: China, Germany.	BRG 2019; PROSEA 2018; Ecocrop FAO 2018; Ken Fern 2018; BPS 2018a, 2018b; MoARI 2018; BPS Central Kalimantan 2018a, 2018b; survey data and analysis in this study.
Banana/ pisang (*Musa paradisiaca*)	10 - 15 months (the pseudo-stem dies after fruiting, rhizome/ off-shoots/ corms can live >15 years)	12 (9-12) months	5–7 months (twice/year)	17 (14–24)	5000/kg	18,443,100	303,527,000	Fresh/raw fruit, flower and tender core of trunk as vegetables.	Cattle feed (entire plant), medicinal uses (leaves, root), fibre (steam) for textile &paper.	Regencies: Katingan, Seruyan, Lamandau, East Kotawaringin, West Kotawaringin. Provinces: Lampung, North Sumatra, West Java.	South-East Asia Region: Malaysia Global: China, Japan, Uni Arab Emirates, Saudi Arabia,	BRG 2019; PROSEA 2018; Ecocrop FAO 2018; Ken Fern 2018; BPS 2018a, 2018b; MoARI 2018; BRG 2019; BPS Central Kalimantan 2018a, 2018b; survey data and analysis in this study.

	Rambutan (*Nephelium lappaceum*)	15 - 30 years	5 (2 years for grafted trees – 7) years	6–12 months (1–2 times/ year)	14 (12–20)	8000/kg	10,570,000	316,599,950	Fresh/raw fruit, canning fruit, jams, jellies.	Medicinal uses (green fruit, shell of the fruit, root, leaves, bark,	Regencies: Kapuas, Kotawaringin Barat, Pulang Pisau. Provinces: Java, East Kalimantan.	South-East Asia Region: Malaysia Global: China, Taiwan, Europe, Uni Arab Emirates, Saudi Arabia.	BRG 2019; PROSEA 2018; Ecocrop FAO 2018; BPS 2018a, 2018b; Ken Fern 2018; MoARI 2018; BRG 2019; BPS Central Kalimantan 2018a, 2018b; Wösten et al. 2008; Limin et al. 2007; survey data and analysis in this study.
	Snake fruit/salak (*Salacca/ Eleiodoxa* spp.)	20 - 50 years	4 (3–4) years	5–7 months (1–2 times/ year)	11 (8–13)	15000/kg	10,570,000	247,625,000	Fresh/raw fruit, canning fruit, crisp, wine, candied & pickled fruit.	Boiled & roasted seed.	Regencies: Kapuas, East Kotawaringin, Pulang Pisau, Lamandau, West Kotawaringin. Provinces: Java.	South-East Asia Region: Cambodia, Malaysia, Thailand, Singapore, Timor Leste, Global: Hong Kong, China, Uni Arab Emirates, Qatar, Saudi Arabia, UK, Netherlands, Germany.	BRG 2019; PROSEA 2018; Ecocrop FAO 2018; Ken Fern 2018; BPS 2018a, 2018b; MoARI 2018; BRG 2019; BPS Central Kalimantan 2018a, 2018b; Noor et al 2014; Limin et al. 2007; survey data and analysis in this study.
Vegetable	Water spinach/ kangkong (*Ipomoea aquatica*)	3 years	28–40 days	21–70 days (4 times/ year)	8 (3–10)	15000/kg	8,490,000	135,275,000	Fresh/raw vegetable (young shoot, stem & leaves).	Cattle feed/ livestock fodder (stem & leaves), medicinal herbal	Regencies: Kapuas, West Kotawaringin Barat, Lamandau. Provinces: Java, South Kalimantan.	South-East Asia Region: Malaysia, Thailand, Vietnam. Global: China, Europe, Japan	BRG 2019; PROSEA 2018; Ecocrop FAO 2018; Ken Fern 2018; BPS 2018a, 2018b; MoARI 2018; BRG 2019; BPS Central Kalimantan 2018a, 2018b; Najiyati et al. 2005; Chotimah 2002; survey data and analysis in this study.
	Bitter gourd/pare (*Momordica charantia*)	1 year	50–90 days	3-4 days (12-16 times/ year)	15 (13–19)	5000/kg	19,992,500	354,575,000	Fresh/raw vegetable (fruit & leaves)	Medicinal herbal	Regencies: Kapuas, Katingan, East Barito. Provinces: Java, South Kalimantan.	South-East Asia Region: Malaysia, Thailand, Philippine. Global: Hong Kong, China, Taiwan, Japan, Europe.	BRG 2019; PROSEA 2018; Ecocrop FAO 2018; BPS 2018a; BPS 2018b; BRG 2019; BPS Central Kalimantan 2018a, 2018b; Palada and Chang 2003; Chotimah 2002;

													survey data and analysis in this study.
	Edible swamp fern/ kelakai/ midin (*Stenochlaena palustris*)	years but will die after 3 days without inundation.	4 months	6-14 days	5 (1–5)	15,000/kg	2,240,000	152,800,000	Fresh/raw vegetable (young shoot & leaves); kelakai chips.	Medicinal herbal, raw materials for biomass briquettes and composting.	Regencies: Kapuas, Palangka Raya, Gunung Mas, East Barito, Katingan, North Barito. Provinces: South Kalimantan, East Kalimantan, West Kalimantan, Java.	South-East Asia Region: Thailand, Malaysia. Global: Japan.	BRG 2019; PROSEA 2018; Ecocrop FAO 2018; Ken Fern 2018; Nion et al. 2018; Chai 2016; survey data and analysis in this study.
Starch	Sago palm/sagu/ rumbia (*Metroxylon sagu*)	11 - 23 years	8-12 years	18 months	40 (25–40)	5000/kg (starch)	11,970,000	154,010,000	Starch (from the pith of the steam), vegetable (young stems), sago cookie (bagea), sago pearls,	Bioethanol, bioplastic, textile, paper (stark and cortex of trunk), wood, leaves for rooftop, medicinal herb (pollen, tender leaves, bark, seeds), animal feed (food pellet),	Regencies: Kapuas (Budi Mufakat, Sei Dusun village), Pulang Pisau Provinces: South Kalimantan. Riau, Papua, Maluku, Jambi, West Java, West Kalimantan	South-East Asia Region: Malaysia, Philippines. Global: Japan, Korea.	BRG 2019; PROSEA 2018; Ecocrop FAO 2018; Ken Fern 2018; BPS 2018a, 2018b; MoARI 2018; BPS Central Kalimantan 2018a, 2018b; Nishimura 2018; Giesen and Nirmala 2018; JICA 2017; Tata and Susmi-anto 2016; TECA 2015a; survey data and analysis in this study.
Spices; Edible nut	Candlenut/ kemiri (*Aleurites moluccana*)	25-40 years	5 years	6–12 months (twice/year)	16 (4-20)	20,000/kg	83,805,000	252,891,167	Spices, edible nut	seed oil/ candlenut oil (non-edible oil) for shampoo, soap, candle, skin care products, paint & varnish oil; fruit, medicinal herbal (bark, pulped kernel, leaves).	Regencies: Kapuas (Buntoi village), Seruyan, Lamandau, Palangka Raya, North Barito, South Barito, East Barito. Provinces: Java, South Kalimantan, East Kalimantan, West Kalimantan.	South-East Asia Region: Singapore, Malaysia. Global: Saudi Arabia, USA Netherlands.	BRG 2019; PROSEA 2018; Ecocrop FAO 2018; Ken Fern 2018; BPS 2018a, 2018b; MoARI 2018; BPS Central Kalimantan 2018a, 2018b; Krisnawati et al 2011; survey data and analysis in this study.

