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Reviving Peatland Sustainability: Insights of Perception, Willingness to Invest, and Financial Feasibility of Agroforestry Models

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ABSTRACT

Several agroforestry-based peatland restoration models are currently being implemented. However, comprehensive evidence analysing farmers' perceptions, willingness to invest (WTI), and cost-benefit insights remains limited. Addressing this gap is essential for optimising sustainable peatland restoration. Therefore, this study aimed to analyse perceptions of peatland and agroforestry models, examine the factors determining farmers' WTI, and calculate the costs and benefits of agroforestry systems on peatlands. The study was conducted in Perigi Village, Pangkalan Lampam District, and Perigi Village, Kayu Agung District, Ogan Komering Ilir Regency, South Sumatra, Indonesia, where farmers had practised agroforestry for more than five years. Data were collected through a survey of 85 respondents and analysed using tabulation analysis, logit model, and cost-benefit analysis (IRR, NPV, Net B/C, and Gross B/C). The results showed that the majority of respondents perceived agroforestry schemes as an effective method for enhancing productivity by combining various commodities, including agrosilviculture, agrosilvofishery, and agrosilvopastoral systems. These systems were also considered capable of increasing farmer incomes and reducing peatland degradation. Approximately 72% of smallholder farmers in Indonesia were willing to implement the agroforestry model. Factors such as indigenous status, education, production planning, and farmer group activity positively influenced WTI, while dominant land use patterns and knowledge of agroforestry had negative effects. The optimal implementation of agrosilviculture systems, compared with agrosilvofishery and agrosilvopastoral, was necessary for sustainable development. This study suggests promoting smallholder farmers' adoption of agroforestry practices through

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improved decision-making support, social proximity, technical information, welfare benefits, and addressing productivity constraints.

Keywords: Agrosilvopastural, agrosilviculture, agrosilvofishery, restoration, welfare

INTRODUCTION

Tropical peatlands are essential as global carbon repositories. Although discovered in temperate, tropical, and boreal zones, these peatlands store the highest amount of carbon per unit area due to the thickness of the layers and abundance of above-ground biomass (Austin et al., 2025). Furthermore, tropical peatlands offer a range of ecosystem services, including the provision of timber and non-timber forest products, wildlife habitats, and water storage. They play a crucial role in regulating the water balance by mitigating the effects of floods and droughts through water retention following precipitation events and gradual release during dry periods (Loisel & Gallego-Sala, 2022; Pudyatmoko et al., 2023). The area of peatland owned by Indonesia is the second largest in the world after Brazil. It is estimated to cover half of all peatland areas in the entire tropical region and account for approximately 84% in Southeast Asia (Jessup et al., 2020; Lestari et al., 2024). The area in Indonesia is approximately 14.91 million ha, spread across Sumatra 6.44 million ha (43%), Kalimantan 4.78 million ha (32%), and Papua 3.69 million ha (25%) (Wicaksono & Zainal, 2022; Yuwati et al., 2021).

South Sumatra Province has an area of 1.28 million hectares of peatland, in which 0.78 million hectares are degraded and covered with grass and shrubs. This substantially increases the risk of peatland fires, particularly during periods of extreme drought, underscoring the need for integrated and sustainable ecosystem management. The issue continues to reoccur and has become a very serious challenge in the southern part of Sumatra Province. The peatlands of Indonesia, particularly in South Sumatra, are crucial ecosystems with large carbon stocks and unique biodiversity. However, these areas face significant threats from deforestation, unsustainable agricultural practices, and recurring fires, leading to degradation and loss of ecological function (Lestari et al., 2021; Wildayana et al., 2018; Winarno et al., 2022).

The direct impact of forest and peatland fires on humans is the loss of livelihoods, particularly among communities that depend on natural resources for farming, livestock, hunting, fishing, and other subsistence activities. The fires destroy plantations, agricultural lands, and crops, thereby reducing agricultural productivity. In addition to the economic impact, the global environment is also being affected. The combustion of vegetation and peat releases large amounts of carbon into the atmosphere, intensifying global warming. Recurrent burning also depletes soil nutrients and degrades peatland quality, diminishing its ecological functions and economic value for sustainable human use (Wildayana et al., 2018; Wildayana & Armanto, 2018).

The preservation of surviving peatlands is crucial for achieving effective and sustainable restoration. Based on observation, the restoration initiatives are particularly important for generating economic benefits that help secure local revenue (Gunawan et al., 2021; Purnomo et al., 2024). Restoration activities can be implemented through peatland cultivation methods based on the agroforestry concept that correlates with the needs for community welfare. Agroforestry provides a sustainable livelihood alternative that enhances biodiversity and ecosystem services while reducing pressure on forests by enabling the production of forest products within agricultural landscapes (Sheppard et al., 2020; Qurniati et al., 2024). Given these benefits, the Indonesian Ministry of Environment and Forestry has recommended agroforestry as the best practice for peatland restoration. Traditional agroforestry practices on peatlands are often limited to cultivation along riverbanks, where communities manage water levels through tidal movements and canal blockages. Various regions in the area also adopt polyculture practices, such as the surjan system, which combine water-based plants with plants or trees requiring drier soil (Rozaki et al., 2021; Triwanto et al., 2023; Wijayanto et al., 2022).

Although widely recognised as a sustainable method for peatland restoration, agroforestry adoption among smallholder farmers remains limited (Gori Maia et al., 2021; Rozaki et al., 2021; Triwanto et al., 2023). This condition shows that farmers' decisions are influenced not only by economic feasibility but also by socio-economic perceptions and investment considerations (Pusvita et al., 2024; Wijayanto et al., 2022). Previous studies showed that agroforestry provides both ecological and economic benefits. However, the factors influencing willingness to invest (WTI) in peatland agroforestry systems remain insufficiently explored (Adriani et al., 2024; Ema et al., 2023).

Farmers' perceptions of the agroforestry model will determine the WTI in the implementation. Several studies on the agroforestry model have focused more on willingness to pay (WTP) than WTI, even though these are fundamentally different concepts. WTP is the maximum amount of money an individual is disposed to pay towards obtaining a particular good, service, or benefit, or to avoid a negative impact. This concept can be used for environmental economic assessment, ecosystem service valuation, public policy, and social feasibility studies (Gosh et al., 2022). Meanwhile, WTI is the amount of money or resources an individual or investor is committed to investing in a project or innovation, with the expectation of long-term benefits or impact. This concept is used for general applications of green investment, sustainable agriculture projects, bioenergy, and technological innovation (Karasmanaki et al., 2019; Romero-Castro et al., 2023). The implementation of agroforestry on the peatlands is not only a technical process. Understanding farmers' perceptions and motivations, as well as the factors underlying investments in agroforestry, is equally essential.

