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Sustainable land preparation for farmer-managed lowland agriculture in Indonesia

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ABSTRACT

In almost all forms of agriculture and farming practice, land clearing is the initial step. In Indonesia, in general, the most cost effective means of clearing land is through the use of fire. However, this use of fire often results in uncontrolled outbreaks, particularly in lowland areas especially and during prolonged dry seasons. In recent years, these uncontrolled fire outbreaks have had a catastrophic environmental, social and economic impact. The Indonesian government has expressed a strong commitment to controlling these outbreaks, as demonstrated by a broad set of laws, regulations, decrees, guidelines, and directives to control and manage land and forest fire. However, despite these measures, the occurrence of widespread, high-intensity fire outbreaks is still unacceptably high. This study assessed land-clearing techniques associated with a low risk of fire outbreaks, comparing the costs associated with a range of these techniques. It then analyzed intervention options that would involve the adoption of these techniques by farmers. These low-risk techniques included: (i) zero-burning practices involving traditional machinery and farmer groups; (ii) zero-burning involving modern machinery and partnerships with government agencies/private enterprises; (iii) controlled burning; and (iv) the chemical removal of biomass using herbicides. The study finds that the costs for all four of these options are higher than with land-clearing techniques that use fire alone. However, it also showed that the cost implications for farmers could be mitigated by taking a more holistic view of farming practices as a system, rather than focusing only on land-clearing practices in isolation. It found that when land-clearing practices that involve low risks of fire outbreak are combined with good agricultural practices (GAP), farmers could still achieve higher levels of profitability and productivity than under a business as usual (BAU) scenario. The study produced scenarios involving BAU practices; land clearing without fire and with BAU practices; and land clearing without fire and with good agricultural practices (GAP) for four agricultural commodities (oil palm, cocoa, rubber, and paddy). It found that the return on land (NPV) in the case of the scenario involving land clearing without fire and with GAP was still higher than under the BAU scenario, except in the case of rubber, with which the NPV was higher in the scenario with modern machinery and GAP. The study concludes that a systems approach is necessary to effectively control fire outbreaks. Government programs should be designed and implemented on the basis of this systems approach with the involvement of a wide range of stakeholders, including through partnerships with the private sector operators, to effectively control the risk of fire outbreaks while at the same time supporting farmers' livelihoods by ensuring that they are enabled to generate higher levels of productivity and profitability from their land.

1. Introduction

The use of fire for land clearing in agricultural practices creates major challenges for sustainable land management. This use of fire is often blamed for causing deforestation and generating unacceptable levels of CO2 emissions (Heymann et al., 2017). In Indonesia, at the national level, approximately 20% of deforestation can be attributed to the conversion of forest to grassland/scrublands, with a large proportion of this deforestation in peak years being attributed to the use of fire (Austin et al., 2019). The increasing intensity, frequency, and scale of land and forest fires in recent years in Indonesia has resulted in a series of catastrophic environmental disasters. For example, in 2015, forest

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and land fires resulted in much of the region being covered in a thick, toxic cloud of smoke, with severe negative impacts on the health, education, and livelihoods of millions of Indonesians (Tacconi, 2016; Koplitz et al., 2016). The haze also affected neighboring countries, particularly Malaysia and Singapore, reaching as far as southern Thailand. The total volume of emissions from forest and land fires in Indonesia was estimated to stand at between 0.8 and 1.1 Gt CO2-e, depending on the emission factors calculated. Economic losses resulting from the fires reached a value of approximately USD 16.1 billion (IDR 221 trillion) (World Bank, 2016). While the incidence of forest and land fires declined in 2016 and 2017, they have been on an increasing trend in 2018 and 2019 (Fig. 1). This trend raises questions as to whether Indonesia's existing institutional, legal and regulatory frameworks are functioning effectively. With a complex range of factors driving the outbreak of fires and with these fires affecting multiple stakeholders, efforts to prevent and control them must address not only technical considerations, but also a wide range of social and ecological considerations, with a need for interventions to facilitate behavioral changes.

Indonesia's lowland areas, including its peatlands, are both environmentally fragile and relatively highly prone to the risk of fire. These areas play an essential role in the production of key commodities. "Lowland areas" are defined as areas of land at an elevation of 0–200 m above sea level (WACLIMAD, 2012). Fires on peatlands results in a much higher level of emissions than do fires on land with mineral soils (Agus et al., 2010). In Indonesia, in 2015, about 81% of total $CO_{2\ e}$missions resulted from fires on peatlands (Pribadi and Kurata, 2017).

Lowland areas play a vital role in Indonesia's smallholder farming sector. In Southern Sumatra, farmers have traditionally engaged in a practice known as *sonor,* a system of rice cultivation, in which surface vegetation is burnt during the dry season, with rice then sown on the ash-enriched soil (Chokkalingam and Suyanto, 2004). Local communities in Papua engage in similar practices to plant sago, a staple food in the region (Cabuy et al., 2012). The expansion of oil palm as a cash crop by smallholders in Sumatra and Kalimantan, particularly in peatland areas, has increased the general risk of fire (Schoneveld et al., 2019).

Appropriate land preparation practices are vital to ensure that agricultural fields are in optimum condition for planting. In Indonesia, both smallholder farmers and large plantations have a long history of using open burning practices to prepare land for agriculture, particularly to remove trees and bushes from the land surface. Among other reasons for the use of open burning practices, they are regarded as the most cost-effective, fastest, and easiest method to clear and prepare land for agricultural purposes (Purnomo et al., 2017; Attwell et al., 2015; Dennis et al., 2005; Guyon and Simorangkir, 2002; Pausas and Keeley, 2009; and Suyanto et al., 2004). In addition, it is regarded as an effective means of controlling pests, diseases and weeds and for facilitating the rapid recycling of soil nutrients. However, it has been demonstrated that these practices are only effective for these purposes in the short term (Murniati, 2018; Simorangkir et al., 2002; Vickerman, 1988).

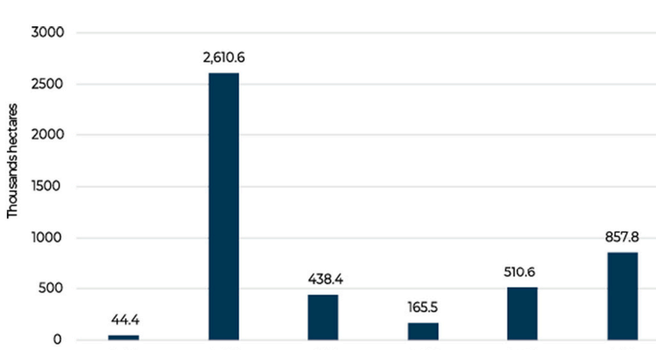

Fig. 1. Forest fire areas in Indonesia between 2014 and 2019 (MoEF, 2019).