Edible oil & fats	Illipenut/ tengkawang (*Shorea* spp.)	18-90 years	8 years	once /4 years	20 (9–40)	8000/kg	17,954,545	42,500,000	Edible oil and nut from seed (similar uses to Cacao butter)	Medicinal uses: illipenut oil/fat for skin, for making soap, candles, polishes and cosmetics. Tree for timber. Fruit for animal feed.	Regencies: Kapuas, Katingan, West Kotawaringin, Gunung Mas, East Barito. Provinces: Java, South Kalimantan, East Kalimantan, West Kalimantan.	South-East Asia Region: Malaysia, Thailand, Singapore. Global: India, Japan, Europe (Italy & the Netherlands).	BRG 2019; PROSEA 2018; Ecocrop FAO 2018; Ken Fern 2018; Giesen and Nirmala 2018; JICA 2017; Tata and Susmi-anto 2016; TECA 2015b; survey data and analysis in this study.

Appendix 5.4 The opportunities and barriers of cultivation of 15 paludiculture food crops in Central Kalimantan peatlands.

Type of paludiculture food crop	Opportunities	Bottlenecks
Mangosteen/manggis (*Garcinia mangostana*)	i) Can be cultivated in both partly and/or fully rewetting peatland areas (shallow to deep peat), tolerant to inundation. ii) Self-seedling by farmers. iii) Easy to be maintained and harvested manually by farmers. iv) Possible to be cultivated with intercrop/ companion species (particularly in the early stage) such as banana, pineapple or other seasonal crops. v) Already available in the community-based system and as a long continued heritage. vi) Scaling-up for a plantation-based system maybe possible. vii) Other potential products are for medicinal uses (extractions of peels and leaves).	i) Long time period is needed before the first harvest. ii) High cost on pesticide and herbicide. iii) Product quality (certification product) particularly for exports of the fruits. iv) Farmers are lacking in post-harvest handling.
Sago/sagu (*Metroxylon sagu*)	i) Can be cultivated in both partly and fully rewetting peatland areas (shallow to deep peat), tolerant to inundation. ii) Self-seedling by farmers or wildly-grown. iii) Possible to be cultivated with intercrop/ companion species (particularly in the early stage) such as kelakai edible fern, rattan, illipenut, etc. iv) Already available in the community-based system. v) Scaling-up for a plantation-based system maybe possible. vi) Other potential products are for bioethanol, bioplastic, textile, paper, animal feed (food pellet), and growing media for *Volvariella volvacea* mushrooms and breeding *Rhynchophorus* larvae which is a good source of protein.	i) Long time period is needed before the first harvest. ii) Long and laborious starch extraction process. iii) Lack of facilities for post-harvest handling.
Water spinach/ kangkong (*Ipomoea aquatica*)	i) Can be cultivated in fully rewetting peatland areas (shallow to deep peat), tolerant to inundation. ii) Self-seedling by farmers iii) Easy to be maintained and harvested manually by farmers. iv) Short–time period until the first harvest. v) Already available in the community-based system. vi) Possible as a companion species for paddy, edible corn taro/talas. vii) Other potential products are for cattle feed/ livestock fodder (stem & leaves).	i) Water supply/irrigation and water quality control is fully required. ii) Farmers do not have facilities for maintaining and harvesting products. iii) Not recommended for scaling-up based on a plantation-based system due to economic risks for infrastructure.
Kelakai edible fern (*Stenochlaena palustris*)	i) Can be cultivated without requiring any agricultural treatment (off-farm) in both partly and/or fully rewetting peatland areas (shallow to deep peat), tolerant to inundation. ii) Survive well in critical lands. iii) A wild-grown species and/or self-seedling by farmers. iv) Easy to be maintain and harvested manually by farmers. v) Short–time period until the first harvest. vi) Possible as the intercrop or a ground cover in mass planting for all type of perennial crops (e.g. durian, rambutan, mangosteen, etc.). vii) Other potential products are for medicinal uses (extractions of leaves), food pellets, raw materials for biomass briquettes and composting.	i) Mostly considered as weeds by the farmers in their farming fields. ii) Short shelf life so that difficult to export as the raw product/vegetable. iii) Lack of post-harvest handling. iv) Not recommended for scaling-up based on a plantation-based system due to limited market access and economic risks for infrastructure.

Dragon fruit/ buah naga (*Hylocereus undatus*)	i) Currently having high market price and demands both for domestic and export. ii) Easy to maintain and harvest manually by farmers. iii) Short–time period until the first harvest. iv) Already available in the community-based system. v) Possible to be cultivated with intercrop/companion species such as pineapple, banana, rambutan, etc. vi) Other potential products are for food colouring agent, tea (flowers), ornamental flower fragrant.	i) Only cultivated in partly rewetting peatland areas (shallow and medium peat), warrant strict water management or limited drainage. ii) Low tolerant to inundation (die after 10 days inundation). iii) Lack of access to seedling so that farmers should buy the high quality of seedlings. iv) Product quality (certification product) particularly for exports of the fruits. v) Farmers are lacking in post-harvest technology. vi) High cost on fertilisers, pesticide and herbicide. vii) Not recommended for scaling-up based on a plantation-based system due to economic risks for infrastructure.
Pineapple/nanas (*Ananas comosus*)	i) Self-seedling by farmers. ii) Easy to maintain and harvest manually by farmers. iii) Short–time period until the first harvest. iv) Already available in the community-based system. v) Possible as a ground cover in mass planting of perennial crops (e.g. rambutan, dragon fruit, candlenut, etc.). vi) Other potential products are for cattle feed, fibres for textile (leaves), and enzyme bromelain (steam and fruit).	i) Only cultivated in partly rewetting peatland areas (shallow and medium peat), warrant strict water management or limited drainage. ii) No tolerant to inundation. iii) Product quality (certification product) particularly for exports of fruits. iv) High cost on fertilisers, pesticide and herbicide. v) Lack of post-harvest technology. vi) Not recommended for scaling-up based on a plantation-based system due to economic risks for infrastructure.
Banana/pisang (*Musa paradisiaca*)	i) Can be cultivated in both partly and fully rewetting peatland areas (shallow to deep peat), tolerant to inundation. ii) Self-seedling by farmers. iii) Easy to maintain and harvest manually by farmers. iv) Short–time period until the first harvest. v) Possible as the intercrop/companion species particularly in the early stage of all perennial crops. vi) Already available in the community-based system. vii) Other potential products are for cattle feed, fibres for textile and paper (steam), and medicinal uses (leaves and root).	i) Product quality (certification product) particularly for exports of the fruits. ii) Lack of post-harvest technology. iii) High cost on fertilisers, pesticide and herbicide. iv) Farmers are lacking in facilities for transporting products. v) Scaling-up for a plantation-based system maybe possible but not recommended.

