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REVIEW PAPER

Risk barriers and sustainability in payment for ecosystem service implementation in smallholder forestry

A, Ibrahim[1], S. Withaningsih[2], R. Kinseng[3], Parikesit[4,*], D. Muhamad[5]

[1] Doctoral Program on Environmental Sciences, Postgraduate School, Universitas Padjadjaran, Bandung City, West Java, Indonesia

[2] Master Program on Sustainability Science, Postgraduate School, Universitas Padjadjaran, Bandung City, West Java, Indonesia

[3] Departement of Communication and Community Empowerment, Faculty of Human Ecology, Bogor Agricultural University, Bogor City, West Java, Indonesia

[4] Departement of Biology, Faculty of Mathematics and Natural Sciences, Padjadjaran University, Sumedang, West Java, Indonesia

[5] Indonesia Research Institute Japan, Shibuya Tokyo, Japan

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ABSTRACT

Agroforestry offers sustainable solutions for small-scale farmers and the environment, crucial for climate change adaptation and resilience. They store carbon, conserve biodiversity, maintain water and soil fertility, and support livelihood diversification. Payment for ecosystem services has the potential to safeguard agroforestry systems in theory, yet it encounters obstacles concerning the permanence of these systems and associated risks and barriers. The primary objective of this research is to examine the obstacles and uncertainties related to the implementation of Payment for ecosystem services in smallholder agroforestry systems. This study plays a crucial role in enhancing the efficiency and effectiveness of Payment for ecosystem services schemes, thereby encouraging the widespread adoption of agroforestry practices. A systematic literature review was conducted to assess the payment for ecosystem services model and its implementation. Data were obtained from databases of scientific publications such as Scopus, Semantic Scholar, Crossref, and Google Scholar. A total of 40 pertinent studies were selected due to the intricate array of obstacles and uncertainties that hinder the effective implementation of payment for ecosystem services initiatives. The findings indicate that financial limitations arise as a noteworthy obstacle, as small-scale farmers encounter considerable economic hardships and discouragingly expensive implementation expenses (ranging from 150 United States dollar per metric ton of carbon dioxide). Additionally, they face a low credit price (approximately 50 United States dollar per metric ton of carbon dioxide equivalent). Socio-cultural factors, including gender dynamics, traditional beliefs, and generational disparities, shape farmers' attitudes toward payment for ecosystem services adoption, necessitating targeted interventions to foster trust and community acceptance. The importance of reliable data is emphasized by technical hurdles like accurate measurement of ecosystem services and monitoring complexities, necessitating innovative solutions and robust methodologies. Biophysical conditions like rainfall patterns and soil health further influence program success, demanding tailored approaches for effective implementation. The payment for ecosystem services programs entails a multitude of risks, which encompass various dimensions. These risks include uncertainties in the market, internal factors within the programs, flaws in program design, and environmental challenges. Market risks, like delayed credit payments, hinder financial cycles in programs. Other factors like farmers' commitment, inequitable benefit sharing, and labour displacement contribute to program sustainability risks. The success of programs is further endangered by subpar program design, insufficient conservation measures, and the adverse effects of climate change. Ultimately, comprehending and addressing these obstacles is essential in order to fully realize the benefits of payment for ecosystem services in agroforestry.bComprehensive strategies, including policy support, stakeholder engagement, and fair compensation coupled with collaborative efforts from governments, non-government organizations, local communities, and private enterprises are essential. Through the mitigation of risks barriers highlighted in this study, the utilization of payment for ecosystem services has the potential to become an effective instrument in advancing sustainable agricultural land practices, combating climate change, and improving the well-being of smallholder farmers.