To reduce the outbreak of uncontrolled fires and to mitigate their impact, since 1997/98, the Indonesian government (and provincial and district governements throughout the country) have promulgated a wide range of laws, regulations, decrees, and guidelines related to the management of forest and land fires. The most significant of the measures defined by these legal instruments involves a ban on the use of fire use for land clearing for agriculture. Forestry Law Number No. 41/1999, Plantation Law No. 18/2004, Environmental Protection and Management Law No. 32/2009 and Peatland and Protection law No. 71/2014, all stipulate a ban of on the use of fire for these purposes. As a specific measure to control fire on peatlands, Indonesia issued a temporary moratorium on the award of new licenses in primary natural forests and peatlands in 2011, which was made permanent in 2019.

There are two major constraints on the use of zero-burning practices for land clearing by farmers, these being: (i) farmers' limited financial capability to bear the associated costs; and (ii) farmers' limited access to the technology and machinery required to implement them. Agribusiness and pulp paper companies have implemented various types of incentive schemes to reduce the outbreak of fires, including through the provision of financial incentives to villages. For example, through the fire-free village (FVT) program in Riau, one major company provides cash incentives of IDR 100,000,000 (equivalent USD 7218) to villages in Sidorenko if there is no occurrence of fire, with an incentive of half this amount if the area affected by fire outbreaks is less than 2 ha. No incentive is paid if the area affected by the fire exceeds 2 ha. Since the application of zero-burning practices is mandated by law, the incentive scheme can be regarded as a measure to encourage farmers to comply with these regulations (APRIL, 2017; Watts et al., 2019).

This paper focuses on farmer-managed farming practices. However, interactions, challenges, and opportunities to combine efforts with large-scale land operators are also integral to the analysis. The objectives of this study are to: (i) identify land clearing practices associated with a low risk of fire outbreak; (ii) compare the costs and benefits of a range of land-clearing practices for agriculture; (iii) recommend intervention options to facilitate the behavioral changes required for the widespread uptake of fire-free land preparation practices. The paper explores the economic and ecological impacts of a range of land-clearing techniques associated with low fire risk. It also investigates the enabling conditions required for the uptake of each of these techniques. It further discusses the implications of these findings to develop intervention options for sustainable land preparation for farmer-managed lowland areas in Indonesia. Finally, it proposes policy options for the implementation of land-clearing techniques associated with low risk of fire outbreaks.

2. The framework of analysis on lowland agriculture in Indonesia

Land and forest fire outbreaks in Indonesia's lowland areas, particularly its peatlands, have created major issues at multiple levels of jurisdiction, from local, regional to national. The occurrence of these outbreaks is already frequent, with the frequency expected to increase into the future as a result of climate change and forest degradation. The impact of these outbreaks has been devastating and widespread. A wide range of regulations have been implemented at all these levels of jurisdiction to ban the use of fire to prepare land for agriculture, although these measures have so far had only minor and/or short-term impacts. At the local level, the enforcement of bans is often weak, with local police and law enforcement agencies often reluctant to enforce the measures stipulated by regulation (Murniati, 2018). This reluctance often stands from a perception that local communities have no other means to prepare their land with their current level of capacities. Researchers in the field have found many cases of members of local communities expressing a strong desire for the bans to be rescinded (Silvianingsih et al., 2020).

It is acknowledged that zero-burning land preparation practices may result in direct increased opportunity costs (Purnomo et al., 2017). Thus, some research has been directed to exploring the effectiveness of providing incentives to farmers who do not use fire (the "carrot approach") (Watts et al., 2019; Tacconi, 2012), in addition to the imposition of sanctions for failure to comply (the "stick approach"). Some research is also being conducted to explore a range of interventions intended to facilitate the prevention of fire outbreaks (Carmenta et al., 2020). These studies focus on high-precision policies and interventions that single out the use of fire, without reference to a more holistic, comprehensive view of community livelihoods and the nature of communities' interactions with large landholders and government stakeholders (Santika et al., 2020). This tendency to view the use of fire in isolation from these other factors may be a significant cause for the relative ineffectiveness of current policies and interventions. It is proposed that the provision of incentives as part of a broad spectrum policy that addresses multiple drivers and pressures related to fire use may be more effective. At present, the impact and effectiveness of environmental policies and programs is often low because it does not take a broader view of the context in which agriculture is practiced (Borner et al., 2020). In addition, it has been suggested that there is a better need for greater alignment between these policies and programs with local and global development goals. Reactive forest fire legislations have often proven to be ineffective, since these are not based on a more holistic view of forest management and planning, with a range of relevant factors being considered only in isolation (Mourao and Martinho, 2019).

The current "carrot and stick" approach to policies and regulations related to the use of fire and fire outbreaks may be effective in the short term, if these measures are enforced stringently during periods of particularly high fire risk (e.g., El Nino). However, unless these measures are integrated and aligned with other areas of policy and supported by well-funded programs, they are unlikely to address the complex underlying issues. Rather, it is necessary to support the development of public-private partnerships to create solutions that are economically and socially viable for members of local communities. This will involve a considerably broader conception of relevant issues than is required merely to implement measures to punish farmers for the use of fire and to incentivize them for compliance with the regulations. Internalizing the externalities of social costs and benefits can be addressed by broadening the cost and benefit of a certain practice by targeting the system by which the practices are adopted. While a full examination of the social and economic measures required to facilitate behavior change by farmers is beyond the scope of this paper, it recognizes that these measures are ultimately crucial to the development of sustainable agricultural practices.

This paper focuses on identifying effective measures to implement non-fire, zero-burning land preparation practices on the basis of a comprehensive examination of the economics of smallholder agriculture. It will also explore potential collaboration between smallholder farmers and large companies operating in close proximity to each other within a defined area and within the same landscape.