Illipenut/tengkawang (*Shorea* spp.)	i) Can be cultivated in both partly and fully rewetting peatland areas (shallow to deep peat), tolerant to inundation. ii) Self-seedling by farmers. iii) Easy to maintain and harvest manually by farmers. iv) Possible to be cultivated with intercrop/companion species (particularly in the early stage) such as banana, kelakai edible fern, liberica coffee, pineapple, etc. v) Already available in the community-based system, and as a long continued heritage. vi) Scaling-up for a plantation-based system is recommended. vii) Other potential products are for animal feed (fruit), making soap, candles, polishes and cosmetic (from illipenut oil/fat), and timber (tree).	i) Long time period is needed before the first harvest. ii) Only harvested once per 4 years. iii) Illipe-nut is included as one of prohibited commodities for exports. iv) Farmers are lacking in the facilities for producing illipenut-oil. v) Farmers have lack of post-harvest technology.
Sweet melon/melon (*Cucumis melo*)	i) Self-seedling by farmers. ii) Easy to maintain and harvest manually by farmers. iii) Short–time period until the first harvest. iv) Possible to be cultivated with intercrop/companion species such as lemongrass, eggplant, corn, etc. v) Already available in the community-based system. vi) Other potential products are for cosmetic (seed oil), and medicinal herbal (root, leaves).	i) Only cultivated in partly rewetting peatland areas (shallow and medium peat), warrant strict water management or limited drainage. ii) No tolerant to inundation. iii) Product quality (certification product) particularly for exports of fruits. iv) High cost on fertilisers, pesticide and herbicide. v) Lack of post-harvest technology. vi) Not recommended for scaling-up based on a plantation-based system due to economic risks for infrastructure.
Rambutan (*Nephelium lappaceum*)	i) Self-seedling by farmers. ii) Easy to be maintained and harvested manually by farmers iii) Already available in the community-based system, and as a long continued heritage. iv) Scaling-up for a plantation-based system maybe possible. v) Possible to be cultivated with intercrop/companion species (particularly in the early stage) such as legumes, banana, pineapple or mangosteen. vi) Other potential products are for medicinal uses (green fruit, shell of the fruit, root, leaves, bark).	i) Only cultivated in partly rewetting peatland areas (shallow and medium peat), warrant strict water management or limited drainage. ii) No tolerant to a long time period of inundation. iii) Long time period is needed before the first harvest. iv) Product quality (certification product) particularly for exports of fruits.
Snake fruit/salak (*Salacca/Eleiodoxa* spp.)	i) Can be cultivated in both partly and fully rewetting peatland areas (shallow and medium peat), tolerant to inundation. ii) Self-seedling by farmers. iii) Easy to maintain and harvest manually by farmers. iv) Possible to be cultivated with intercrop/companion species such as bitter bean/petai, kelakai edible fern, etc. v) Already available in the community-based system. vi) Scaling-up for a plantation-based system maybe possible. vii) Other potential products are boiled and roasted seeds.	i) Long time period is needed before the first harvest. ii) Product quality (certification product) particularly for exports of fruits. iii) High cost on fertilisers, pesticide and herbicide. iv) Farmers are lacking in post-harvest technology.

Candlenut/kemiri (*Aleurites moluccana*)	i) Easy to maintain and harvest manually by farmers. ii) Already available in the community-based system. iii) Scaling-up for a plantation-based system is recommended. iv) Possible to be cultivated with intercrop/companion species (in the early stage) such as banana, pineapple, lemongrass or other seasonal crops. v) Candlenuts are used as spices and edible nut. vi) Other potential products are seed oil/candlenut oil (non-edible oil) for shampoo, soap, candle, skin care product, paint and varnish oil.	i) Only cultivated in partly rewetting peatland areas (shallow and medium peat), warrant strict water management or limited drainage. ii) No tolerant to a long time period of inundation. iii) Lack of access to seedling so that farmers should buy the high quality of seedlings. iv) Long time period is needed before the first harvest. v) Product quality (certification product) particularly for exports. vi) High cost on fertilisers, pesticide and herbicide.
Bitter gourd/pare (*Momordica charantia*)	i) Self-seedling by farmers. ii) Easy to maintain and harvest manually by farmers. iii) Short–time period until the first harvest. iv) Possible to be cultivated with intercrop/companion species such as lemongrass, chili or eggplant. v) Already available in the community-based system. vi) Other potential products are for medicinal herbal (leaves).	i) Only cultivated in partly rewetting peatland areas (shallow and medium peat), warrant strict water management or limited drainage. ii) No tolerant to inundation (die after 4 days inundation). iii) Product quality (certification product) particularly for exports of fruits. iv) Not recommended for scaling-up based on a plantation-based system due to economic risks for infrastructure.
Durian (*Durio zibethinus*)	i) Self-seedling by farmers. ii) Already available in the community-based system, and as a long continued heritage. iii) Scaling-up for a plantation-based system maybe possible. iv) Possible to be cultivated with intercrop/companion species (particularly in the early stage) such as banana, pineapple, liberica coffee, kelakai edible fern. v) Other potential products are for medicinal uses (fruit, root, leaves) fuel (dried rind of the fruits).	i) Only cultivated in partly rewetting peatland areas (shallow and medium peat), warrant strict water management or limited drainage. ii) No tolerant to a long time period of inundation, require a lot of water after harvest. iii) Long time period is needed before the first harvest. iv) Lack of harvesting tools (difficult to harvest fruits with manual technique) v) Product quality (certification product) particularly for exports of fruits.
Liberica coffee/ kopi liberika (*Coffea liberica*)	i) Easy to maintain and harvest manually by farmers. ii) Already available in the community-based system. iii) Scaling-up for a plantation-based system maybe possible. iv) Possible to be cultivated with intercrop/companion species (particularly in the early stage) such as banana, pineapple, bitter gourd or kelakai edible fern. v) Other potential products are for medicinal uses (leaves).	i) Lack of access to seedling so that farmers should buy the high quality of seedlings. ii) Long time period is needed before the first harvest. iii) Only cultivated in partly rewetting peatland areas (shallow and medium peat), warrant strict water management or limited drainage. iv) No tolerant to inundation (die after 10 days inundation). v) Product quality (certification product) particularly for exports of coffee.

Appendix 5.5 The options to promote the use of 15 paludiculture food crops in Central Kalimantan peatlands.

Type of paludiculture food crop	**Options**
Mangosteen/manggis (*Garcinia mangostana*)	i) Scalable but need to support for farmers since a long time period is needed before the first harvest (of which most farmers cannot cover the costs). ii) Provide access to (free) seedlings which are resistant to pest and weeds and/or subsidies for fertilisers, pesticide and herbicide. iii) Provide assistances (e.g. via agricultural extension agents) related to post-harvest handlings/technology and product quality (certification product) particularly for export of fruits. iv) Provide facilities for making other potential products (e.g. extraction of peels and leaves for medicinal uses) and support for international marketing.
Sago/sagu (*Metroxylon sagu*)	i) Scalable, but need to support for international marketing (e.g. as bioplastic, bioethanol, etc.) and support for farmers since long time is needed before first harvest takes place, and farmers cannot cover this. However once mature since it is a coppice plant once the crop is mature it is very profitable. ii) Provide access and/or subsidies for fertilisers, pesticide and herbicide. iii) Provide facilities for making processed food (e.g. sago cookie/bagea, sago pearls, etc.) and other potential products (e.g. animal feed/food pellet, and growing media for *Volvariella volvacea* mushrooms and breeding *Rhynchophorus* larvae which is a good source of protein).
Water spinach/kangkong (*Ipomoea aquatica*)	i) Farming within community-based system. ii) Provide assistances (e.g. via agricultural extension agents) related to water management and water quality control. iii) Provide access and/or subsidies for fertilisers, pesticide and herbicide. iv) Provide assistances related to post-harvest handlings/technology and product quality (certification product) particularly for exports.
Kelakai edible fern (*Stenochlaena palustris*)	i) Farming within community-based system. ii) Provide assistances related to post-harvest handlings/technology and product quality. iii) Provide facilities for making processed food products (e.g. kelakai chip snacks and crackers) and other potential products such as medicinal uses (extractions of leaves), animal feed (food pellet), biomass briquettes and composting that support for national and international marketing.
Dragon fruit/buah naga (*Hylocereus undatus*)	i) Scalable with limited drainage. ii) Provide access to (free) seedlings and/or subsidies for fertilisers, pesticide and herbicide. iii) Provide assistances (e.g. via agricultural extension agents) related to post-harvest handlings/technology and product quality (certification product) particularly for export of fruits. iv) Provide facilities for making other potential products (e.g. food colouring agent, tea from flowers, ornamental flower fragrant).
Pineapple/nanas (*Ananas comosus*)	i) Scalable but with limited drainage. ii) Provide access to (free) seedlings which are resistant to pest and weeds and/or subsidies for fertilisers, pesticide and herbicide. iii) Provide assistances (e.g. via agricultural extension agents) related to post-harvest handlings/technology and product quality (certification product) particularly for export of fruits. iv) Provide facilities for making other potential products (e.g. fibres for textile from leaves and enzyme bromelain from steam and fruit) that also support for international marketing.
Banana/pisang (*Musa paradisiaca*)	i) Scalable but with limited drainage. ii) Provide access and/or subsidies for fertilisers, pesticide and herbicide. iii) Provide assistances (e.g. via agricultural extension agents) related to post-harvest handlings/technology and product quality (certification product) particularly for export of fruits. iv) Provide facilities for making other potential products (e.g. fibres for textile and paper from steam) that also support for international marketing.