Previous studies have given limited attention to WTI, emphasising the need to identify its key determinants. Existing agroforestry literature has predominantly examined WTP, while WTI remains unexplored. Although WTP reflects the level of individual preferences for selected benefits or environmental improvements, WTI captures a longer-term commitment to resource allocation and investment (Karasmanaki et al., 2019; Romero-Castro et al., 2023). Therefore, understanding farmers' perceptions and investment intentions is essential for promoting the successful implementation of agroforestry systems in peatlands.

Based on these considerations, this study aims to: (1) analyse farmers' perceptions of agroforestry implementation in peatland areas, (2) identify the factors influencing WTI, and (3) evaluate the economic feasibility of agroforestry models in the peatlands of South Sumatra. The result is expected to address the existing gap regarding the limited understanding of WTI determinants and the economic value of agroforestry as a sustainable restoration strategy.

METHODOLOGY

Selection of Study Area

The greatest amounts of degraded peatlands in the region were discovered in Ogan Komering Ilir (OKI) Regency, a part of South Sumatra Province, Indonesia. The degraded peatlands cover 1,687,348 hectares, or 49.25% of the province's total area. Furthermore, the study was conducted in (1) Perigi Village, Pangkalan Lampam District, and (2) Perigi Village, Kayu Agung District, Ogan Komering Ilir Regency, from June 2024 until completion. These locations were selected purposively, considering that a Pilot Project for the implementation of integrated peat restoration trials through the agroforestry model had been conducted since 2017 (Figure 1). The peatland in both villages was classified as degraded and characterised by a decline in ecological, production, and hydrological functions. The impact of this degradation is the decline in land productivity, compounded by frequent yearly burning.

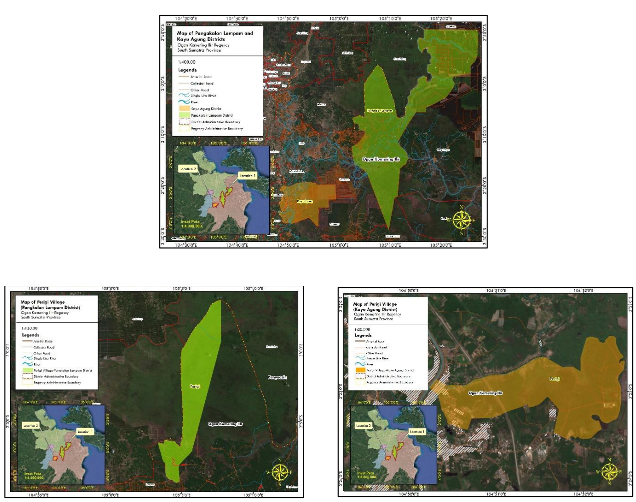

Figure 1. Study site

Survey Design and Data

A survey method was used to obtain quantitative data on farmers' beliefs, opinions, characteristics, behaviours, and perceptions regarding peatland restoration and agroforestry practices. The method was selected because it captured field-based conditions while providing an appropriate basis for examining the relationships among variables and testing the proposed hypotheses.

The present study adopted a balanced stratified random sampling method to obtain a representative sample of farmers participating in the peatland restoration program across the selected villages. The target population was stratified by village, and respondents were randomly selected from each stratum in proportion to its population size. This method improved sample representativeness and reduced potential bias related to population heterogeneity, consistent with established sampling principles. (Choi et al., 2024; Howell-Moroney, 2023). A sample proportion of 30% from each group was considered sufficient to represent the overall population because the characteristics of farmers within each stratum were relatively homogeneous. Furthermore, the selected proportion was considered adequate to capture respondent variability and support reliable statistical analysis of peatland restoration activities (Goswami et al., 2024; Howell-Moroney, 2023).

A quantitative survey method was used to obtain data that occurred in the past or present, about beliefs, opinions, characteristics, behaviour, relationships of variables, as well as to test certain hypotheses. This study adopted a balanced stratified random sampling method for farmers who had participated in the peatland restoration program, as detailed in Table 1.

Table 1
Sampling method

No.	Location	Population	Sample	Percentage
1	Perigi Village, Pangkalan Lampam District, Ogan Komering Ilir Regency	167	50	30%
2	Perigi Village, Kayu Agung District, Ogan Komering Ilir Regency	120	36	30%

The questionnaire consisted of several sections, including (1) general characteristics of the respondents, (2) perceptions of peatlands and agroforestry models, (3) WTI in agroforestry models, and (4) the costs and benefits associated with selected models. The primary study question was: To what extent are farmers who have received assistance through agroforestry programs willing to invest independently to sustain the implementation of various agroforestry models? The description of the variables is presented in Table 2.

Table 2
Description of study variable

Name of Variable	Variable	Variable Definition	Measurement
X1	Age		Years
X2	Indigenous people		1 = Yes: 0 = No
X3	Gender		1 = Man; 0 = Woman
X4	Education		Years
X5	Family size		Person
X6	Land productivity	Land is used or not used	Land is used =1 Land is not used = 0
X7	Land scale	Land area	Ha
X8	Land certificate		1 = Own ownership; 0 = Non-ownership
X9	Dominant land use for agriculture	Rice, corn, and others	1 = Yes; 0 = No
X10	Dominant land use for plantation	Rubber, Palm Oil, and others	1 = Yes; 0 = No
X11	Plans to increase productivity	Having a plan to improve land productivity	1 = Yes; 0 = No
X12	Have knowledge of the technical aspects of restoration	Level of knowledge and skill about agroforestry	1 = High; 0 = Low
X13	Member of farmers organisation	Active Member of farmers community	1 = Active; 0 = Passive

A logistic regression model was used to address the second objective, namely analyzing the WTI (Karasmanaki et al., 2019). This method was selected for the ability to accommodate non-linear relationships between the dependent (WTI) and a range of independent variables, both categorical and continuous. Through this model, it became possible to identify demographic, social, and farm-related characteristics that had predictive power over farmers' propensity to adopt innovative commodity combination models. Respondents who were willing and unwilling to invest in agroforestry were coded as 1 and 0, respectively. The binary nature of the dependent variable necessitated the use of a logistic regression model to analyse the effects of independent variables on the respondents' WTI in agroforestry. The model specification is given in Equation 1.

$$
\begin{aligned}
Z_i &= ln\left(\frac{p}{1-p}\right) \\
&= \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_6 x_6 \\
&\quad + \beta_7 x_7 + \beta_8 x_8 + \beta_9 x_9 + \beta_{10} \\
&x_{10} + \beta_{11} x_{11} + \beta_{12} x_{12} + \beta_{13} x_{13} + \varepsilon \ldots
\end{aligned} \qquad [1]
$$

In the estimated model, α is the intercept and βi is the regression coefficient that provides the expected change in WTI when the corresponding independent variable increases by one unit (ceteris paribus).