The study focuses on lowland areas in three large islands of Indonesia, these being Sumatra, Kalimantan, and Papua. To delineate lowland areas, it uses the data produced by the Water Management for Climate Change Mitigation and Adaptive Development in the Lowlands (WACLIMAD) project in 2010–2012, updated in 2018 (World Bank, 2018). The total area covered by such ecosystems amounts to 33.7 Mha, or about 25% of the total terrestrial area of the three islands under study. In addition, Indonesia has the largest area of tropical peatlands of any nation, with these peatlands also distributed in the lowland areas of these three islands (World Bank, 2018).

Based on the fire risk modeling conducted by ICRAF using fire hotspot data in 2015 and several explanatory data layers, fire risk maps for these three large islands were produced (Dewi et al., 2015). Fig. 2 presents these fire vulnerability maps for the lowland areas in the three islands. A large percentage of the lowland areas in Sumatra and Kalimantan were identified as being at high risk of fire. While the risk of fire in the low lands in Papua were relatively lower, they were still substantial, particularly in the southern areas of the island, where most peatlands are located.

2.1. Smallholder farming practices in the lowland areas of Indonesia

Lowland areas a play a vital role in Indonesia's agricultural sector, supporting a huge number of smallholder farmers and their livelihoods. The most extensive smallholder farming systems involve the cultivation of lowland rice and tree crops for export commodities, including oil palm, rubber, cocoa and coffee, which are cultivated under both monoculture and agroforestry systems. Around 80% (14.25 million households) of total households involved in paddy farming in Indonesia (17.73 million households) can be categorized as small-scale farmers, with average landholding of less than 0.5 ha per household, an area that may not even be sufficient to meet these farmers basic household needs (Indonesia investment, 2017; Nasir et al., 2015; Zahri and Febriansyah, 2014; Anggoro, 2014. Given the social and economic importance of smallholder farming in Indonesia, Lakitan (2014) argues that the success of agricultural practices should be assessed not only in terms of productivity, but also in terms of inclusiveness and sustainability as important indicators. Lakitan also finds that the adoption of readily useable agricultural technologies by smallholder farmers in Indonesia that could facilitate higher levels of achievement in terms of these indicators has been limited by agronomical, financial, and/or socio-cultural constraints.

In Indonesia, smallholder farmers have traditionally grown oil palm and rubber on peatlands, as these crops can grow well in poor soil (Wahyunto and Agus, 2010). Although large companies continue to

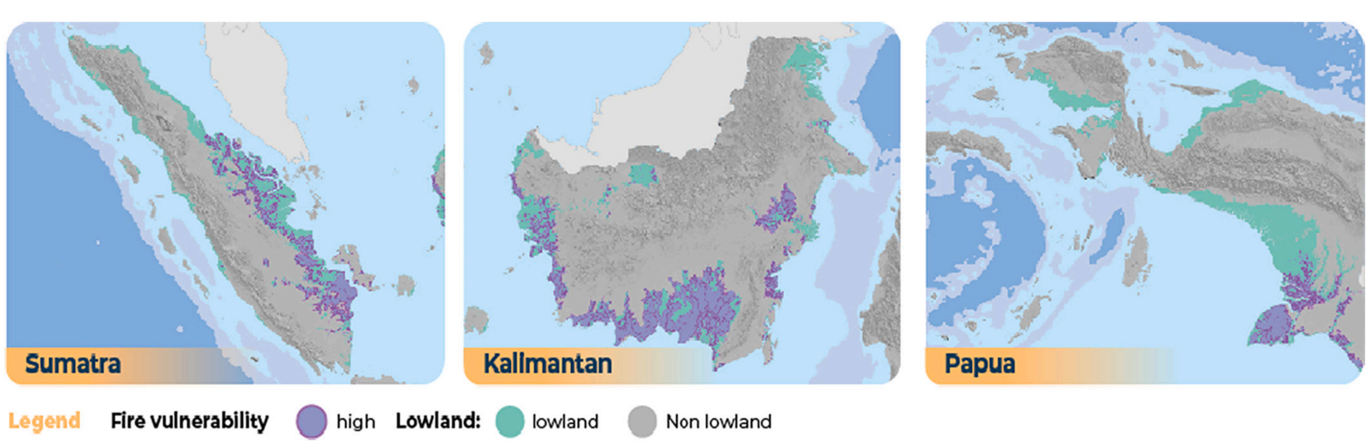

Fig. 2. Fire risk maps in the lowland area of Sumatra, Kalimantan, and Papua.

dominate the cultivation of oil palm on peatland, the role of smallholders has increased significantly over recent years, with the total proportion of peatland used for the cultivation of this crop and under the management of smallholders increasing from 28.0% in 2000 to 46.6% in 2017.

In addition to oil palm, smallholders also cultivate coconut, pineapple, sago palm, rubber, and a number of other crops (Miettinen et al., 2012). Unlike oil palm, rubber plantation in Indonesia is dominated by smallholders, who manage approximately 86% of the 3.5 million hectares used to cultivate this crop. Peatland has been used for the cultivation of this crop by smallholders since around 1920 (Firmansyah et al., 2012), and now constitutes a significant source of livelihoods (Suyanto et al., 2009).

At a global scale, approximately 90% of cocoa is produced by smallholders with farms of less than five hectares. In Indonesia, it is estimated that 1.6 million smallholder farmers are involved in cocoa production (ICCO, 2012). The majority (71%) of Indonesia's cocoa production is concentrated on Sulawesi. The majority of the remainder of Indonesia's cocoa is produced on Sumatra, Kalimantan, with a small progression produced on other islands, including Bali and Flores (Ruf et al., 1996).

2.2. Land preparation with fire and without fire

Land clearing is the initial stage of preparing land for agricultural activities. Land clearing is defined as "*The process of removing trees, stumps, brush, stones and other obstacles from an area as required to increase the size of the crop-producing land base of an existing farm or to provide land for a new farm operation*" (The New Brunswick Department of Agriculture, Fisheries and Aquaculture, accessed 20 January, 2020). Choices related to methods to clear land will differ according to the initial land cover conditions and their implications for planting. In general, in Indonesia, land cleared for agricultural, plantation, and forest plantation activities are covered with secondary forest, shrubs and bushes, grassland, and *Imperata*.

In general, the use of fire to clear land involves four steps. Initially, bushes and small trees with a diameter of less than 15 cm are cut down using axes, machetes, and/or bulldozers. The next step involves the felling of larger trees with a diameter of more than 15 cm using excavators, chainsaws and/or axes, following which their stems, branches, following which twigs are cut and stacked. Finally, the branches of the trees are burnt. To implement zero-burning techniques, instead of burning the stems and branches, they are cut and stacked into regular rows at specified distances from each other to form a planting path, then the remaining portions of the plant are cleaned to make a path to facilitate the planting process. With this technique, the tree biomass can generate economic benefits through the production of organic fertilizer and/or charcoal, which can be used as a fuel to create bioenergy and/or for other purposes (Fig. 3).