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*Corresponding Author:
Email: *parikesit@unpad.ac.id*
Phone: +62813 2184 1418
ORCID: 0000-0001-8214-7126

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INTRODUCTION

Agroforestry systems offer sustainable solutions to small-scale farmers and the environment, addressing agricultural challenges while boosting their income (Mahmood and Zubair, 2020; Dou *et al*., 2023). Widely practiced and integral part in rural areas (Holmes *et al*., 2017; Bogale *et al*., 2023), these smallholder farming systems are crucial for climate change adaptation and resilience (Tremblay *et al*., 2015; Mulatu and Hunde, 2020). Forests also contribute to the mitigation of climate change through the storage of carbon and the reduction of emissions (De Beenhouwer *et al*., 2016; Sharma *et al*., 2016; Burgess and Rosati, 2018). Beyond climate benefits, agroforestry also conserves higher biodiversity compared to conservative agricultural systems (Toensmeier, 2022), maintains water and soil fertility (Kaushal *et al*., 2021), and cultural heritage (Vázquez-Delfin *et al*., 2022), and livelihood diversification (Parikesit *et al*., 2021). Agroforestry plays a vital role in mitigating the impacts of climate change due to its various functions. This makes it an essential practice in today's world (De Zoysa and Inoue, 2014; Jara-Rojas *et al*., 2020). In recent decades, agroforestry has encountered the repercussions of climate change, including alterations in temperature and precipitation patterns, as well as the occurrence of extreme weather events. The escalating sustainability challenges have necessitated a closer examination of these impacts on agroforestry practices (Manrique, 2024). Affect tree growth and development, disrupting ecological functions and balance, and reducing resilience, impacting nutrient cycling, pollination, and symbiotic relationships (Zawude Bakure *et al.,* 2022; Hazarika *et al.,* 2024). Payment for ecosystem services (PES) is a program that offers incentives to landowners in exchange for the environmental advantages produced by their land. This approach is considered effective in safeguarding agroforestry systems and simultaneously offering supplementary benefits to smallholder farmers (Laporta *et al*., 2021; Ranjan, 2021; Dominicis *et al*., 2023). Despite the potential benefits that agroforestry systems can provide, there are concerns among critics regarding their efficacy and fairness. They contend that PES programs may disproportionately benefit landowners, leaving farmers facing significant barriers to accessing incentives and support (de Lima *et al.,* 2017; Nath *et al., 2023*). There is ongoing discourse regarding the sustainability of PES initiatives in the long run, which has sparked apprehension regarding the potential risks linked to funding mechanisms for sustainability and the enduring environmental consequences (Alarcon et al., 2017; Mcdonald *et al.,* 2021). Underscoring these concerns, the limited inclusion of agroforestry within global schemes like the Clean development mechanism (CDM) (Sharma *et al.,* 2021) and national climate plans (Richards *et al.,* 2015) highlights the need for broader recognition and policy support for this land-use practice (Cardinael *et al*., 2021; Quandt *et al*., 2023). The limited inclusion of agroforestry within global climate initiatives highlights a critical disparity, impedes research activities, and consequently hinders the development of credit methodologies for projects based on these agricultural systems, especially for smallholder lands (Zomer *et al*., 2016). A nuanced understanding of the complexities, trade-offs, risks, and barriers associated with implementing PES in agroforestry landscapes is necessary. Additional research and program implementation are necessary due to the limited amount of existing studies and initiatives focused on PES in smallholder agroforestry systems. Several studies that evaluate PES programs for smallholder agroforestry have often been overly general, focusing primarily on specific financial aspects rather than considering the program holistically. As such, the information obtained lacks comprehensiveness. A comprehensive study is required to investigate the various barriers and risks associated with PES implementation in smallholder agroforestry to unlock the full potential of payment for ecosystem services in agroforestry and assist stakeholders such as businesses, non-governmental organizations (NGOs), and government agencies to incorporate smallholder agroforestry systems into climate change mitigation strategies. This study is anticipated to foster the advancement of credit methodologies specifically designed for smallholder agroforestry practices. This will help ensure the preservation and sustainability of these valuable land-use systems, which play a crucial role in providing essential ecosystem services. The exploration of this issue can be undertaken through the compilation of research within the framework of a systematic literature review (SLR). This framework has the capability to offer a lucid, thorough, and impartial summary of current research or condensed information (Aromataris and Pearson, 2014; Franco and Groesser, 2021). SLR is also valuable for informing policy formulation, encompassing fundamental principles to technical guidelines, as it ensures transparent, reproducible, and precision information (Mengist *et al*., 2020; Page *et al*., 2021; Gazley, 2022). The current study seeks to provide a comprehensive overview of past studies on the risks, barriers, and sustainability identification associated with the implementation of payment for ecosystem services in smallholder agroforestry systems. This study has been carried out in Indonesia in 2023.