The third objective of this study was achieved by a cost-benefit analysis, which evaluated the total economic value of the proposed investment. The profitability analysis was generally categorised into four parts, namely Financial analysis with indicators of Net Present Value (NPV), Benefit Cost Ratio (BCR), Internal Rate of Return (IRR) and Payback Period (PP). An extended cost-benefit analysis method was applied to evaluate the benefits of selected agroforestry scenarios on degraded peatlands due to restoration efforts.

To assess the most suitable agroforestry method for sustainable peatland utilisation, this section presents a comparative overview of three integrated land-use models, namely Agrosilviculture, Agrosilvofishery, and Agrosilvopastural. Each model integrated forestry components with agricultural, aquaculture, or livestock elements within a one-hectare plot, reflecting a multifunctional land management strategy. The comparison covered critical dimensions such as economic life, discount rate, types and quantities of commodities planted or reared, spatial arrangement (planting distance or infrastructure), as well as projected final outputs. The Agrosilviculture model combined *meranti* timber production with pineapple and rice farming over a relatively short economic life of 10 years. In contrast, the Agrosilvofishery model, with a longer horizon of 30 years, integrated *jelutung* trees, pineapples, and catfish, demanding higher initial investment and more complex water infrastructure. The Agrosilvopastural system, extending over 35 years, integrated *nyamplung* trees with rice farming and duck husbandry, showcasing diversified biological outputs and intensive management needs. This structured comparison enabled stakeholders, particularly farmers, policymakers, and development agencies, to identify trade-offs and select the most context-appropriate agroforestry model based on ecological compatibility, economic returns, and operational feasibility. To further support decision-making, the comparative framework also emphasised the varying levels of technical capacity and institutional support required for each model's implementation. Additionally, differences in output timing, whether short-term annual yields or long-term forestry benefits, played a crucial role in determining model attractiveness to smallholder versus commercial-scale actors.

A comparative analysis of the agrosilviculture, agrosilvofishery, and agrosilvopastural systems showed distinct configurations of integrated land-use practices (Chappa et al., 2024), each with its own set of ecological, economic, and managerial implications. These agroforestry models have been specifically designed to optimise the sustainable utilisation of peatland resources by combining forestry with agricultural, aquacultural, or livestock components (Zerbe, 2022). The agrosilviculture model presents the most accessible entry point among the three, primarily due to relative simplicity, shorter economic time horizon, and lower initial capital requirements (Mössinger et al., 2022). It integrates timber-yielding tree species with seasonal crops and horticultural commodities, thereby enabling farmers to generate periodic income from annual harvests while awaiting returns from the longer-term forestry component. The model is particularly appealing to smallholder farmers or community-based enterprises with limited investment capacity. This is because agrosilviculture allows for the gradual accumulation of revenue and mitigates the financial risks commonly associated with long- maturity agroforestry ventures (Dhakal et al., 2022).

The agrosilvofishery model represented a more complex and technically demanding system, designed to exploit the hydrological characteristics of peatlands by incorporating aquaculture alongside forestry and agricultural crops (Indrajaya et al., 2022). The model fostered ecological and economic diversification by enabling concurrent outputs from tree-based products, aquaculture yields, and fruit harvests. However, its implementation required higher levels of technical knowledge, greater financial inputs, and infrastructural development, such as fish pond construction and water management systems (Cheyo et al., 2024).

The agrosilvopastural model was the most integrated and multifunctional method among the three. It combined tree cultivation, seasonal cropping, and livestock rearing into a single land-use system, thereby facilitating nutrient cycling, biodiversity conservation, and multi-product outputs (Mantziaris et al., 2022). The inclusion of livestock, such as ducks, not only diversified income streams but also contributed to improved farm resilience and ecological synergies (Chappa et al., 2024). However, the model demands high levels of managerial skill, continuous labour input, and infrastructural readiness, particularly for animal housing and health management. Its extended project horizon and complex operations suggested that the model is best suited for organised farming collectives or individual farmers with long-term investment capacities and technical competencies.

The selection of an appropriate agroforestry model should be conducted in consideration of a confluence of factors. These include the ecological characteristics of the site, the socio-economic profile of the farming community, the availability of institutional support, and the temporal trade-offs between short-term returns and long-term sustainability. While the agrosilviculture model offered immediate benefits with lower complexity, the agrosilvofishery and agrosilvopastural systems provided broader ecological and economic advantages. These systems required greater investment, labour, and technical expertise. The comparative strengths and constraints of the models emphasise the importance of context-specific planning in the sustainable development of peatland-based agroforestry systems.

RESULTS AND DISCUSSION

Farmers Characteristics

The results showed that the majority of peatland farmers in South Sumatra were male. Approximately 66 and 34% of respondents were male and female farmers, as detailed in Table 3. Both genders play important and different roles in supporting household livelihood strategies. However, males tended to play a more visible role in meeting the household's economic needs (Yazid et al., 2024). In terms of age, the older adults dominated the respondent profile. This group constituted approximately 72% of the total respondents, ranging from 38 to 70 years of age. The trend points to the low participation of younger generations in agricultural activities and shows a continuous challenge in the regeneration of the agricultural workforce. The low participation of young people may be attributed to limited economic prospects in farming, the attraction of off-farm employment, and the perception that peatland farming offered uncertain long-term prospects (Adriani & Septiani, 2023). Most farming households had five to seven members in terms of size. This was higher than the result reported for households in Java. More family members are proportional to higher economic pressure, which encouraged farmers to maximise the productivity of their peatland in order to meet needs. The education level of respondents was generally low, with 78% only receiving primary education. Limited educational background among farmers may constrain the ability to accept new knowledge and perspectives as well as slow down the adoption of agricultural technologies and innovations (Rosnan & Yusof, 2023). Although training and agricultural extension programs are available, their effectiveness in promoting innovation adoption may be constrained by the generally low educational attainment of farmers. However, the participation rate in these programs was relatively high. A total of 58% of the respondents had attended training sessions or extension activities organised by government agencies or academic institutions as part of community empowerment initiatives. In addition to developing technical expertise, the informal learning opportunities were expected to encourage better cooperation among farmers and improve the implementation of future agricultural development programs.