The study identifies four alternative land-clearing techniques that result in the production of relatively low levels of smoke emission, as follows: 1) zero-burning techniques involving the use of traditional machinery and farmer groups; 2) zero-burning techniques involving the use of modern machinery; 3) controlled burning; and 4) the application of chemicals to remove biomass.

2.2.1. Zero-burning with traditional types of machinery

This technique is implemented collectively with the involvement of farmer groups. All land-clearing activities use manual labor, with the use of simple, traditional agricultural tools such as hoes, machetes, axes, and plows (manual). Alternatively, this technique may use a combination of manual labor and equipment such as chainsaws and mowers. Small-scale farmers implement this technique on areas of a limited size and with a limited budget (Nugroho, 2012). This technique can be used to clear land with a wide range of topographies, land cover types, and soil types (mineral and peat). While it results in minimal damage to soil, with no compaction, it is labor-intensive and time-consuming.

2.2.2. Zero-burning with modern types of machinery

This technique can be implemented in partnership with government

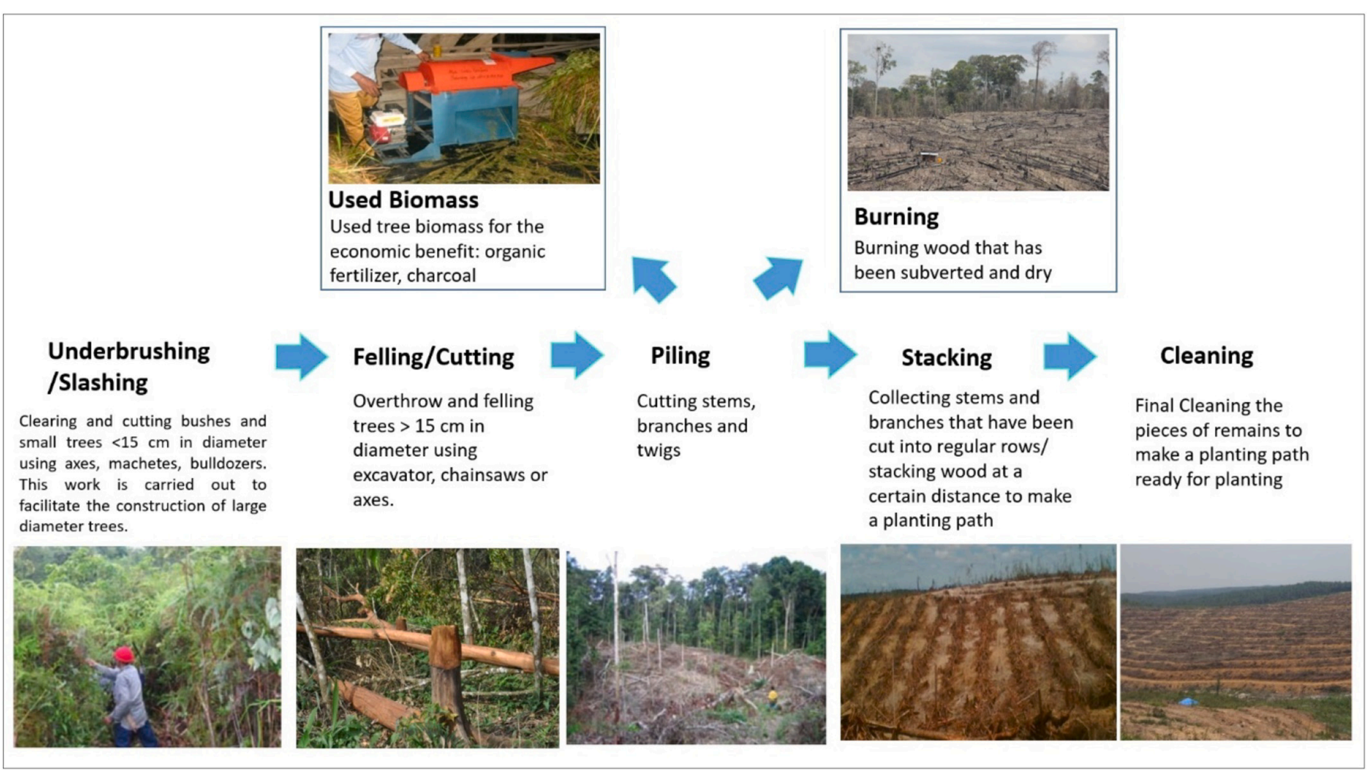

Fig. 3. Land clearing activities. (Photos were taken from ICRAF database, 2011–2019).

agencies and/or private enterprises. Land preparation activities make use of heavy machinery, including tractors, bulldozers, and excavators. The use of this machinery and equipment enables the land preparation process to be completed more rapidly. Thus, it may be suitable for the preparation of large areas of land. This technique is not labor-intensive, but it may not be suitable for land with steep inclines of greater than 21%, nor may it be ideal for the clearing of small areas of land (FAO, 1985a, 1985b). The disadvantages of this technique are that: (i) it requires significant financial investments, both to purchase or rent the equipment and to operate it; (ii) it results in soil compaction; (iii) it requires the deployment of skilled workers or operators. Despite these disadvantages, smallholders can utilize this technique in partnership with government agencies and/or private enterprises to facilitate their access to heavy machinery.

2.2.3. Controlled burning

This technique involves the controlled application of fire to a defined vegetated area to maintain or modify a system to meet a predetermined objective (Wade and Lundsford, 1990). In other words, controlled burning involves the use of fire on a specific area of land under selected weather conditions to accomplish well-defined management objectives. Controlled burning practices can be used by smallholder farmers (Saharjo and Munoz, 2003). This technique should only be applied on a small scale in areas with strong community controls and/or *adat* law and when zero-burning techniques are not feasible, such as on steeply sloped lands where it is difficult or impossible to use heavy machinery.