METHODOLOGY

This study thoroughly examined the challenges faced by PES programs in smallholder agroforestry systems. Following established guidelines of Preferred reporting items for systematic reviews and meta-analysis (PRISMA) to comprehensively assess benefits through meta-analysis (Pati and Lorusso, 2018; Xiao and Watson, 2019; Dede *et al*., 2023), and a transparent framework of the Protocol, search, appraisal, synthesis, analysis, reporting (PSALSAR) (Mengist *et al*., 2020; Andriuškevičius *et al*., 2022; Kamali Saraji and Streimikiene, 2023), an SLR will be employed. Participant, Intervention, comparators, and outcome (PICO) elements defined the research scope (Shamseer *et al*., 2015; Fernández del Amo *et al*., 2018; Eyzaguirre and Fernandes, 2024), excluding a Comparator due to the focus on identifying barriers and risks in PES implementation, regardless of research methods. The selection of criteria for literature selection is based on inclusion and exclusion. Keywords in scientific publications ought to be selected with consideration to the population outlined in the PICO framework (Table 1). These keywords include “smallholder agriculture,” “agroforestry system,” “carbon credit,” “payment for ecosystem services,” “carbon farming,” and “climate-smart agriculture”. Other agricultural landscapes besides smallholder agroforestry are also included. The sources for these publications are Scopus, Semantic Scholar, Crossref, and Google Scholar. Scopus is a comprehensive abstract and citation database by Elsevier (Maflahi and Thelwall, 2014). Semantic Scholar is an Artificial inelligence (AI)-powered database that excels at identifying influential citations (Dardas *et al*., 2023). Crossref is a digital object identifier (DOI) registration agency for scholarly content ensuring authenticity (Pentz, 2022). Google Scholar lacks some details but it can capture uncatalogued citations not indexed elsewhere (Martín-Martín *et al*., 2018; Mengist *et al*., 2020). The search focuses on peer-reviewed publications from 1997 onwards, coinciding with the start of carbon credit trading under the Kyoto Protocol (UNFCCC, 1997). The initial step involves conducting a thorough search for pertinent literature, utilizing predetermined criteria as a basis for selection. Software like Publish or Perish is used to speed up the search. Initially, 2291 literature sources were found. In the second stage, irrelevant materials were removed and reduced to 219 literatures. Upon reviewing of the titles and abstracts, a total of 202 pieces of literature were deemed suitable for additional scrutiny. Subsequent to this, 40 papers were chosen to proceed to the final stage of analysis. (Fig. 1). These papers represent 1.8 percent (%) of the initial set. After the identification of pertinent articles, a literature review advances through three essential stages. The synthesis stage involves extracting and classifying data from those papers. This encompasses both broad details like the year of publication and the location of the study, as well as specific details like the obstacles and temporary risks that have been identified. In the analysis stage, the data that has been generated is scrutinized in order to create a comprehensive summary of the information and gain a deeper understanding of internal validity through the utilization of descriptive statistics. This process ultimately improves the interpretation of the results and enables the selection of appropriate studies to be concluded (Grant *et al*., 2016). The reporting phase of SLR explains the entire process, presenting the results derived from the selected literature.

SLR identified 40 studies through a deliberate choice aimed at achieving comprehensive coverage while ensuring depth and rigor in the analysis. Representative of study aspects, scope and focus, and relevance of how barriers and risks affecting PES implementation to support climate change mitigation through agroforestry practices were considered during the identified process. The results show that studies focused on agroforestry systems for instance fruit farms (White *et al*., 2022), silvopasture and alley cropping (Holderieath *et al*., 2012), community-based forestry systems (Lasco *et al*., 2010), and monoculture systems, such as, grasslands and farmlands (Bremer *et al*., 2014). Terms like carbon farming (Nath *et al.,* 2015), climate-smart agriculture (CSA) (Zerssa *et al.,* 2021), and Conservation Agriculture (CA) (Bhan and