In this study, 90% of the respondents cultivated legally and self-owned peatland. Meanwhile, the remaining 10% cultivated land that belonged to other family members or leased assets from their parents. The size of the average peatland owned by farmers was 1 to 2 hectares, and only 2% of the respondents had 5-to 6-hectare holdings. This distribution showed that land ownership for peatland farmers tends to be restricted. These constraints can limit the scope for extending farming operations and increasing profitability but can be managed to some extent by agricultural intensification. Most respondents had also been long-term experienced peatland farmers. Approximately 33% had been farming for between 2 and 10 years, while the other 67% had more than ten years of experience.

This accumulated knowledge is possibly to have a positive influence on the perception and decision of farmers to manage their farming activities.

The household income distribution showed that the majority of the respondents fell within the low-income category, while relatively few fell within the middle-income category, and only a small proportion belonged to the high- and very high-income categories. The trend is consistent with the predominance of smallholder farmers whose monthly income was typically low and often fluctuated over time. These financial conditions reflected the economic vulnerability of the farming households that remained heavily reliant on seasonal agricultural production for income. The households had a limited ability to absorb the production costs and meet expenses during the non-harvest periods.

Table 3
Farmers characteristics

Variable	Percentage (%)	Average	Standard Deviation (±)
Gender			
Man	66	-	-
Woman	34		
Age			
27-37 years	28		
38-48 years	28	46	9.3 (70.27)
49-59 years	36		
60-70 years	8		
Family Members			
2-4 persons	24	4	1.3 (7.20)
5-7 persons	76		
Formal Education			
No School and Primary School	78		
Junior High School	12	8	2.4 (16.60)
Senior High School	4		
Bachelor Degree	6		
Land Status			
Owned by Individuals	90	-	-
Leased Land	10		
Land Scale			
1-2 ha	72	2.00	1.41 (61.00)
3-4 ha	26		
5-6 ha	2		
Farm Experience			
2-10 years	32		
11-19 years	22		
20-28 years	20	20	11.8 (50.21)
29-37 years	18		
38-46 years	6		
> 47 years	2		

Table 3 (*continued*)

Variable	Percentage (%)	Average	Standard Deviation (±)
Income Range (IDR/Month)			
1,000,000 - 4,500,000 (Low)	47.67		
> 4,500.000 - 8,000,000 (Medium)	36.05	5,258,140	3,301,608 (62.78)
> 8,000,000 -11,500,000 (High)	11.63		
> 11,500,000 - 15,000,0000 (Very High)	4.65		

Farmers' Perception of the Agroforestry Model for Optimising the Sustainability of Agricultural Businesses on Peatlands

Farmers’ perceptions can be positive or negative depending on the assessment of their experiences and the conditions of peatland management. Figure 2 provides a more detailed overview of these perceptions, including farmers’ opinions on the advantages and difficulties of peatland utilisation. The results provided an important empirical basis for the design of more adaptive, participatory and context-specific intervention strategies, thereby favouring a transition towards more sustainable peatland-based agricultural systems. Farmers' knowledge of agroforestry remained relatively limited, as confirmed by 58.1% of respondents (50 out of 86 respondents). Although farmers were familiar with peatland utilisation, their understanding of agroforestry and paludiculture systems remained relatively low. The limited knowledge may be associated with inadequate access to extension services, technical training, and practical exposure to sustainable peatland management practices.

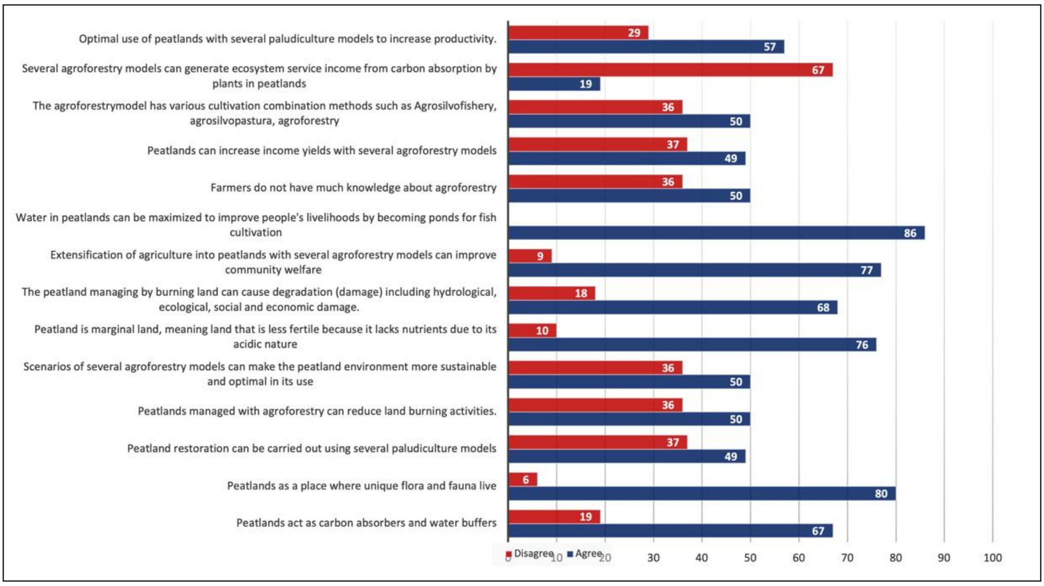

Figure 2. Farmers' perception of the agroforestry model for optimising the sustainability of agricultural businesses on peatlands

Optimal Utilisation of Peatland with the Agroforestry Model

The majority of respondents agreed that optimal utilisation of peatland through various alternative commodity combination models can enhance productivity. The agroforestry commodity integration model combines multiple commodities, such as agricultural crops and aquaculture in wetland areas, to increase farmers' incomes while promoting environmental sustainability (Qurniati et al., 2024). This was further supported by a study where combining agricultural crops with native trees or other plants provided additional economic value and mitigated the risk of peatland degradation (Applegate et al., 2022).

Agroforestry Model as a Multifunctional Method

Respondents expressed a high level of consensus on the role of the innovative commodity combination model in promoting diverse cultivation methods, including agrosilvofishery, for income diversification. Agrosilvofishery integrates food crops, timber trees, and aquaculture activities within a single land-use system, thereby creating opportunities for income diversification among farmers in line with (Adriani et al., 2024; Goswami et al., 2024). This method not only contributed to enhancing household food security but also served as an adaptive strategy to address economic and environmental risks, while simultaneously providing access to more sustainable alternative income sources. Numerous studies have shown that this type of diversification can also improve environmental sustainability by preventing the overexploitation of land resources (Agbodjato & Babalola, 2024; Mondal & Palit, 2022).