Illipenut/tengkawang (*Shorea* spp.)	i) Scalable, but need policy to support international trading (exports) of raw illipenut (e.g. revoking policy that prohibit the export of raw illipenut seeds) ii) Provide support for farmers since a long time period is needed before the first harvest. iii) Provide access and/or subsidies for fertilisers, pesticide and herbicide. iv) Provide facilities for producing illipenut-oil, and also for making other potential products such as for animal feed (fruit), making soap, candles, polishes and cosmetic (from illipenut oil/fat).
Sweet melon/melon (*Cucumis melo*)	i) Farming within community-based system. ii) Provide access and/or subsidies for fertilisers, pesticide and herbicide. iii) Provide assistances (e.g. via agricultural extension agents) related to post-harvest handlings/technology and product quality (certification product) particularly for export of fruits. iv) Provide facilities for making other potential products (e.g. seed oil for cosmetic).
Rambutan (*Nephelium lappaceum*)	i) Scalable, but with limited drainage and need support for farmers since a long time period is needed before the first harvest. ii) Provide access to (free) seedlings which are resistant to pest and weeds and/or subsidies for fertilisers, pesticide and herbicide. iii) Provide assistances (e.g. via agricultural extension agents) related to post-harvest handlings/technology and product quality (certification product) particularly for exports of fruits. iv) Provide facilities for making other potential products such as for medicinal uses from green fruits.
Snake fruit/salak (*Salacca/Eleiodoxa* spp.)	i) Scalable but with limited drainage and need support for farmers since a long time period is needed before the first harvest. ii) Provide access and/or subsidies for fertilisers, pesticide and herbicide. iii) Provide assistances (e.g. via agricultural extension agents) related to post-harvest handlings/technology and product quality (certification product) particularly for export of fruits. iv) Provide facilities for making other potential products such as boiled and roasted seeds.
Candlenut/kemiri (*Aleurites moluccana*)	i) Scalable, but with limited drainage and need support for farmers since a long time period is needed before the first harvest. ii) Provide access to (free) seedlings which are resistant to pest and weeds and/or subsidies for fertilisers, pesticide and herbicide. iii) Provide assistances (e.g. via agricultural extension agents) related to post-harvest handlings/technology and product quality (certification product) particularly for exports. iv) Provide facilities for making other potential products such as seed oil/candlenut for shampoo, soap, candle, skin care product, paint and varnish oil.
Bitter gourd/pare (*Momordica charantia*)	i) Farming within community-based system. ii) Provide access and/or subsidies for fertilisers, pesticide and herbicide. iii) Provide assistances (e.g. via agricultural extension agents) related to post-harvest handlings/technology and product quality (certification product) particularly for export of vegetables (fruits). iv) Provide facilities for making other potential products (e.g. medicinal herbal from leaves).
Durian (*Durio zibethinus*)	i) Scalable, but with limited drainage and need support for farmers since a long time period is needed before the first harvest. ii) Provide access to (free) seedlings which are resistant to pest and weeds and/or subsidies for fertilisers, pesticide and herbicide. iii) Provide assistances (e.g. via agricultural extension agents) related to post-harvest handlings/technology and product quality (certification product) particularly for exports of fruits. iv) Provide facilities for making processed food (e.g. ice cream, cake, etc.) and other potential products such as for medicinal uses and fuel (from dried rind of the fruits).
Liberica coffee/ kopi liberika (*Coffea liberica*)	i) Scalable, but with limited drainage and need support for farmers since a long time period is needed before the first harvest. ii) Provide access to (free) seedlings which are resistant to pest and weeds and/or subsidies for fertilisers, pesticide and herbicide. iii) Provide assistances (e.g. via agricultural extension agents) related to post-harvest handlings/technology and product quality (certification product) particularly for exports of coffee beans. iv) Provide facilities for making coffee powder and for other potential products such as for medicinal uses (leaves).

Summary

The management of Indonesian peatlands poses several economic and environmental challenges. The pressure to both develop and preserve Indonesian tropical peatlands is greater than ever before. The increasing demand for agricultural land has led to the increasing conversion of natural peatlands and drainage of the peatland areas. On the other hand, an increasing understanding of the value of tropical peatlands and the local and global environmental problems (caused by the conversion, drainage and fires) has led to an increasing demand to conserve peatland areas and properly manage them. At the same time, the increasing amount of natural peatland areas which are being degraded and destroyed by fires contributes to the increasing socio-ecological impacts on people who live in the affected areas. In spite of increasing efforts by the government of Indonesia, there is still some drainage of peatlands, and efforts to rehabilitate the peatlands are not always effective. A better understanding of the state and impact of the current utilisation and management of peatland, and the options to promote a different, more sustainable management is required.

This thesis studies the sustainability of peatland management in Indonesia by analysing the selected social, health and ecological impacts of peatland utilisation and by identifying potential response options. To achieve this objective, four Research Questions (RQs) are formulated, i.e. RQ1 (Chapter 2): 'What are the peatlands' uses and the ecosystem services supplied by the peatlands, the key sustainability issues and the potential response options to move towards sustainability?' RQ2 (Chapter 3): 'What type of health effects are caused by the recurrent annual peatland fires in Indonesia, and how can these health effects on the local populations be quantified?' RQ3 (Chapter 4): 'How is the institutional fit of the peatland governance in Indonesia and to what degree do these institutions promote sustainable peatland management?' RQ4 (Chapter 5): 'What are the alternative development options for Indonesian peatlands, with regard to the sustainability, profitability, scalability of the market and the acceptability to the farmers?'.

The relevance of this thesis is based on the facts that (1) forests and peatlands in Indonesia are actively undergoing rapid changes and developments that affect the hydrology and peatsoil conditions; (2) changes to the condition of peatland ecosystems affects the environment and humans living in and near the peatlands; (3) air pollution from (annually recurrent) peatland fires has impacted the human health of local populations and the global climate; (4) local people livelihoods depend on the peatlands, particularly the forestry and agriculture sectors;

(5) the interests related to peatlands' utilisation vary among stakeholders and (6) the involvement of stakeholders (particularly peatland users) is needed in order to deliver sustainable management of the peatlands.

In Chapter 2 of this thesis, I assessed peatland uses in Indonesia during 2010-2014 and quantified the ecosystem services supplied by the Indonesian peatlands. I analysed the key sustainability issues for the peatlands and subsequently presented the potential response options for more sustainable uses of peatlands, based on four types of peatland conditions, i.e. 1) non-productive or forest use with drainage; 2) non-productive or forest use without drainage; 3) productive (agricultural) use with drainage; and 4) productive (agricultural) use without drainage. A literature review and spatial analysis were conducted, mainly based on the government data in order to quantify the land cover/use and land-use change and estimate the dynamics of the seven ecosystem services provided by the Indonesian peatlands during the period from 2000 to 2014. This chapter concluded that large areas of peatland in Indonesia have increasingly been converted during the period from 2000 to 2014 for agricultural purposes, in particular for oil palm and acacia, while in this process the ecosystem services provided by the peat swamp forests (e.g. carbon sequestration, biodiversity conservation) have been replaced by the production of agricultural commodities. On the positive side, this has led to major increases in palm oil production (nearly a factor three increase in production on peatlands between 2000 and 2014) and biomass production for pulp (a factor 20 increase in the same period). On the negative side, these production levels are not sustainable since progressive soil subsidence will lead to seasonal flooding of the drained plantations in the coming decades ensuring that they will need to be taken out of production. Besides, there are significant externalities related to peat fires and health problems, CO_2 emissions and the loss of habitat. These findings also indicate that the negative side of peatland conversions in Indonesia overshadows the positive side of these conversions. To move towards sustainability, alternative peat development scenarios should be created, which should involve a gradual phasing out of oil palm and other drained crops on peat and replacing them by crops that do not require drainage in combination with forestry including timber and non-timber forest production.