Table 1: SLR Protocol that delineate the research scope using PICO framework

Framework	Definition	SLR application
Participant	Specific group in research.	Smallholder agroforestry
Intervention	Investigating treatment, exposure, or program	Modelling or implementation of PES in smallholder agroforestry
Comparators	Comparison group or alternative intervention	Not applicable
Outcome	Specific result or effect that measuring in research.	Identification of barriers and non-permanence risks associated with PES in smallholder agroforestry

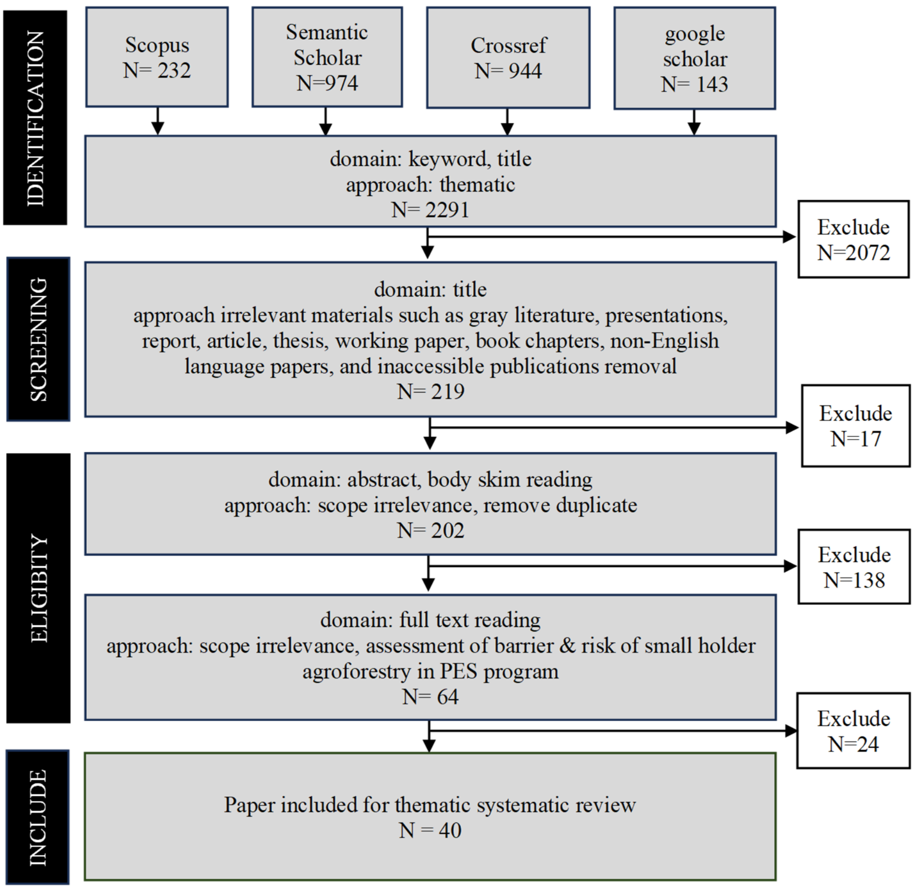

Fig. 1: The PRISMA diagram of articles selecting processes

Behera, 2014) encompass agroforestry practices that generate ecosystem services. The inclusion of woody perennial plants in agricultural landscapes, particularly in agroforestry systems, has the potential to enhance both carbon sequestration and soil fertility (Getnet *et al*., 2023; Kiran *et al*., 2023; Kimaro *et al*., 2024). Integrating these interventions with annual crops can enhance the productivity and profitability of agricultural systems for farmers (Temani *et al*., 2021; Staton *et al*., 2022; Yadav and Yadav, 2023). Various studies have examined the challenges associated with implementing PES in agricultural systems, categorizing them into financial, socio-cultural, political, and technical dimensions, which also involve biophysical factors. Financial aspects indicate sub-aspect such as implementation cost (Makundi

Table 2: Summary of articles related with risks barriers in smallholder PES program