Peatlands as a Source of Increased Income and Alternative Cultivation

More than 50% of the respondents agreed that the peatlands offered great potential as an alternative area of cultivation to increase the income of the farmers. The respondents further stated that integrated commodity systems, particularly paludiculture, generated a variety of high-value products from peatlands, including sap, honey and freshwater fish. According to previous studies, multi-commodity farming systems tended to generate more stable and sustainable income than monoculture systems, which were generally more susceptible to market and climatic variability (Adriani et al., 2024). This strategy was very important to improve farmer welfare while maintaining the sustainability of the ecosystem (Syahza et al., 2020).

The Role of Peatlands in Ecosystem Conservation

A total of 44 respondents agreed that peatlands played a significant role in regulating environmental balance, particularly in their function as a carbon store and in maintaining water table balance (Kwon et al., 2022). This opinion is in line with the ecological role, as the largest reservoir of water and carbon on Earth for thousands of years. However, unsustainable peatland management practices, such as drainage and burning, release substantial amounts of stored carbon into the atmosphere, thereby contributing significantly to greenhouse gas emissions (Ruwaimana et al., 2020). The respondents viewed the introduction of paludiculture as a pragmatic management solution, because the model maintains the ecological functions of peatlands while generating direct economic benefits for local communities through the sustainable production of high-value commodities.

Although agroforestry on peatlands holds great potential, there are several important challenges for its implementation. First, farmers were not aware of other combinations of commodities. A large proportion of respondents admitted to not being aware of alternative commodity integration models for peatland cultivation, reflecting a significant gap between information and technical capacity. This limitation is a major obstacle to the expansion of paludiculture systems. Farmers are generally not enthusiastic to adopt new practices without a clear understanding of their management requirements and expected benefits (Ziegler et al., 2021).

To address this challenge, continuous extension services and capacity-building programmes are needed to strengthen farmers' knowledge and practical skills in adopting sustainable agricultural practices appropriate for peatland ecosystems (Choi et al., 2024). Second, another challenge is water management in peatland areas. A total of 49 respondents agreed that improvement of water management has the potential to enhance community welfare. Among the characteristics of peatlands is the natural ability to retain water, which offers opportunities to support aquaculture and agricultural irrigation systems (Hairani & Noor, 2020). Good management has been shown in previous studies to be important in reducing the risk of fires and facilitating the successful implementation of paludiculture systems (Tan et al., 2021). These systems require high stability of the groundwater table to maintain ecological balance and support sustainable land productivity. Therefore, strengthening capacity in water management is a strategic aspect of developing sustainable agriculture based on the ecosystems (Thornton et al., 2020). Third, Land Burning Risk, a total of 38 respondents acknowledged that peatland burning practices are recognised as the primary cause of environmental degradation. Despite being a common method for land clearing among some farmers, it reduces soil fertility, damages the peatland ecosystem structure, and releases large quantities of greenhouse gas emissions into the atmosphere (Sofiyuddin et al., 2021). Most peatlands that have been drained and converted for agricultural use still hold potential for transition into paludiculture systems. Approximately one-third of the total swamp area can be optimised for various types of paludiculture. Furthermore, the biodiversity characteristic of swamp ecosystems tends to increase when rewetting (restoring wet conditions) and the practices are implemented, compared to conditions where the land remains dry or degraded (Munawar et al., 2024).

Paludiculture, which avoids burning, offers a more environmentally friendly solution to enhance productivity without damaging ecosystem structure (Budiman et al., 2020). Fourth, Peatlands as Marginal Land, a total of 41 respondents stated that peatlands are classified as marginal lands with low fertility levels. The soils are typically highly acidic and deficient in essential nutrients, thereby requiring adaptive cultivation methods. The paludiculture model offers a viable solution to these limitations through the use of diverse commodities that are capable of thriving in marginal conditions while also providing economic benefits (Wicaksono & Zainal, 2022).

The overall results show that the communities in the South Sumatra areas support the use of peatlands through the paludiculture method to enhance agricultural productivity while maintaining the sustainability of the ecosystem. However, several important challenges were observed, including the limited knowledge of paludiculture practices among farmers and the continuing threat of land burning. These constraints can be overcome by sustained educational efforts, as well as promotion of more environmentally sustainable land management practices. The adoption of paludiculture supported by government and academic institutions offered a promising solution to improve economic well-being and ensure the long-term conservation of peatland ecosystems.

Analysis of Farmers' WTI in Agroforestry Models to Optimise the Sustainability of Agricultural Businesses in Peatlands

Table 4 explains the distribution of farmers' WTI in the agroforestry model as a method for sustainable peatland management. The majority of respondents (72.09%) showed WTI, while 27.91% were not willing. This distribution reflected a reasonably good level of acceptance of the suggested agroforestry model by farmers. Investment decisions were largely influenced by perceptions of the commodity diversification opportunities offered by agroforestry systems, which allowed for more productive land use compared to conventional monoculture systems (Belay & Melka, 2024). Farmers tended to favour annual monoculture systems due to the quicker financial returns and lower short-term risks. However, these benefits were projected to decline in the long term as a result of unsustainable land use practices (Goswami et al., 2024).

The innovative commodity combination model within agroforestry was considered to have strategic potential for expanding farmers' economic base, particularly in peatland areas that possess unique ecological characteristics and high vulnerability to degradation. By integrating multiple commodities, including food crops, forestry species, and aquaculture, this model enhances farmers' income diversification, strengthens food security, and promotes more environmentally sustainable agricultural practices. Its flexibility in adapting to the biophysical conditions of peatlands makes the model highly relevant for implementation in landscape-based agriculture that is resilient to climate change and environmental crises (Nugroho et al., 2025).

Table 4
Farmers' WTI

WTI	Frequency (%)	Reasons	Frequency	Percentage (%)
Yes	62 (72.09%)	Product Diversifications	27	42.86
		Sharing Production Costs for Total Cost Decreasing	9	14.29
		Higher Income	9	14.29
		Decreasing Land Burning	18	28.57
		Total	62	100.00
No	24 (27.91)	Limited Financial Resources	15	63.79
		Absence of Governmental Assistance	1	5.17
		Ignorance of Knowledge and Experience	5	20.69
		Decreasing of Agriculture Land and Labour	2	10.34
		Total	24	100.00

The study showed significant structural barriers to the model implementation. Most farmers who were unwilling to invest cited limited access to financial resources as the primary constraint (Goswami et al., 2024). A lack of capital not only obstructs the initial development of agroforestry systems but also limits farmers' capacity to access technology, training, and other productive inputs (Castle et al., 2021). Therefore, policy interventions that facilitate access to financing, provide investment subsidies or incentive schemes, and strengthen institutional capacity are crucial prerequisites for promoting the expansion and long-term sustainability of this model at the grassroots level.