In Chapter 3, I assessed the long-term health impacts of frequent exposure to $PM_{2.5}$ concentrations on the human population in Central Kalimantan, due to smoke and peatland fires in the period from 2011 to 2015. The conclusions highlighted that the 2.5 million people in Central Kalimantan are exposed to annual mean $PM_{2.5}$ concentrations of 26 $\mu g/m^3$ (of which the average annual mean $PM_{2.5}$ concentrations from hotspots in the deep peat and shallow peat were each 13 μg/m^3), which exceed the WHO AQG of 10 μg/m^3. This caused 648 premature mortality cases per year (equals to 26 mortality cases per 100,000 population), which includes 55 mortality cases due to chronic respiratory diseases, 266 mortality cases from cardiovascular diseases and 95 mortality cases from lung cancer. It is noted that the mortality cases due to chronic respiratory disease include six mortality cases of children aged below five years (2 mortality cases per 100,000 children aged below five years). Based on the sensitivity analysis, the number of all–cases mortality increased with the increasing concentration of $PM_{2.5}$. The premature mortality cases increase by 34% for an increase of 10 μg/m^3 in the $PM_{2.5}$ concentration, while with a decrease of 10 μg/m^3 in the $PM_{2.5}$ concentration, the premature mortality will decrease by 45%. The findings are very distinctive for Central Kalimantan's case, but can indicate that a large number of fatalities due to peat fires and smog may have occurred in Indonesia, when taking into account that Sumatra and Kalimantan, as the areas most affected by the smoke caused by the annual burning of peatlands, have about 73 million inhabitants (57 million inhabitants in Sumatra and 16 million inhabitants in Kalimantan). This chapter confirms the importance of studying the long–term health effects and the great urgency for addressing the ongoing peatland conversion and degradation in Indonesia. The assessment of the long-term health impacts on the local population will help the local government and stakeholders in Central Kalimantan to better assess the health implications of different peatland uses and to take initiatives to set and enforce higher standards for sustainable peatland management (particularly mitigation policies on fires and drained peatland uses, and also adding air quality monitoring stations). In general, this asserts the need for the public health authority to raise community awareness about the health risks of the ongoing peatland conversion and degradation in Indonesia, in particular caused by peatland fires due to drained peatland and slash-and-burn practices.

Chapter 4 gives an overview of the institutional fit assessment between national peatland regulations and the practices of the peatlands' users in two provinces in Indonesia (Jambi and Central Kalimantan). The concept of institutional fit is applied for assessing the degree of fit between rules creators (in this thesis, the national regulations and the practices engrained in these regulations) and adopters (in this thesis, the local peatland users that need to comply with the national regulations). The four main national peatland regulations in Indonesia include Government Regulation (PP) No. 57/2016 (the emendation of PP No. 71/2014) on the Protection and Management of the Peatland Ecosystems; Presidential Instructions (Inpres) No. 10/2011, No. 6/2013, and No. 8/2015 on the (Extended) Moratorium of the Granting of New Licences and the Improvement of Governance of Natural Primary Forest and Peatland;

the Government Regulation (PP) No. 4/2001 on the Control of Natural Damage and or Pollution related to Land and Forest Fires; and the Minister of Agriculture's Decree (Kepmentan) No. 14/2009 on Guidance for the Utilisation of Peatland for Oil Palm Cultivation). The main key finding of this chapter is that the degree of institutional fit (technical, political, and cultural fit) for Indonesia's current peatland management is mostly low to moderate, for both Jambi and Central Kalimantan. This indicates that many peatland users in Indonesia are insufficiently aware of peatland regulations which the existing practices of the peatland users are largely incompatible with the national peatland regulations. The lack of technical knowledge about the different types of zero burning methods, the lack of availability of technology to put out (sometimes massive) peatland fires, as well as a lack of information on the actual (accurate) location of deep peatlands and the ground water table, are leading causes of the low technical fit of these four regulations. The low political fit can largely be explained by issues related to unclear land titles and the lack of information sharing between different governmental agencies. The low cultural fit seems to be related to the absence of (knowledge about) alternatives for traditional forms of peat management and land clearing in particular. The village governments, farmers groups (associations) and NGOs play important roles to increase the degree of fit. To move towards sustainable peatland management in Indonesia, further work is needed including the establishment of value chains for paludiculture crops, so that profitable alternatives for the drained-peatland-based crops (e.g. oil palm, acacia and rubber) can be promoted. Also, it is important to educate people living in and around the peatlands about the regulations governing peatland uses but also of the reasons why such regulations have been established, including the massive health effects that peatland fires cause. This involves also working with NGOs and other stakeholders in testing and rolling out alternative peatland uses that generate local incomes.

Chapter 5 presents the integrated social-ecological appraisal on the various alternatives of paludiculture crops in peatlands, with a particular study case conducted in Central Kalimantan. This study assesses 15 paludiculture food crops that could be used in Indonesia in terms of their sustainability, profitability, scalability of market and the acceptability to the farmers. It is important to identify suitable paludiculture crops for Indonesian peatlands given the high CO_2 emissions and irreversible soil subsidence that are characteristic of current peat management practices. In this chapter, the key opportunities and bottlenecks for the development of these paludiculture crops are analysed in order to formulate some recommendations for the implementation of paludiculture in Indonesia. This chapter concludes that all paludiculture crops can be grown with no or minimum drainage, with CO_2 emissions from these paludiculture ranging from 0 to 49 tonnes CO_2/ha/year. There are, however, major differences in the profitability, with the most promising crops (sago (*Metroxylon sagu*), mangosteen (*Garcinia mangostana*)) in principle are able to compete with oil palm, provided that the markets for these crops can be supported and enlarged. Other species, that can be of local interest to farmers are water spinach, *Stenochlaena palustris* edible fern/kelakai, dragon fruit (*Hylocereus undatus*), pineapple (*Ananas comosus*) and banana (*Musa paradisiaca*), even though some of these crops still require some drainage. These paludiculture crops would contribute to sustainable peatland uses and food security at the regional and national level. The findings in this chapter can be used as inputs for business plans and for value chain development programmes designed for a sustainable peatland management. Critical factors in promoting paludiculture crops are i.e. the development of markets for paludiculture crops; the adaptation and enforcement of the legislation governing peatlands; further improvements to the farming and harvesting technologies, and support to farmers to meet international quality standards.

In conclusion, my thesis quantified the social, health and ecological impacts of the peatlands' utilisation by integrating social and ecological data. My research provides insights on how to (i) identify the impacts, (ii) address the perceptions and institutional fit, and (iii) identify policy priorities. By addressing the critical socio-ecological issues, this thesis contributes to formulating potential response options based on the technical, political and socio-cultural aspects for better peatland management in Indonesia.