No.	Agriculture type	Aspect	Location	Methods	Source
1	Agroforestry	Project cost condition affect	Brazil, Mexico, Indonesia, China, India, Tanzania, Philippines	Comprehensive Mitigation assessment process (COMAP)	Makundi *et al*., 2004
2	Agroforestry	Carbon price	Great Southern; Eastern Wheatbelt Region, Australia	Model of an Integrated Dry land agricultural system (MIDAS)	Flugge and Abadi, 2006
3	Terraces, agroforestry	Carbon price	Peruvian Andes, North Peru	Econometric-process simulation model	Antle *et al*., 2007
4	Forestry, Agroforestry	Baseline and leakage	Scolel Te´ project (Chiapas, Mexico)	Climafor	De Jong *et al*., 2007
5	Agroforestry	Successful factors of PES	Southeast Asia	Literature review	Roshetko *et al*., 2007
6	AFOLU	Successful factors of PES	Developed and developing countries	Literature review	Wunder *et al*., 2008
7	Forestry, Grassland	Opportunity cost	Kalimantan; Sulawesi; Lampung, Indonesia	Forests, agroforests, low-value-landscape, or, wastelands (FALLOW) model	van Noordwijk *et al*., 2008
8	Forest corridor	Successful factors of PES	Vohidrazana-Mantadia Corridor Restoration and Conservation Carbon Project, Madagascar	Literature review	Pollini, 2009
9	Community-Based Forest	Successful factors of PES	Tanay watershed; Philippines Sierra Madre Project; Kalahan Forestry Carbon Project, Philippines	Literature review	Lasco *et al*., 2010
10	Agroforestry	Project cost condition affect	Jambi and Sumatera, Indonesia	Bioeconomic analysist	Wise and Cacho, 2011
11	Silvopasture and Alley cropping	Offset carbon incentive	Missouri, USA	Ex-ante modelling scenario	Holderieath *et al*., 2012
12	Silvopasture	Farmers perspective	Oak Corridor, Eastern Andes, Colombia	Interview	Hayes, 2012
13	Agroforestry, Family farms	Transaction cost	Indonesia, Australia	Multivariate analysis	Cacho *et al*., 2013
14	Forestry, Agroforestry	Transaction cost	Bangladesh, India, Pakistan	Net present value	Wicke *et al*., 2013
15	Forest Community	Successful factors of agroforestry implementation as climate mitigation	Kakamega, Western Kenya	Descriptive research design	Chimoitaligare, 2014
16	Grasslands	Successful factors of PES	Socio Páramo program, Ecuador	Interview	Bremer *et al*., 2014
17	AFOLU	Successful factors of PES	Latin America	Literature review	Grima *et al*., 2016
18	Agroforestry	Profitability of carbon offsets program	Rubirizi; Mitoma; Kabale district, South Western Uganda	Bioeconomic analysis	Kiyingi *et al*., 2016
19	Dryland cropping and mixed crop-livestock	Farmers preference to implement CF	Northern Wheatbelt, Western Australia	Best-worst scaling survey	Dumbrell *et al*., 2016
20	Agroforestry	Uncertainty on monitoring CSA	Municipality of Las Vueltas, El Salvador	Landscape Degradation Surveillance Framework (LDSF)	Kearney, Coops, *et al*., 2017
21	Agroforestry	Successful factors of agroforestry as climate mitigation	Andean valleys and Norte Potosí region, Bolivia	Interview and Questionnaire	Jacobi *et al*., 2017
22	AFOLU, Watershed	PES development constrains	Indonesia	Literature review	Suich *et al*., 2017
23	Upland livestock, Production, over mixed crop-Livestock farming, Arable farms	Farmers preference to implement PES	Yorkshire; Midlands; Norwich; and Scotland, United Kingdom	Choice Experiment, marginal abatement cost	Aslam *et al*., 2017
24	Agroforestry	Economic value of PES	Natura 2000 Zarandul de Est program,	Toolkit for Ecosystem Service Site-based	Martino and Muenzel, 2018

Table 2: Summary of articles related with risks barriers in smallholder PES program