2.2.4. The application of chemicals to remove biomass

This technique uses herbicide to remove grass, thin thicket, and biomass, and may be appropriate when the land is covered by *Imperata* and/or thin thicket. Chemical control methods using a chemical spray and systemic weedkiller destroy whole plants and may involve repeated defoliation. The land classifier may have to advise on the terrain conditions for the application of weedkiller by mechanical methods if large areas are to be treated. At some sites, the limited availability of water for spraying may act as a constraint (FAO, 1985a, 1985b). This technique should only be applied on a small scale and away from areas where herbicides might contaminate water sources, watercourses, or drainage facilities.

3. Method

3.1. Data collection

The research was conducted on the basis of the collection of secondary data from literature studies and of primary data from the field study. We reviewed existing data availability, accessibility, quality, and the gap from published and unpublished articles to identify zero-burning land-clearing techniques. This literature review also sought to identify the impacts of a range of identified land-clearing techniques. Based on the results of the literature review, we interviewed experts and conducted focus group discussions on issues related to zero-burning techniques, including a comparison of the costs associated with different techniques of land clearing and the advantages and disadvantages of both burning and zero-burning practices.

A series of field surveys were conducted in Sumatra, Papua and Kalimantan to collect data related to the cost of land-clearing practices and the level of profitability of farming systems. In addition, we also used ICRAF's existing data related to the cost of various farming practices to calculate a cost comparison between types of land-clearing techniques, commodities prices, wage rates, and farming budgets for selected commodities. The impact of the range of intervention options was analyzed on the basis of a comparison with current practices, with the intervention options investigated in terms of economic indicators such as net present value, cost of establishment, and marginal rate of return.

3.2. Data assumptions and analysis

In this study, the primary instrument used to determine levels of financial feasibility was the Land-Use Profitability Assessment (LUPA), which is an analytical framework used to conduct an economic assessment of land-use systems, implemented at the landscape level. LUPA estimates monetary surplus (profitability) for each land area on the basis of the level of investment allocated by operators, including both smallholders and large-scale operators (Rahmanullah et al., 2013).

Net present value (NPV) is the most common indicator used to compare the level of profitability from different types of investment in a profitability analysis. The NPV of an investment is defined as the sum of the present values of the annual cash flows, minus the initial investment. The annual cash flows are the net benefits generated from the investment during its lifetime. These cash flows are discounted or adjusted by incorporating the uncertainty and time value of money (Gittinger, 1982). NPV is one of the most robust financial evaluation tools available to estimate the value of an investment. The investment for a specific land-use is determined to be profitable if the NPV is higher than 0. The formula to calculate the NPV is given below.

$$NPV = \sum_{t=0}^{t=n} \frac{B_t - C_t}{(1+i)^t}$$

Where B_t is the benefit at year t, C_t is the cost at year t, t is time denoting year, and i is the discount rate. A profitability assessment requires a detailed farm-budget calculation. It is necessary to clarify the macroeconomic assumptions and the appropriate prices for the calculation of the cost and return used in this assessment. In this study, a number of macroeconomic parameters are used (see Table 1).

The profitability calculations in the study are based on 2019 macroeconomic data. The exchange rate stood at IDR 13,853 per USD 1 at the time the data was collected. The average daily wage rate for agricultural work was estimated to stand at USD 5.8 for Sumatra, USD 7.2 for Kalimantan, and USD 8.7 for Papua Island. Real interest rates (that is, interest rate net of inflation) are the discount factors used to value future cash flows in the current term. A private discount rate of 7% was selected as the initial value for a range of different land-use activities.

The research applies two profitability indicators: (1) return to land; and (2) cost of establishment. The study uses NPV estimates to measure returns to land because they can be regarded as the 'surplus' remaining after accounting for costs of labor, capital (through discounting), and purchased inputs. The cost of establishment is defined as the accumulated costs incurred up to positive cash flow. We develop two basic scenarios for a range of farming practices and management scenarios across the selected lowland commodities by estimating the profitability of each and comparing them. Current common practices are referred to as Business-As-Usual/BAU practices, while those associated with the proposed interventions are described as *good agricultural practices* (GAP). These scenarios are developed for selected farming systems that are important in lowland areas. The selection of farming systems was conducted to include crops and plantations. The selected lowland commodities were monoculture oil palm, monoculture cocoa, monoculture rubber, and rice paddy. Basic assumptions for BAU and intervention scenarios are defined (Table 2). We formulated the assumptions for the GAP interventions for fertilizer and productivity based on research conducted by a national research agency (Darmosarkoro et al., 2003; DGP, 2014) and on the basis of simulations conducted by ICRAF.

Table 1
Macro-economic parameters.

Macro-Economic Parameters	Year 2019
Official exchange rate (IDR/USD)	13,853
Real interest rate (per annum)	7%
Agricultural wage rate (USD/person/day)	
Sumatra	5.8
Kalimantan	7.2
Papua	8.7

Table 2
Assumptions for the BAU and intervention scenarios.

No	Farming System	Scenario	Seedling	Number of Trees (Trees/ha)	First Time Production (year)	Product	Fertilization (kg/ha/year)	Average Productivity (ton/ha/year)
1	Oil Palm Monoculture	BAU	Local wildlings	136 trees	3	FFB	less	15
		GAP Intervention	Certified seedling	136 trees	3	FFB	Urea 280 TSP 227 Kieserite 165	22
2	Cocoa Monoculture	BAU	Local seedling	1100 trees	4	Bean	less	0.55
		GAP Intervention	Certified seedling	1100 trees	3	Bean	Urea 225 TSP 187 KCL 174	1
3	Monoculture Rubber	BAU	Local wildlings	550 trees	8	Latex	no	1.18
		GAP Intervention	Certified seedling	550 trees	5	Latex	Urea 326 TSP 244 KCL 268	2.2
4	Paddy	BAU	Local seedling	25 kg/ha	1	Rice	less	5
		GAP Intervention	Certified seedling	25 kg/ha	1	Rice	Urea 900 TSP 800 KCL 400	7

4. Results and discussion

This study had three main areas of focus. First, it compares the costs of land preparation practices with and without burning. Second, it summarizes the socio-economic and environmental impacts of both burning and zero-burning and their impact on soil fertility and the prevalence of pests and diseases. Third, it analyses the levels of profitability for lowland farming systems both with and without burning and according to a range of intervention options.