Ringkasan

Pengelolaan lahan gambut Indonesia menghadapi beragam tantangan baik dari aspek ekonomi maupun lingkungan. Tekanan-tekanan untuk menggunakan maupun melestarikan lahan gambut tropis Indonesia lebih besar daripada sebelumnya. Meningkatnya permintaan untuk lahan pertanian telah menyebabkan meningkatnya konversi/alih guna lahan gambut alami melalui pengeringan area lahan gambut. Di sisi lain, semakin meningkatnya pemahaman tentang nilai penting lahan gambut tropis serta beragam masalah lingkungan lokal dan global (yang disebabkan oleh konversi, drainase, dan kebakaran) telah menyebabkan meningkatnya permintaan untuk melestarikan lahan gambut dan mengelolanya dengan lebih baik. Pada saat yang sama, meningkatnya jumlah lahan gambut alami yang mengalami kerusakan akibat kebakaran lahan berkontribusi pada meningkatnya dampak sosial-ekologis pada masyarakat yang tinggal di daerah yang terkena dampak tersebut. Meskipun terdapat peningkatan upaya yang telah dilakukan oleh pemerintah Indonesia, namun kegiatan-kegiatan pengeringan lahan gambut masih dilakukan, sehingga upaya untuk merehabilitasi lahan gambut menjadi kurang efektif. Oleh sebab itu, pemahaman yang lebih baik tentang kondisi lahan gambut serta dampak pemanfaatan dan pengelolaan lahan gambut saat ini, dan berbagai pilihan tindakan dalam rangka mempromosikan pengelolaan lahan gambut yang lebih berkelanjutan sangatlah diperlukan.

Disertasi ini menyajikan wawasan dalam pengelolaan lahan gambut yang keberlanjutan di Indonesia dengan menganalisis beberapa dampak terpilih dari segi sosial, kesehatan dan ekologi dari pemanfaatan lahan gambut serta mengidentifikasi pilihan tindakan-tindakan yang lebih baik. Untuk mencapai tujuan ini, empat Pertanyaan Penelitian (RQ) dirumuskan yaitu meliputi RQ1 (Bab 2): ‘Apa saja penggunaan lahan gambut dan jasa ekosistem yang dipasok oleh ekosistem di lahan gambut tersebut, serta masalah-masalah utama yang terkait dengan keberlanjutan dan pilihan-pilihan tindakan yang lebih baik untuk pengelolaan lahan gambut berkelanjutan?’ RQ2 (Bab 3): 'Jenis dampak kesehatan apa saja yang disebabkan oleh paparan asap akibat kebakaran lahan gambut yang berulangkali terjadi setiap tahun di Indonesia, dan bagaimana dampak kesehatan ini pada populasi penduduk lokal dapat dihitung?' RQ3 (Bab 4): 'Bagaimana kesesuaian pengaturan dalam penggunaan lahan gambut di Indonesia dan seberapa jauh kesesuaian pengaturan tersebut dalam mendukung pengelolaan lahan gambut yang berkelanjutan?' RQ4 (Bab 5): 'Apa saja alternatif pilihan dalam penggunaan lahan gambut di Indonesia dikaitkan dengan aspek keberlanjutan, profit/keuntungan, skala pasar, dan penerimaan oleh para petani?'.

Disertasi ini diperlukan berdasarkan fakta bahwa (1) hutan dan lahan gambut di Indonesia Secara aktif dan cepat terus mengalami perubahan serta pengembangan/pembangunan yang mempenga-ruhi kondisi-kondisi hidrologi dan tanah gambut itu sendiri; (2) perubahan kondisi dari ekosistem lahan gambut akan mempengaruhi lingkungan dan kehidupan masyarakat yang tinggal di- dan sekitar lahan gambut tersebut; (3) polusi udara akibat kebakaran lahan gambut (yang sering terulang setiap tahun) membawa dampak-dampak pada kesehatan manusia dari penduduk lokal maupun pada iklim global; (4) mata pencaharian penduduk lokal masih sangat bergantung kepada lahan gambut, terutama pada sektor kehutanan dan pertanian; (5) kepentingan-kepentingan yang terkait dengan pemanfaatan lahan gambut sangat bervariasi diantara para pemangku kepentingan dan (6) keterlibatan dari para pemangku kepentingan tersebut (terutama para pengguna lahan gambut) diperlukan dalam pengelolaan lahan gambut yang berkelanjutan.

Bab 2 dari disertasi ini berisi hasil kajian penggunaan lahan gambut di Indonesia selama tahun 2010 - 2014 serta hasil perhitungan nilai jasa lingkungan yang disediakan oleh ekosistem lahan gambut tersebut. Saya menelaah masalah-masalah utama terkait penggunaan lahan gambut serta menyajikan beberapa pilihan tindakan untuk penggunaan lahan gambut yang lebih lestari, berdasarkan pada empat jenis kondisi lahan gambut yaitu 1) penggunaan lahan gambut secara tidak produktif ataupun hutan dengan ada pengeringan; 2) penggunaan lahan gambut secara tidak produktif ataupun hutan dengan tanpa ada pengeringan; 3) penggunaan lahan gambut secara produktif (untuk pertanian) dengan ada pengeringan; dan 4) penggunaan lahan gambut secara produkstif (untuk pertanian) tanpa ada pengeringan. Saya melakukan tinjauan pustaka dan telaah spasial terutama berdasarkan pada data-data dari Pemerintah dalam rangka menghitung luas tutupan/penggunaan lahan serta luas dari perubahan tutupan lahan tersebut, dan juga memperkirakan dinamika dari tujuh tipe jasa ekosistem yang disediakan oleh lahan gambut Indonesia selama periode tahun 2000 sampai dengan tahun 2014. Dalam bab ini disimpulkan bahwa sebagian besar kawasan lahan gambut di Indonesia telah mengalami peningkatan konversi/alih guna lahan selama periode dari tahun 2000 hingga 2014 terutama untuk tujuan pertanian, khususnya kelapa sawit dan akasia. Sementara dalam proses tersebut, jasa-jasa ekosistem yang disediakan oleh hutan rawa gambut (misalnya penyerapan karbon, konservasi keanekaragaman hayati) telah digantikan dengan memproduksi komoditas-komoditas pertanian. Dari sisi positif, hal tersebut menyebabkan peningkatan yang besar dalam produksi minyak kelapa sawit (dengan peningkatan produksi di lahan gambut hampir tiga kali lipat dari tahun 2000 ke tahun 2014) dan produksi biomassa untuk bubur kertas/pulp (meningkat 20 kali lipat pada periode yang sama). Dari sisi negatif, peningkatan produksi ini bersifat tidak lestari dikarenakan penurunan tanah gambut secara terus menerus akan berujung pada banjir musiman pada perkebunan yang dikeringkan tersebut dalam beberapa dekade mendatang, sehingga dengan pasti menghilangkan produktifitas lahan-lahan perkebunan tersebut. Selain itu, terdapat dampak tambahan lain yang signifikan yaitu terkait dengan kebakaran lahan gambut dan masalah kesehatan, pelepasan karbondioksida (CO_2) dan habitat yang hilang. Hasil studi ini secara jelas menunjukkan bahwa dampak negatif dari konversi lahan gambut di Indonesia membayangi dampak positif dari konversi lahan tersebut. Dalam upaya menuju keberlanjutan, scenario-skenario alternative pilihan pengembangan lahan gambut harus dibuat yaitu dengan mengganti secara bertahap tanaman kelapa sawit maupun jenis tanaman lainnya yang memerlukan pengeringan lahan gambut, dengan jenis tanaman-tanaman yang tidak memerlukan drainase/pengeringan ketika ditanam di lahan gambut, serta dipadukan dengan kehutanan termasuk produksi kayu dan produksi bukan kayu dari hutan.