No.	Agriculture type	Aspect	Location	Methods	Source
25	Agroforestry	Efficiency of PES	Central and Eastern Province; Kirinyaga; Lakipia; Meru; Nyeri Region, Kenya	Flexible transformation function	Benjamin and Sauer, 2018
26	Forestry, Agroforestry	Risk of carbon project	Scolel Te´ project (Chiapas, Mexico)	Interview	Otto, 2019
27	Agroforestry	Farmers preference to implement CSA	Hintalo Wajirat district, Northern Ethiopia	Discrete Choice Experiment	Haile *et al*., 2019
28	Agroforestry, Woodland agroecosystems	Stakeholder roles in carbon project	Moshi Rural and Urambo District, Tanzania	Interview	Bamanyisa *et al*., 2019
29	Agroforestry	Carbon revenue	Central Rift Valley, Ethiopia	Multivariate analysis	Waldén *et al*., 2020
30	Agroforestry	Carbon project review	Kenya Agricultural Carbon Project (KACP) (Kisumu and Bungoma, Kenya)	Interview	Nyberg *et al*., 2020
31	Smallholder Agriculture	Challenge and Opportunity of CSA adoption	Ethiopia	Literature review	Zerssa *et al*., 2021
32	Agroforestry	Successful factors of agroforestry as climate mitigation	Kenya; Uganda; and Tanzania, East Africa	Literature review	Dhyani *et al*., 2021
33	AFOLU	Successful factors of CF	Asia and Africa	Literature review	Dutta *et al*., 2021
34	Dairy, Livestock, Crops, Fruit farms	Farmers perspective to implement PES	Vermont, USA	Focus Group Discussion	White *et al*., 2022
35	Forestry, Agroforestry	Costs and risks	Alajuela Province, Costa Rica	Monte Carlo simulation	Netter *et al*., 2022
36	Silvopasture	Carbon price	Scotland	Real Options techniques	Abdul-Salam *et al*., 2022
37	Agroforestry	PES incentive	Taiwan	Monte Carlo simulation	Liu and Chuang, 2023
38	AFOLU	Successful factors of CF	Tamil Nadu and Northeastern, India	Literature review	Saikanth *et al*., 2023
39	Forest Management	Successful factors of PES	Kenya, Uganda, and Tanzania	Questionnaire and secondary data	Osewe *et al*., 2023
40	Sorghum farm	Successful factors of CSA	Busia, Kenya	Semi structured questionnaire	Atsiaya *et al*., 2023

et al., 2004), transaction cost (Cacho *et al*., 2013), opportunity cost (van Noordwijk *et al*., 2008) or other various attempts to analyze the modelling systems to estimate the economic benefits of PES program (Wicke *et al*., 2013; Netter *et al*., 2022). Socio-cultural and political aspects encompass a range of challenges stemming from social norms, cultural practices, and political dynamics that impede the effective execution of PES initiatives in agroforestry. These barriers reflect the complexities inherent in integrating conservation efforts with socio-cultural contexts and governance structures includes sub-aspects of traditional beliefs (Dumbrell *et al*., 2016), gender inequalities (Nyberg *et al*., 2020), community attitudes to adopt sustainable agricultural practices (Dutta *et al*., 2021), land rights (Suich *et al*., 2017), policy constraints (Dhyani *et al*., 2021), or government knowledge (Zerssa *et al*., 2021). The technical dimension involves a range of difficulties that emerge from the hands-on utilization of scientific expertise, technology, and methodologies in the execution of Payment for PES initiatives, including components related to the quantification of carbon sequestration (Osewe *et al*., 2023), baselines establishment Waldén *et al*., 2020, Identifying the emissions leakage (De Jong *et al*., 2007), monitoring programs (Kearney, Coops, *et al*., 2017) and Biophysical conditions (Flugge and Abadi, 2006). Numerous studies have concentrated their efforts on the advancement of developing regions, namely Africa, Asia, and Latin America. This emphasis is primarily driven by the heavy dependence on ecosystem services in these areas, as well as the difficulties encountered by small-scale farmers (Osewe *et al*., 2023). The aforementioned studies emphasized concerns such as limited financial gains and disputes over land ownership (Roshetko *et al*., 2007; Hayes, 2012; Benjamin and Sauer, 2018). In contrast, studies conducted in developed regions such as the United States of America (USA), Europe, and Australia have focused on more advanced topics, including farmer-friendly practices, policy evaluation, and regional carbon markets (Holderieath *et al*., 2012; Dumbrell *et al*., 2016; White *et al*., 2022). Common methods include bioeconomic analysis (Wise and Cacho, 2011), multivariate analysis (Waldén *et al*., 2020), and Monte Carlo simulation (Liu and Chuang, 2023) was used for economic-focused studies. Other studies use specific models or toolkits such as comprehensive mitigation assessment process (COMAP) (Makundi *et al*., 2004); model of an integrated dry land agricultural system (MIDAS) (Flugge and Abadi, 2006); forests, agroforests, low-value-landscape, or, wastelands (FALLOW) model (van Noordwijk *et al*., 2008); and Toolkit for ecosystem service site-based assessment (TESSA) (Martino and Muenzel, 2018) to assess ecosystem services' benefits in climate change mitigation. In the realm of socio-cultural aspect research, interviews and surveys were conducted with farmers to gain insight into their perspectives regarding the implementation of PES on their agricultural properties (Aslam *et al*., 2017; Haile *et al*., 2019; White *et al*., 2022). Various studies in technical aspect relied on interviews and literature reviews to evaluate existing PES programs include the Scolel Te´ project (De Jong *et al*., 2007; Otto, 2019), the Kenya agricultural carbon project (KACP) (Nyberg *et al*., 2020), the Socio Páramo program (Bremer *et al*., 2014), and the Kalahan Forestry carbon project (Lasco *et al*., 2010). Table 2 provides a detailed of the various studies.