4.1. The costs of land preparation with and without burning

The use of fire to clear land is relatively cost-effective, but it comes at the cost of a significant adverse environmental impact. In terms of initial, short-term financial costs, the use of fire to clear land is the most cost-effective of all the techniques described, both for smallholder farmers and large-scale enterprises in Sumatra, Kalimantan and Papua. By contrast, zero-burning techniques are significantly more expensive. Two examples are presented to compare the costs of applying zero-burning practices to clear land covered by secondary forest and *Imperata*. The first example explores the cost of applying zero-burning techniques to clear land covered by secondary forest. For smallholder farmers, the cost of applying zero-burning techniques to clear land covered with secondary forest in Sumatra (Fig. 4) is 41% higher than the use of burning when manual labor is used exclusively; 131% higher when semi-mechanical means are used; and 182% higher when heavy machinery is used. Similarly, compared to the cost of burning by smallholders in Kalimantan, the cost of applying zero-burning techniques is 29% higher when using manual labor, 92% higher when using semi-mechanical means, and 123% higher when heavy machinery is used. For smallholders in Papua, the cost of applying zero-burning techniques is 29% higher when manual labor is used exclusively; 66% higher when semi-mechanical means are used; and 90% higher when heavy machinery is used.

The second example examines the cost of zero-burning practices to clear *Imperata* (Fig. 4). The cost of semi-mechanical zero-burning practices to clear land covered with *Imperata* is the highest, ranging from between 69 and 92% higher than burning practices. Applying chemicals to remove *Imperata* is the most cost-efficient land clearing method. The land clearing cost is 12–18% lower than burning practices in the case of smallholders. Zero-burning techniques that use chemicals means to clear *Imperata* should therefore be considered as an alternative option.

While it is acknowledged that the initial costs associated with the use of fire to clear land are relatively low, the costs associated with the environmental disasters that the use of fire can cause are often not accounted for as an integral component of cost calculations. The economic costs associated with the 1997/1998 uncontrolled land and forest fire outbreaks in Indonesia have been estimated to stand at more than USD 9 billion (ADB, 2001), while the 2015 fires resulted in damfage and losses to a value of approximately at USD 16.1 billion (World Bank, 2016). Similarly, the economic losses resulting from the widespread fires in 2019 are estimated to stand at USD 5.2 billion (World Bank, 2019). Section 4.3 discusses the advantages and disadvantages of land clearing without fire in terms of environmental and social factors. Further, in Section 4.4, rather than looking only at the costs associated with land clearing, we use levels of profitability as an important economic indicator to assess agricultural practices as systems. In this section, we compare performance in terms of the indicators according to a range of farming system scenarios to produce oil palm, cocoa, rubber, and paddy.

4.2. Impacts of zero-burning techniques

In recommending policies and interventions, it is vitally important to analyze the relative advantages and disadvantages of zero-burning techniques for land clearing (Table 3). The impacts of zero-burning techniques have been intensively researched, with studies in terms of environmental impacts (Rasyid, 2014; Jhariya and Raj, 2014; Awaluddin, 2016; Islam et al., 2016; Andini et al., 2018; Yue and Unger, 2018); socioeconomic impacts (Rabade and Aragoneses, 2003; Paveglio et al., 2015; Simorangkir, 2007); and impacts in terms of soil fertility (Dennis et al., 2013; Jhariya and Raj, 2014; Ratnaningsih and Prastyaningsih, 2017; Choiruddin et al., 2018; Wasis et al., 2017); pest control (Firmansyah and Subowo, 2012; Hauser and Norgrove, 2013; Ooi and Heriansyah, 2005; ASEAN, 2003); and weed control (Ditomaso and Johnson, 2006; Friesen, 2009; Mutch et al., 2008).F.

Based on this available literature, we summarize the impacts of applying zero-burning techniques in terms of five factors: environmental, soil fertility, pest and diseases, weed control and socioeconomic. Zero-burning has a number of significant advantages in terms of lower impacts on the environment and soil fertility but disadvantages in terms of occurrences of pests and diseases, weeds. Finally, it has a relatively high level of burden in terms of socio-economic factors (Table 3).

In general, it was found that while fires resulted in huge losses at the landscape, provincial and national levels, this was not reflected at the farm level. The World Bank (2019) estimated that the economic damage resulting fires in that year at the provincial levels amounted to 7.9% of Central Kalimantan's GDP and to 6.1% of West Kalimantan's GDP. However, analysis at the farm level of the economic advantages and disadvantages of zero-burning is crucial as a basis to identify

Fig. 4. Cost comparison of land-clearing techniques in the case of land covered by secondary forest and *Imperata* on the three islands.

interventions that result in behavioral change among farmers and their adoption of zero-burning practices to clear land.

4.3. The profitability of main lowland farming systems with and without burning

The intervention options are developed by analyzing the impacts of zero-burning techniques under the BAU and GAP simulation scenarios. The simulation was conducted to analyze the impact of interventions if zero-burning techniques are applied in terms of a number of economic indicators, including return to land, establishment costs, and marginal rate of Return (Table 4). We selected four main lowland farming systems that involve smallholders to a significant extent (i.e., oil palm, cocoa, rubber and paddy). For this analysis, we used data from Sumatra, Kalimantan and Papua.

The results of the scenario simulation for the intervention options for the selected farming systems are discussed below.

4.3.1. Oil palm

It was found that the return to land (NPV) under the current practices (BAU) scenario with zero-burnings (using manual techniques) was lower (1.4%) than under the current practices (BAU) scenario with burning. Interventions involving good agricultural practice (GAP) have the most significant impact in terms of levels of profitability (Table 5). With the addition of controlled burning practices, the level of profitability declines by 0.4% if controlled burning is applied; with the addition of zero-burning practices with manual techniques, the level of profitability declines by 1.4%; and with the addition of zero-burning practices with modern machinery, the level of profitability declines by 4.5%. A scenario in which zero-burning techniques are combined with GAP still results in a higher level of profitability than the scenario involving current practices (BAU). The level of profitability for a scenario

Table 3
Advantages and disadvantages of zero-burning techniques.