Table 4 shows that the majority of farmers at 72.09 % were WTI. This interest was driven primarily by commodity diversification, increased income, and production cost efficiency. Agroforestry is also perceived as being able to reduce land burning practices (28.57%), which is relevant in the context of sustainable peatland management. Conversely, approximately 27.91% of farmers were unwilling to invest. This is primarily due to limited financial resources (63.79%), followed by lack of knowledge and experience, limited labour and land, and minimal government support. These results confirmed that investment decisions were more influenced by economic factors and knowledge capacity than other structural factors. Therefore, policy interventions need to focus on improving access to financing, extension services, and strengthening farmer institutions.

In the binary logistic regression model in Table 5, the Pseudo R^2 value for the 13 explanatory variables was 0.31, reflecting a moderate level of explanatory power. The log pseudo-likelihood value of 40.66 showed that the WTI was significantly different from zero, and the applied model provided a better fit compared to the null model. Therefore, the estimation of farmers' WTI is considered valid as a basis for further analysis (Wiradanti et al., 2020).

Table 5
Binary logistic regression for farmers' WTI in implementing various agroforestry models on peatland

Variables	Coef.	Wald	Exp(B)	Sig
(X1) Age	0.0344	0.050498	1.0350	0.496
(X2) Indigenous people	3.2367	1.793711	25.4498	0.071*
(X3) Gender	-0.7021	1.273711	0.4956	0.581
(X4) Education	1.3616	0.76561	3.9026	0.075*
(X4) Family size	-0.4353	0.320494	0.6471	0.174
(X5) Land productivity	0.6793	1.952534	1.9725	0.728
(X6) Land scale	0.5834	0.420857	1.7921	0.166
(X7) Land certificate	0.0880	0.887793	1.0920	0.921
(X8) Dominant land for agriculture	-4.1969	1.624618	0.0150	0.010***
(X9) Dominant land for plantation	-3.1388	1.77135	0.0433	0.076*
(X10) Dominant land for forestry	-1.1994	1.300358	0.3014	0.356
(X11) Having a plan for increasing productivity	1.3193	2.777069	3.7408	0.001***
(X12) Knowledge about peatland management	-1.4580	2.410044	0.2327	0.001***
(X13) Member of farmer organisation	0.7374	1.136898	2.0904	0.017**
Constanta	1.9883	6.846975	7.3032	0.772

Note. Range interval. * $p < 0,1$; ** $p < 0,05$; *** $p < 0,01$

Among the variables representing demographic characteristics, indigenous status ($p < 0.1$) was discovered to significantly influence farmers' WTI in implementing various agroforestry commodity combination models. In this case, 96% of the respondents identified as indigenous people and expressed willingness to allocate funds toward innovative agroforestry systems. Farming experience in the region also influenced WTI, and indigenous community members holding traditional authority and responsibilities show greater willingness than migrants. Indigenous communities play a crucial role in environmental and territorial governance because of close interactions with local ecosystems and community networks. These communities frequently serve as trusted sources of information, influence public land-use decisions, and promote the adoption of sustainable land-use practices. Indigenous knowledge and leadership further support the development of climate-resilient, environmentally sustainable food production strategies. Another demographic characteristic with a significant influence was the level of education. The higher the educational attainment, the greater the possibility of adopting agroforestry models in peatlands ($p < 0.1$). Individuals with longer years of schooling are generally more open to innovation and more receptive to agroforestry practices (Buyinza et al., 2020)**.** However, other variables such as age, gender, household size, land productivity, land area, and land tenure status did not show significant influence within the model. This is because the variables do not directly increase adaptive capacity or reduce business risks in peat ecosystems with high biophysical uncertainty and are relatively uniform across farmers. The factors do not influence investment decisions strongly enough compared to more decisive aspects such as knowledge and institutional support.

From the perspective of farming characteristics, farmers engaged in intensive land use for food crop production ($p < 0.01$) and timber plantation purposes ($p < 0.1$) were generally less WTI in innovative agroforestry systems. The individuals may be satisfied with the current systems and not want to introduce new practices that may disrupt the established way of working. This is consistent with previous studies where the adoption of new agricultural practices by farming households with high land productivity is less possible. Farmers who wanted to increase productivity in their region ($p < 0.01$) also had less tendency to adopt commodity combination models. This showed that the local community does not view the models as having the potential to enhance productivity. These results are consistent with the perception that innovative agroforestry in peatlands is not considered a productive or viable alternative. Expectations about the future of the farm and the probability of succession over generations also appear to influence investment decisions.

The expectation may be mediated by the length of residence in a given area. Families that are multi-generational and have lived in the area for a long time tend to be more attached to the land and have longer-term aspirations. Therefore, other factors such as the age of the household head, number of descendants, and the possibility of intergenerational continuity may be important in sustaining farming activities over time.

Technical knowledge about various agroforestry models had a negative effect on WTI ($p < 0.01$). This result suggests that farmers with better knowledge of peatland management tend to evaluate agroforestry more critically and cautiously. Those with dominant land use for agriculture (Coef. = -4.1969; $p < 0.01$) and plantations (Coef. = -3.1388; $p < 0.1$) also showed lower WTI, possibly due to greater awareness of the capital requirements, management complexity, and long-term sustainability challenges related to agroforestry implementation. Therefore, higher knowledge does not always increase WTI, but may reflect more rational and risk-aware decision-making.

A negative relationship was observed between agroforestry knowledge and WTI. This suggests that higher knowledge does not necessarily translate into higher investment intention. Instead, farmers with better understanding tend to evaluate agroforestry more critically, particularly in terms of capital requirements, management complexity, and long-term risk-return trade-offs. This result should not be interpreted as a perception that agroforestry is unsustainable, but reflects more cautious and realistic investment behaviour under existing constraints such as limited capital access, opportunity costs, and reliance on established land-use systems. Accordingly, the study emphasises heterogeneity in investment decision-making and bounded rationality among farmers in assessing new land-use innovations.