Dalam bab 3 berisi hasil-hasil telaah dampak kesehatan jangka panjang akibat seringkali terpapar partikel materi $PM_{2.5}$ pada populasi penduduk local (Provinsi Kalimantan Tengah sebagai wilayah studi kasus) yang disebabkan oleh asap dari kebakaran lahan gambut yang terjadi pada periode tahun 2011 hingga tahun 2015. Kesimpulan-kesimpulan yang diperoleh menyoroti bahwa sebanyak 2,5 juta penduduk di Provinsi Kalimantan Tengah telah terpapar $PM_{2.5}$ dengan rata-rata tahunan konsentrasi $PM_{2,5}$ sebesar 26 $\mu g/m^3$ (dimana rata-rata tahunan konsentrasi $PM_{2.5}$ dari titik-titik panas/api di tipe gambut dalam dan tipe gambut dangkal didapati sama yaitu masing-masing 13 $\mu g/m^3$), dimana angka tersebut telah melebihi batasan angka yang dianjurkan dari WHO AQG yaitu 10 $\mu g/m^3$. Dengan rata-rata tahunan konsentrasi $PM_{2.5}$ sebesar 26 $\mu g/m^3$ tersebut, maka perkiraan dampak kesehatan yang ditimbulkan adalah menyebabkan sebanyak 648 kasus kematian dini (prematur) per tahun (atau sebanyak 26 kasus kematian dini per 100.000 penduduk), termasuk didalamnya 55 kasus kematian akibat penyakit pernapasan kronis, 266 kasus kematian akibat penyakit kardiovaskular (jantung) dan 95 kasus kematian akibat kanker paru-paru. Perlu dicatat bahwa dalam kasus kematian akibat penyakit pernapasan kronis ini adalah juga termasuk sebanyak enam kasus kematian anak - anak berusia di bawah lima tahun (atau sebanyak 2 kasus kematian per 100.000 anak berusia di bawah lima tahun). Berdasarkan telaah uji kepekaan/sensitivitas, jumlah semua kasus kematian akan meningkat dengan adanya peningkatan konsentrasi $PM_{2.5}$. Jumlah kasus kematian dini akan meningkat sebesar 34% untuk setiap peningkatan konsentrasi $PM_{2.5}$ sebesar 10 $\mu g/m^3$, sedangkan dengan penurunan konsentrasi $PM_{2.5}$ sebesar 10 $\mu g/m^3$ maka jumlah kematian dini akan menurun sebanyak 45%. Walaupun hasil temuan ini sangat khusus hanya untuk kasus di Provinsi Kalimantan Tengah, hal ini dapat menandakan akan adanya suatu jumlah korban yang besar yang mungkin terjadi di Indonesia akibat paparan asap ($PM_{2.5}$) dari kebakaran gambut selama periode tersebut, dengan mengingat bahwa Sumatera dan Kalimantan, yaitu dua wilayah yang paling sering terpapar oleh asap dari kebakaran tahunan lahan gambut, memiliki sekitar 73 juta penduduk (57 juta penduduk di Sumatera dan 16 juta penduduk di Kalimantan). Bab ini menegaskan akan pentingnya mempelajari efek kesehatan jangka panjang serta desakan yang besar untuk segera menangani konversi dan kerusakan lahan gambut yang masih terus berlanjut di Indonesia. Penilaian terhadap dampak kesehatan jangka panjang pada penduduk lokal (setempat) akan membantu pemerintah daerah serta berbagai pemangku kepentingan, terutama di Kalimantan Tengah, untuk dapat menilai secara lebih baik akan implikasi kesehatan dari setiap penggunaan lahan gambut serta dapat mengambil inisiatif untuk menetapkan dan menegakkan standar-standar yang lebih tinggi untuk pengelolaan lahan gambut berkelanjutan (khususnya kebijakan mitigasi kebakaran lahan dan penggunaan lahan gambut dengan dikeringkan, dan juga perlunya menambahkan stasiun-stasiun pemantauan kualitas udara). Secara umum, hal ini menegaskan kebutuhan akan pesan-pesan kesehatan masyarakat yang mampu meningkatkan kesadaran masyarakat dalam mengatasi konversi dan kerusakan lahan gambut yang terus berlanjut di Indonesia, khususnya yang disebabkan oleh kebakaran lahan gambut akibat pengeringan lahan gambut dan praktik-praktik tebas-dan-bakar dalam pembersihan lahan.

Bab 4 berisi gambaran dari penilaian kesesuaian antara peraturan-peraturan nasional terkait penggunaan gambut dengan praktik-praktik yang dilakukan oleh para pengguna lahan gambut di dua provinsi di Indonesia (Jambi dan Kalimantan Tengah). Konsep kesesuaian pengaturan digunakan untuk menilai tingkat kesesuaian antara aturan dari pencipta/pembuat (dalam disertasi ini yaitu peraturan-peraturan nasional serta praktik-praktik yang tersurat di dalam peraturan-peraturan tersebut) dengan pengadopsi (dalam disertasi ini adalah para pengguna lahan gambut setempat yang harus mematuhi peraturan-peraturan nasional tersebut). Empat peraturan nasional terkait penggunaan gambut di Indonesia yang ditelaah dalam bab ini meliputi: Peraturan Pemerintah (PP) No. 57/2016 (merupakan perbaikan PP No. 71/2014) tentang Perlindungan dan Pengelolaan Ekosistem Gambut; Instruksi Presiden (Inpres) No. 10/2011, No. 6/2013, dan No. 8/2015 tentang (Perpanjangan) Penundaan Pemberian Izin Baru dan Penyempurnaan Tata Kelola Hutan Alam Primer dan Lahan Gambut; PP No. 4/2001 tentang Pengendalian Kerusakan dan atau Pencemaran Lingkungan Hidup yang berkaitan dengan Kebakaran Hutan dan atau Lahan; dan Peraturan Menteri Pertanian (Permentan) No. 14/2009 tentang Pedoman Pemanfaatan Lahan Gambut untuk Budidaya Kelapa Sawit. Adapun hasil utama menunjukan bahwa tingkat kesesuaian pengaturan (kesesuaian teknis, politik, dan budaya) dalam pengelolaan lahan gambut di Indonesia (Jambi maupun Kalimantan Tengah) saat ini adalah sebagian besar pada tingkat rendah sampai sedang. Hal ini menandakan bahwa praktik-praktik yang dilakukan oleh para pengguna lahan gambut di Indonesia sebagian besar tidak sesuai dengan peraturan-peraturan nasional yang ada terkait penggunaan gambut yang dibuat oleh pemerintah. Kurangnya pengetahuan teknis tentang berbagai jenis metode atau cara pembersihan lahan tanpa pembakaran, kurangnya ketersediaan teknologi untuk memadamkan kebakaran lahan gambut (yang terkadang masif), serta kurangnya informasi tentang lokasi yang aktual (akurat/tepat) tentang kedalaman gambut dan ketinggian air tanah di lahan gambut adalah penyebab-penyebab utama rendahnya kesesuaian secara teknis dari keempat peraturan ini. Rendahnya kesesuaian politik sebagian besar dapat dijelaskan oleh masalah-masalah yang berkaitan dengan status/sertifikat kepemilikan tanah/lahan yang tidak jelas serta kurangnya berbagi informasi antar berbagai lembaga pemerintah terkait. Kesesuaian budaya yang rendah tampaknya terkait dengan tidak adanya (pengetahuan tentang) akan alternatif/pilihan pengelolaan lahan gambut yang lebih baik secara tradisional khususnya dalam hal pembersihan lahan. Hasil telaah dalam studi ini juga menunjukkan bahwa pemerintah desa, kelompok-kelompok tani (asosiasi petani) dan Lembaga Swadaya Masyarakat (LSM) memainkan peranan penting untuk meningkatkan derajat kesesuaian pengaturan antara peraturan-peraturan gambut tersebut dengan praktik-praktik yang dilakukan oleh para pengguna lahan gambut. Untuk menuju pengelolaan lahan gambut yang berkelanjutan di Indonesia, perlu dilakukan banyak upaya lebih jauh termasuk mengubah pandangan tentang pemilihan tanaman pertanian yang berbasis pengeringan lahan gambut (misalnya kelapa sawit, akasia dan karet) kepada tanaman paludikultur (tanaman yang tidak memerlukan pengeringan gambut). Selain itu, adalah penting juga untuk mendidik para penduduk yang tinggal di- dan atau sekitar lahan gambut tentang peraturan-peraturan yang mengatur penggunaan lahan gambut, juga alasan-alasan mengapa peraturan-peraturan tersebut dibuat/ditetapkan, dan termasuk juga tentang dampak-dampak kesehatan yang besar yang disebabkan dari kebakaran lahan gambut. Hal ini dapat melibatkan LSM dan para pemangku kepentingan lainnya dalam menguji dan memperkenalkan alternatif penggunaan-penggunaan lahan gambut yang dapat memberikan pendapatan lokal.