Advantages	Disadvantages
• Does not cause air pollution. • Result in lower levels of GHG emissions, particularly CO_2. • Minimizes the risk of water pollution resulting from leaching or surface washing of nutrients. • Minimizes nutrient loss through run-off. • Limited dependence on weather conditions. • Ensures the sustainability of wildlife habitats. • Result in long-term ecological sustainability. • Improves soil organic matter (SOM) content. • Reduces the need for chemical fertilizers by recycling the nutrients in SOM. • Causes less soil disturbance, leading to the preservation of soil biological diversity. • Ensures long-term soil health and sustainability • Result in improved soil properties (pH and soil structure). • Releases nutrients over a longer period. • Results in a low level of erosion.	• May result in pests and diseases causing serious losses to the newly planted vegetation. • Creates breeding grounds for rats. • Results in increased susceptibility to attacks by termites. • Increases dependence on pesticides and herbicides, which may have acute and chronic impacts on human health, and which may contaminate the atmosphere, ground and surface water. • May create problems related to weed growth. • May threaten native plants and animals and disturb natural systems. • May result in weed infestations that reduce farm and forest productivity, invade crops, smother pastures and harm livestock. • May result in weed invasions affecting natural biodiversity and the balance of ecological communities. • May result in weeds causing problems for human health, with some weeds being poisonous and causing skin irritation. • May result in increased costs, with more complicated procedures that may require the use of heavy equipment. • Require strong social capital, with strong customary law and community fire control systems.

Table 4
The intervention options for land-clearing techniques and farming practices.

Scenario	Explanation
Business as Usual (BAU)	Existing common practice with burning land clearing
Business as Usual (BAU) with Zero-burning (Zb)	Existing common practice with zero-burnings (manual technique)
Intervention 1	Good Agriculture Practices (GAP) using certified seedling and optimal fertilization with burning land clearing
Intervention 2	GAP with controlled burning technique
Intervention 3	GAP with zero-burnings (manual technique)
Intervention 4	GAP with zero-burnings (modern types of machinery /mechanics)

involving GAP interventions with controlled burning is 48% higher than under the BAU scenario. Similarly, the profitability under a scenario involving GAP interventions with manual techniques is 47% higher than under the BAU scenario, while under a scenario involving GAP interventions with modern machinery, it is 43% higher. A scenario involving the addition of zero-burnings to the current practices and intervention options increased establishment costs. Under a scenario involving GAP interventions with controlled burning, establishment costs increased by 44%; if manual techniques were used instead, by 51%; and if modern machinery was used by 67%. The marginal rate of return under the scenario involving GAP interventions with burning was the highest (48%). By applying zero-burning techniques, the marginal rate of return was higher than under the BAU scenario but lower than under the scenario involving GAP interventions with burning.

4.3.2. Cocoa

As with oil palm, in the case of cocoa, the return to land (NPV) under the current practices (BAU) scenario with zero-burning and the use of manual techniques is lower (3%) than under the current practices (BAU) scenario with burning. In the case of a scenario involving GAP interventions with good agriculture practice (GAP) and zero-burning, the return to land is lower than under the scenario involving GAP with burning (0.7–8%). However, under a scenario in which zero-burning techniques are combined with GAP, the level of profitability is still higher than under the current practices (BAU) scenario (Table 5). Under the scenario with GAP interventions with controlled burning, the level of profitability is 131% higher than under the BAU scenario. Similarly, the level of profitability under the scenario with GAP interventions with manual techniques is 129% higher than under the BAU scenario; while under the scenario with GAP interventions with modern machinery, it is 124% higher. Adding zero-burnings to current practices (BAU) increased the establishment costs. The establishment cost under the scenario with GAP interventions with controlled burning increased by 28%; under the scenario with GAP interventions with manual techniques, it increased by 34%; and under the scenario with GAP interventions with modern machinery, it increased by 46%. Under the scenario with GAP interventions with burning, the marginal rate of return is the highest (132%). With the application of zero-burning techniques, the marginal rate of return is higher than under the BAU scenario but lower than under scenario with GAP interventions with burning.

4.3.3. Rubber

Under a current practices (BAU) scenario with zero-burning and the use of manual techniques, the return to land (NPV) is 18% lower than under the BAU scenario with burning. GAP Interventions have the most significant impact on profitability (Table 5). However, if zero-burning

Table 5
Profitability analysis of intervention options of sustainable land preparation.

Farming System	Profitability Indicator	Intervention					
		BAU	BAU + Zb	Intv 1	Intv 2	Intv 2	Intv 4
Oil Palm	NPV (USD ha^{-1})	5479	5404	8091	8070	8016	7845
	Change from BAU (%)		−1.4	48	47	46	43
	Est Cost (USD ha^{-1})	1045	1120	1500	1522	1575	1746
	Change from BAU (%)		7	44	46	51	67
Cocoa	NPV (USD ha^{-1})	3089	2992	7176	7155	7079	6931
	Change from BAU (%)		−3	132	131	129	124
	Est Cost (USD ha^{-1})	1254	1350	1589	1610	1686	1835
	Change from BAU (%)		8	27	28	34	46
Rubber	NPV (USD ha^{-1})	527	425	605	583	530	422
	Change from BAU (%)		−19	15	11	1	−20
	Est Cost (USD ha^{-1})	1359	1461	2498	2519	2573	2681
	Change from BAU (%)		7	84	85	89	97
Paddy	NPV (USD ha^{-1})	11,953	11,236	20,701	20,415	19,698	18,524
	Change from BAU (%)		−6	73	71	65	55
	Est Cost (USD ha^{-1})	1157	1214	1240	1264	1321	1416
	Change from BAU (%)		5	7	9	14	22

practices are added, the level of profitability declines by 4%–30%. Except under the scenario with GAP interventions with modern machinery, the scenario under which zero-burning techniques are combined with GAP interventions still has a higher level of profitability (between 1 and 11%) than under the BAU scenario. Under the scenario with zero-burning with the use of modern machinery, the level of profitability is 20% lower than under the BAU scenario. Adding zero-burnings to current practices increased the establishment costs. The establishment cost in the case of the scenarios with zero-burning techniques increases by 85%–97%. The marginal rate of return under the scenario with GAP intervention with burning is the highest (15%). With the application of zero-burning techniques, the marginal rate of return is higher than under the BAU scenario but lower than under have the scenario with GAP interventions with burning, except in the case of the scenario with GAP interventions with modern's machinery.