Several successful community-based agroforestry practices in Indonesia support the feasibility of the proposed model in this study. For example, agroforestry systems in the *Gunung Salak* Valley, West Java, have successfully combined fruit trees, timber trees, and agricultural crops, contributing to household income while maintaining biodiversity and ecosystem sustainability. These results showed that community-based agroforestry can serve as a realistic and sustainable land management strategy (Rahman et al., 2021).

Costs and Benefits Insight of Several Agroforestry Models

Table 6 provides a clear and structured comparative overview of the differences in characteristics, costs, and benefits of each agroforestry model. By presenting aspects of components, economic life, inputs, and production outputs, the table helps explain the economic and technical basis underlying farmers' investment choices. Furthermore, it strengthens the analysis by showing how the level of diversification affects potential profits and risks, providing empirical evidence to support the discussion of factors influencing WTI. The existence of this table is important to increase the clarity, validity, and depth of the analysis in explaining the relative advantages of each agroforestry model on peatlands. Table 6 is the detailed comparison of the agroforestry models.

Table 6
Comparative overview of agroforestry models: Agrosilviculture, agrosilvofishery and agrosilvopastural

Aspect	Agrosilviculture	Agrosilvofishery	Agrosilvopastural
Main Components	Integration of forestry and seasonal agricultural crop cultivation.	Integration of forestry, agricultural system, and aquaculture activities.	Integration of forestry, agricultural systems, and livestock husbandry.
Commodities	*Meranti*, Pineapple, Rice Farming	*Jelutung*, Pineapple, Catfish	*Nyamplung*, Rice Farming, Duck eggs, Duck
Land Area	1 Hectare	1 Hectare	1 Hectare
Economic Life	10 Years	30 Years	35 Years
Discount Rate	7%	7%	7%
Planting Quantity	342 *Meranti* trees 7,874 Pineapple Seedlings 40 Kg/ha Rice seeds	368 *Jelutung* trees 8,647 Pineapple seedlings 288,000 Catfish Fingerlings	400 *Nyamplung* trees, 40 Kg/ha rice seeds, 7,412 ducks, 100 ducklings
Final Production Output	$311m^3$ *Meranti* Trees 7,412 Pineapples 1,600 Kg/ha Rice	$236m^3$ *Jelutung* Trees 8,235 Pineapples 36,000 Kg/ha Catfish	42 Tons Nyamplung Fruits 1,600 Kg/ha rice 13,650 Duck eggs 170 Duck
Planting Spacing	*Meranti*: 3×8m Pineapple: 1×1m Rice: 25×25cm	*Jelutung*: 3×8m Pineapple: 1×1m Pond: 9 Units (9×4m)	*Nyamplung*: 5×5m Rice: 25×25cm Duck Pen: 10 Units (10×2m)

All three models integrate forestry components with agricultural activities but have varying levels of diversification. The agrosilviculture model combines forestry crops such as *meranti* with annual crops (pineapples and rice), leading to a moderate level of diversification with a relatively short economic life (10 years). Meanwhile, agrosilvofishery integrates a fisheries component, contributing to a more complex system with a longer economic life (30 years) and a wider variety of outputs, including timber, food crops, and fish. The agrosilvopastural model is the most diversified system, integrating forestry, food crops, and livestock. It has the longest economic life (35 years) and produces a variety of products such as timber, rice, meat, and eggs.

Economically, all three models apply the same discount rate but differ in planting density and production volume, reflecting varying levels of land-use intensity and economic returns. Agrosilvofishery and agrosilvopastural models have higher output volume and diversity (Chappa et al., 2024), potentially increasing income stability and reducing business risks compared to agrosilviculture. Both models also include higher levels of management complexity and input requirements. The higher the level of diversification of agroforestry systems, the greater the potential economic and ecological benefits (Raj et al., 2022), but they require greater technical capacity and investment readiness from farmers.

Financial Feasibility of Agroforestry Model

The analysis of the financial profitability of an agroforestry business aims to determine the potential profit, which is subsequently associated with performance. To assess this profitability, the study relies on various investment criteria, including the Net Present Value (NPV) method, the Internal Rate of Return (IRR), the benefit-cost ratio (B/C ratio), and the payback period. For an operation to be considered profitable, NPV, IRR, and B/C ratio shall exceed zero, the interest rate, and one (B/C > 1), respectively. Additionally, the payback period should be shorter than the investment's useful life. The corresponding discount factor is used to calculate the NPV, as detailed in Table 7.

NPV represents the difference between benefits and costs and serves as an investment criterion to measure the feasibility of a business. Table 7 shows that agrosilviculture (*meranti*-pineapple-rice), agrosilvopastural (*nyamplung*-rice-duck), and agrosilvofishery (*jelutung*-pineapple-catfish) are economically viable. This is confirmed by the NPV calculation, which produced a positive value based on an interest rate of 7%. In concrete terms, this implied that an investment in a meranti-pineapple-rice agrosilviculture business generates a profit of IDR266,137,167. Meanwhile, for *nyamplung*-rice-duck agrosilvopastural and agrosilvofishery businesses, the profits amount to IDR1,010,975,032 and IDR1,637,114,339, respectively.

Table 7
Financial feasibility analysis of agroforestry model

No.	Agroforestry Model	Component	Economic Life Scale (Years)	Discount Factor (%)	NPV (IDR)	IRR (%)	B/C Ratio	Payback Period (Years)
1	Agrosilviculture	*Meranti* - Pineapple - Rice	10	7	266,137,167	20	2,01	4.92
2	Agrosilvofishery	*Jelutung* - Pineapple - Catfish	30	7	1,637,114,339	33	1,09	5.50
3	Agrosilvopastural	*Nyamplung* - Rice - Duck	35	7	1,010,975,032	29	2,60	3.28

The financial indicators in the form of IRR for each type of agroforestry were 20%, 33%, and 29%, exceeding the discount rate of 7%. This implied that agrosilviculture, agrosilvofishery, and agrosilvopastural businesses were categorised as feasible to be developed. IRR shows the ability to earn income from invested capital. Agrosilvofishery with a combination of *jelutung* - pineapple - catfish components had the highest NPV and IRRl values compared to other combinations. In terms of the B/C ratio calculation with an interest rate of 7%, the value for each type of agroforestry was more than one (B/C ratio> 1). This implied that agrosilviculture, agrosilvofishery, and agrosilvopastural businesses were profitable and feasible to run. Therefore, the three types of agroforestry are expected to remain economically viable because the B/C ratio value obtained was quite significant.