Bab 5 menyajikan penilaian terpadu aspek sosial-ekologis terhadap 15 tanaman pangan paludikultura yang dapat digunakan di Indonesia berbagai alternatif tanaman paludikultur di lahan gambut, berdasarkan sebuah studi kasus yang dilakukan di Kalimantan Tengah. Studi ini menelaah tanaman pangan paludikultura dalam hal aspek keberlanjutan, keuntungan produk (profit), skala pasar dan penerimaan oleh para petani. Adalah penting untuk mengidentifikasi tanaman paludikultura yang cocok untuk lahan gambut Indonesia, mengingat tingginya emisi CO_2 dan penurunan muka tanah yang tidak dapat dibalikkan kembali yang merupakan karakteristik dari praktik pengelolaan gambut saat ini. Hasil telaah menyimpulkan bahwa semua tanaman paludikultura dapat ditanam dengan tanpa ataupun sedikit drainase/ pengeringan lahan gambut, dengan emisi CO_2 dari paludikultura ini berkisar antara 0 hingga 49 tonCO_2/ha/tahun. Namun, ada perbedaan utama dalam aspek profitabilitas, dimana tanaman yang paling menjanjikan (manggis (*Garcinia mangostana*), sagu (*Metroxylon sagu*)) pada prinsipnya mampu bersaing dengan kelapa sawit, asalkan pasar untuk tanaman ini dapat didukung dan diperbesar. Spesies-spesies lain, yang dapat menarik bagi petani lokal adalah kangkong (*Ipomoea aquatic*), kelakai/pakis yang dapat dimakan (*Stenochlaena palustris*), buah naga (*Hylocereus undatus*), nanas (*Ananas comosus*) dan pisang (*Musa* spp.), meskipun beberapa jenis dari tanaman ini masih membutuhkan drainase. Tanaman paludikultura ini berkontribusi terhadap penggunaan lahan gambut berkelanjutan dan ketahanan pangan di tingkat regional dan nasional. Hasil-hasil yang diperoleh dari penelitian ini dapat digunakan sebagai input/masukan untuk perencanaan bisnis dan program pengembangan rantai nilai komoditi yang dirancang untuk pengelolaan lahan gambut berkelanjutan. Faktor-faktor terpenting dalam mempromosikan tanaman paludikultura meliputi: pengembangan pasar untuk tanaman paludikultura; adaptasi dan penegakan hukum yang mengatur lahan gambut; perbaikan lebih lanjut pada teknologi pertanian dan pemanenan, dan dukungan bagi petani untuk memenuhi standar kualitas internasional untuk ekspor komoditas paludikultur tersebut.

Sebagai kesimpulan akhir, disertasi saya ini menelaah dampak-dampak sosial, kesehatan dan ekologi dari penggunaan lahan gambut dengan memadukan data sosial dan ekologi. Penelitian saya ini menyajikan wawasan baru tentang bagaimana (i) mengidentifikasi berbagai dampak, (ii) menelaah beragam persepsi dan kesesuaian institusi, serta (iii) mengidentifikasi prioritas-prioritas kebijakan. Dengan membahas masalah sosial-ekologis secara kritis, disertasi ini berkontribusi untuk menghadirkan pilihan-pilihan tindakan berdasarkan aspek teknis, politik dan sosial-budaya bagi pengelolaan lahan gambut yang lebih baik di Indonesia.

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I do hope that the outcomes of this PhD study will be useful for the Indonesia people particularly for a better peatland management in Indonesia.

About the author

Saritha Kittie Uda was born on September, 19th 1974 in Palangka Raya, Central Kalimantan, Indonesia as the second child from five siblings in a Dayaknese family. She finished her primary school in Palangka Raya city and the high school at SMA Regina Pacis in Bogor, West Java – Indonesia. In 1998, Saritha completed her undergraduate degree with a *cum laude* at the University of Padjadjaran (UNPAD) in Bandung, West Java – Indonesia with a specialisation on the Biology Sciences. Her thesis was on the assessment of the bacteria population from peat soils in various peatlands' uses in Central Kalimantan and also analysed the susceptibility patterns of the pathogenic bacteria to various antibiotics. She then worked as a temporary staff at the Environmental, Social, and Cultural Division in the Regional Development Planning Agency (BAPPEDA) of Central Kalimantan Province. Since 2002, she started to work as a lecturer and researcher at the University of Palangka Raya (UPR) at Biology Study Program with subjects focused on environmental sciences, policy and education, and also joined in the Centre for International Cooperation in the Sustainable Management of Tropical Peatlands (CIMTROP) at the same university. During 2005 - 2007, Saritha took an MSc in Environmental Sciences at the Environmental Sciences Group (ESG) in Wageningen University & Research (WUR), the Netherlands with a scholarship from IIEF-Ford Foundation. Her MSc thesis was about the integrated assessment of peatland fires in Indonesia, with a case study in Central Kalimantan, Indonesia. In 2014, Saritha started her PhD at the Environmental Systems Analysis (ESA) Group in Wageningen University & Research (WUR) with a scholarship from Lembaga Pengelola Dana Pendidikan/LPDP (the Indonesia Endowment Fund for Education), the Ministry of Finance of the Republic of Indonesia. Her PhD research focused on analysing the socio-ecological dynamics of peatland management in Indonesia towards sustainable peatland management.

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List of relevant publications

International peer review journals:

Uda SK, Hein L & Sumarga E (2017) Towards sustainable management of Indonesian tropical peatlands. *Wetlands Ecology and Management*, 25:683-701. doi: 10.1007/s11273-017-9544-0.

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Other scientific publications:

Uda SK & Pristiwati G (2016) Valuing and mapping ecosystem services hotspot and trade-off to support sustainable peatland management. Proceedings on the 15th International Peatland Society Congress 2016: Peatlands in Harmony- Agriculture, Industry & Nature. Kuching Sarawak, Malaysia, 15 - 16 August 2016. Organised by the International Peatland Society (IPS).

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- Grasping Sustainability (2015)
- Research in context activity: 'Contributing to EU Study Visit Assistance and Information Exchange on 'Effective Peatland Management Strategies' of Indonesian delegation, the Ministry of Environment and Forestry, Republic Indonesia (3-12 April 2016)'
- Resilience of living systems (2018)

Selection of other PhD and Advanced MSc Courses

- Techniques for Writing and Presenting a Scientific Paper, Wageningen Graduate Schools (2014)
- Integrated Ecosystem Assessment in Regional Management, WUR (2014)
- Cost-Benefit Analysis and Environmental Valuation, WUR (2014)
- Teaching and supervising thesis students, Wageningen Graduate Schools (2017)

Selection of external training at a foreign research institute

- System thinking and systems simulation – modelling dynamic feedbacks systems with VENSIM, Helmholtz Centre for Environmental Research UFZ, Germany (2016)
- Training on biomass burning: forecasting emissions from vegetation fires and their impacts on human health and security in South East Asia, The Agency for Meteorology Climatology and Geophysics and World Meteorological Organization, Indonesia (2016)

Management and Didactic Skills Training

- Supervising three MSc students with thesis (2015-2017)
- Co-organisation of Wageningen Indonesia Scientific Exposure Symposia (2016 and 2017)

Selection of Oral Presentations

- *Valuing and mapping ecosystem services hotspot and trade-off to support sustainable peatland management*. 15th International Peatland Society Congress 2016, 15-16 August 2016, Sarawak, Malaysia
- *Towards sustainable management of Indonesian tropical peatlands*. Wageningen Indonesia Scientific Exposure (WISE) Symposium 2019, 12 March 2019, Wageningen, the Netherlands

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