4.3.4. Paddy

Under a current practices (BAU) scenario with zero-burning and the use of manual techniques, the return to land (NPV) is 6% lower than under the BAU scenario with burning. GAP Interventions have the most significant impact on profitability (Table 5). However, if zero-burning practices are added, the level of profitability declines by 2%–18%. The scenario under which zero-burning techniques are combined with GAP interventions still has a higher level of profitability than under the BAU scenario. Under the scenario with GAP interventions with controlled burning, the level of profitability is 71% higher than under the BAU scenario. Similarly, the level of profitability under the scenario with GAP interventions with manual techniques is 65% higher than under the BAU scenario; while under the scenario with GAP interventions with modern machinery, it is 55% higher. Adding zero-burnings to current practices (BAU) increased the establishment costs. The establishment cost under the scenario with GAP interventions with controlled burning increased by 9%; under the scenario with GAP interventions with manual techniques, it increased by 14%; and under the scenario with GAP interventions with modern machinery, it increased by 22%. Under the scenario with GAP interventions with burning, the marginal rate of return is the highest (73%). With the application of zero-burning techniques, the marginal rate of return is higher than under the BAU scenario but lower than under scenario with GAP interventions with burning.

Except in the case of rubber, the various scenarios for the three other farming systems show similar patterns in terms of the defined economic indicators. Interventions involving the application of good agriculture practices result in the highest level of profitability. With the addition of zero-burning techniques, the level of profitability declines. However, the application of zero-burning techniques in combination with good agriculture practices still results in a higher level of profitability than current practices. In all intervention scenarios, establishment costs increased. The marginal rate of return is highest under the scenarios with GAP interventions with burning. By applying zero-burning techniques, the marginal rate of return is higher than under the BAU scenarios but lower than under the scenarios involving GAP interventions with burning. In contrast to this general pattern, in the case of rubber, the level of profitability in the case of the scenario involving mechanical techniques of land clearing and the application GAP is lower than under the BAU scenario.

5. Recommendations and conclusions

The findings of this study support our hypothesis that interventions to facilitate the achievement of sustainable land preparation must address a far broader range of issues and include measures beyond punishing farmers for using fire to clear land and rewarding them for refraining from doing so. The findings demonstrate that while the application of zero-burning techniques reduce levels of profitability, they are still important, considering their environmental advantages. With ineffective law enforcement to prevent the use of fire to clear land, it is clear that measures to ensure the uptake of zero-burning practices need to be accompanied by a complementary strategy. Rather than focusing exclusively on measures intended to ensure that farmers clear land without the use of fire, it is clear that there is a need for a systems approach that takes a holistic view of farming practices, with due consideration given to improving farmers' levels of productivity, sustainability, and profitability. Policymakers must address not only technical considerations, but also a wide range of social and ecological factors, with particular attention to behavioral change. In doing so, policymakers should consider intervention options that involve a combination of zero-burning techniques with good agricultural practices. Since it has been clearly demonstrated that the combination of zero-burning techniques with good agricultural practices results in higher levels of profitability than under the BAU scenario, zero-burning options may still be attractive to farmers if they are enabled to apply these good agricultural practices.

The cost margin between burning and zero-burning scenarios can be used as a basis to design economic instruments to enable people to implement zero-burning practices to prepare land. Rather than being presented as an incentive scheme, under which farmers are rewarded for refraining from activities such as burning practices that may be attractive to them in the short term, we recommend an approach involving the provision of support to enable farmers to adhere to good agricultural practices and thereby to comply with the regulations that ban the use of fire to clear land without suffering loss. For this purpose, partnerships could be established between local government agencies, national and international research institutions, and private sector operators to strengthen the capacity of farmers to implement good agricultural practices in lowland areas and thereby to ensure sustainable water and land management, with adjustments for the specific characteristics of peatlands.

Government policies and programs that are intended to prevent and mitigate the outbreak of land fires and the associated smoke and haze should be enforced and monitored. The implementation of awareness-raising campaigns and the strengthening of the capacities of the institutions involved in implementing these campaigns should be well-coordinated, with sufficient budget allocations.

Awareness building campaigns involving piloting and demonstration plots to educate farmers on matters related to good agricultural practices are necessary to convey the message that they can achieve higher levels of profitability while at the same time refraining from land clearing practices that involve the use of fire. Campaigns of this sort are essential to demonstrate to farmers and other stakeholders that they can achieve higher levels of profitability and productivity from the land while at the same time reducing health risks if they engage in collective action to conduct mechanized land clearing and preparation processes, rather than using fire to clear land. Thus, it is essential to pilot demonstration plots to improve capacities and to increase awareness of methods to clear land without the use of fire. In cases where zero-burning methods are not feasible, it may be necessary to consider the application of well-planned controlled burning. In cases where this is unavoidable, high levels of social capital, enforced by strong local customary (*adat*) law, are required to implement indigenous knowledge-based practices related to fire management, with these practices belonging to and being sustained by local farmers and other members of the community.

The public funding used to implement these measures can be justified in terms of their effectiveness as an instrument to achieve zero-burning. In the case of large companies, zero-burning practices are already clearly mandated in existing regulations. However, effective monitoring and enforcement are essential to ensure that these regulations are fully implemented in practice. Measures could be taken to involve financial institutions in the development and implementation of economic incentive systems (green investments, green banking, and partnership funding) to enable both smallholder farmers and private sector organizations to implement zero-burning practices. We also propose that measures should be taken to encourage the allocation of

Village Funds to purchase machinery collectively at the village level or to access other technologies and/or to build the capacity of institutions to prevent and combat fires.

Sustainability standards have been developed for a range of agricultural commodities, both at the national and global levels. These standards create strong incentives and a compelling need for agricultural commodity producers to address and minimize a wide range of environmental and social risk factors, including fire. Thus, measures should be taken to ensure that private sector operators are aware of the benefits of green product certification (involving compliance with the use sustainability standards) in terms of gaining access to international markets. Certification indicates that these operators' products do not harm people or planet by using fire to clear land or through other environmentally damaging activities. The certification systems are intended to provide clear proof and assurance that a certified business is socially and environmentally responsible and that it plays a strong, positive role in enabling farmers to reduce the risk of fire and to improve their livelihoods by providing them with access to machinery or other facilities to implement zero-burning land clearing processes. In addition, policymakers should give careful consideration to establishing and implementing co-designed schemes to enable farmers to access all necessary inputs to implement good agricultural practices, including in particular by providing access to good-quality planting materials. The involvement of all stakeholders will be necessary to ensure that these inputs are well matched with local capacities, needs, and contexts.

Credit author statement

M Sofiyuddin (MS) and S Suyanto (SS) designed the research with input from Sonya Dewi (SD). MS collected and analyzed the data with input from SS. SD provided substantial input in the framing and discussions of the manuscript. MS and SS wrote original draft preparation. SD and Sabarudin Kadir (SK) reviewed the manuscript. SS, MS and SD edited the manuscript.

Declaration of Competing Interest

None.

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