Based on the payback period calculation, representing the time required to recoup investment expenditures, it takes agrosilviculture, agrosilvofishery, and agrosilvopastural 4.92 years (4 years 335 days), 5.50 years, and 3.28 years (3 years 102 days), respectively, to recover the investment costs. Given that these payback periods are shorter than their respective maximum economic lifespans (10, 35, and 30 years), the investment projects for agrosilviculture, agrosilvofishery, and agrosilvopastural are feasible and acceptable.

In general, the three types of agroforestry modalities proved to be profitable and advantageous. This is because agroforestry integrates diverse agricultural components, including crops, livestock, and fisheries, thereby increasing overall productivity and improving harvest yields. The high yields achieved through these systems contribute to increasing farmers' income. The agroforestry system offers great potential for environmental conservation and promotes human welfare (Hasannudin et al., 2022). From an economic perspective, this system offers farmers greater income-generating opportunities by enabling the cultivation of high-value crops and the integration of profitable livestock or aquaculture enterprises.

Based on field observations, farmers in the study area generally rely on diversified livelihood strategies to maintain household income during the waiting period before harvest. In addition to farming activities such as rubber and oil palm cultivation, several respondents also worked as labourers, traders, construction workers, motorcycle taxi drivers, teachers, and civil servants. This shows that livelihood diversification plays an important role in supporting household economic resilience while waiting for agroforestry commodities to generate income. Limited financial capacity during the early implementation stage remains a major challenge for smallholder farmers adopting agroforestry systems.

The results of this study show that various sociodemographic factors significantly influence smallholder farmers' willingness to adopt agroforestry practices. Family members, particularly the household head and spouse, play a significant role in shaping investment intentions toward the agroforestry model. Certain aspects related to wood production shape how education level and experience affect the adoption of these practices. The study shows that indigenous populations also invest in the agroforestry model, possibly due to deep knowledge of the region and its resources. Specific agricultural characteristics have a negative impact on the adoption of agroforestry practices (Quaye et al., 2021). Farmers who manage their land by prioritising productivity and combining agricultural crops with tree plantations showed a greater tendency not to adopt agroforestry systems (Jordon et al., 2023). This result is in line with previous reports stating that economic incentives and resource-related factors can negatively influence the adoption of agroforestry systems (Autio et al., 2021; Bist et al., 2024). Furthermore, knowledge of technical aspects negatively impacts farmers' WTI (Li et al., 2021; Ranacher et al., 2021). This can be attributed to the perception of difficulties or impracticalities regarding the techniques. The results emphasise the importance of developing effective teaching methods. Building confidence in the benefits of the agroforestry system is also crucial for the adoption of these practices. Finally, the perception of improved well-being resulting from innovative agroforestry practices positively influences the farmers' willingness. This underscores the importance of communicating the system's potential health and environmental benefits (Ntawuruhunga et al., 2023).

In light of these results, the following proposals can be formulated to foster the adoption of agroforestry systems in support of low-carbon agriculture and improved livelihoods: (1) Target decision-makers: to increase the tendency of adoption, extension services should prioritize collaboration with heads of households and their spouses, who hold decision-making power within the family (Antwi-Agyei & Stringer, 2021; Lecoutere et al., 2023); (2) Foster social proximity: encourage the participation of indigenous groups and local resource users, given that these actors are more inclined to invest in agroforestry practices (Cancino et al., 2022); (3) Simplify technical information: develop effective communication strategies to dispel misconceptions regarding the complexity of agroforestry systems and facilitate understanding of their functioning and benefits (Kumar, 2025); (4) Prioritize well-being: prove how these systems can improve community health and well-being—aspects the community values more than economic gains (Rahman et al., 2021); and (5) Address productivity: provide evidence of the effectiveness of agroforestry methods in boosting agricultural productivity (Noeldeke et al., 2022).

This study has certain limitations that need to be addressed. The 86 farmers in the sample may not accurately reflect the entire population of smallholders in the region. Furthermore, the cross-sectional nature of the data limits the ability to establish causal relationships between the factors analysed and the willingness to adopt the practice. Future studies should rely on longitudinal data to better understand the dynamics of this adoption process over time and use larger, more diverse participant samples to validate the results. For policymakers and practitioners seeking to promote agroforestry models in Indonesia, analysing the impact of incentive programs or specific policy measures on adoption rates could also provide valuable insights. Further study is needed to identify peatland agroforestry models that are widely accepted by farmers, along with the barriers to their development and compatible local cultural practices, to determine the most suitable method for implementation.

The results of this study have significant implications for the development and implementation of the innovative commodity combination restoration model as a means to promote low-carbon agriculture and improve livelihoods in Indonesia. By targeting decision-makers, promoting social proximity, simplifying technical information, emphasising welfare benefits, and addressing productivity issues, extension services as well as policymakers can better support the implementation of the agroforestry model practices among smallholder farmers. This will then contribute to ongoing efforts to restore degraded peatlands, mitigate climate change, and improve the well-being of local communities.

CONCLUSION

In conclusion, the majority of respondents agreed that productivity can be increased through effective utilisation of peatlands by combining many alternative commodities in agroforestry schemes. The combination of agrosilviculture, agrosilvofishery, and agrosilvopastural on wetlands led to increased farmer incomes while preserving environmental sustainability. The study showed that the respondents also agree that the integration of native trees or other suitable plants with agricultural products increased economic value and lowered the danger of peatland degradation.

Approximately 72.09% of WTI respondents expressed a willingness to implement the proposed agroforestry model. The results identified several significant determinants of WTI. Indigenous status, education level, plans to increase land productivity, and participation in farmer groups showed positive associations. Meanwhile, dominant land use for agriculture and plantations, as well as agroforestry-related knowledge, showed significant negative associations. Other variables, including age, gender, household size, land productivity, and land ownership, were not significantly associated with WTI. Economic analysis confirmed that the agrosilvofishery and agrosilvopastural models require greater investment than the agrosilviculture model. Among the three scenarios, agrosilviculture generated the highest profitability.

The results provided valuable insights for developing and implementing innovative commodity-based restoration models that support low-carbon agriculture while improving rural livelihoods in Indonesia. Governments and extension services promoted agroforestry adoption among smallholder farmers by targeting key decision-makers, strengthening farmer organisations, simplifying technical information, emphasising livelihood benefits, and addressing productivity constraints. These efforts contributed to climate change mitigation, peatland restoration, and improved community welfare.

This study had several limitations, particularly related to its geographically specific scope and the potential constraints of the sample size, which may affect the generalizability of the results. Therefore, future study is recommended to expand the geographical coverage, increase the sample size, and test the model across different ecosystem conditions as well as commodity types in order to enhance the external validity of the results.

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