Barriers to implementing pes in smallholder agroforestry systems

PES programs highlight their potential to incentivize sustainable land management practices like agroforestry, particularly among smallholder farmers. This approach could generate environmental benefits while providing financial support to rural communities (Wunder *et al.,* 2008; Wunder *et al.,* 2018). Despite growing interest, there are notable obstacles that impede the execution of PES initiatives within smallholder agroforestry systems (Suich *et al*., 2017). Barriers within carbon offset projects encompass any challenges that hinder the progress of creating environmental and social advantages through carbon credits (Newton *et al*., 2016; Peterson St-Laurent *et al*., 2017; Pan *et al*., 2022). A multitude of challenges span across various dimensions, including financial, socio-cultural, political, technical, and biophysical aspects (Acampora *et al*., 2023; Roy and Bhan, 2024). Financial structure poses a significant challenge for smallholder agroforestry. Critics point to high program administration costs such as baseline determination (De Jong *et al*., 2007), program monitoring (Kearney, Coops, *et al*., 2017), and complex data verification processes (Osewe *et al*., 2023) when more farmers are involved. The financial burden is further intensified by the intricate

Table 3: Financial barriers related to PES implementation in smallholder agroforestry system

No.	Financial barriers	Sources
1	High costs for project implementation ■ Baseline determination ■ Program monitoring ■ Complex data verification processes ■ Transaction cost/ Negotiation process	De Jong *et al*., 2007; Cacho *et al*., 2013; Wicke *et al*., 2013; Kearney, Coops, *et al*., 2017; Osewe *et al*., 2023;
2	Low credit price	Flugge and Abadi, 2006; Lasco *et al*., 2010; Holderieath *et al*., 2012
3	Opportunity cost	Antle *et al*., 2007; van Noordwijk *et al*., 2008
4	Delayed benefits ■ Credit benefit ■ Yield benefit ■ Uncertainty of credit distribution	Pollini, 2009; Haile *et al*., 2019; Osewe *et al*., 2023
5	Benefits loss from conventional agriculture practice	Bremer *et al.* (2014); Jacobi *et al*., 2017; Haile *et al.* (2019)
6	Low income ■ Limited initial capital ■ Inadequate infrastructure	Haile *et al*., 2019; Zerssa *et al*., 2021; Jacobi *et al*., 2017; Saikanth *et al*., 2023
7	Lack of financial support	Jacobi *et al*., 2017; Ranjan, 2021; Netter *et al*., 2022

nature of price negotiation, rendering it economically unfeasible for small-scale farmers (Cacho *et al*., 2013) as evidenced in Table 3. For instance, implementing CSA practices among Ethiopian farmers may involve an expense of $US 150 per ton of Carbon dioxide equivalent (CO2e), leading to a significant financial burden for farmers and potentially impacting their income levels (Antle *et al*., 2007). Consequently, the lack of economic feasibility of these programs deters smallholder involvement, impeding the overall effectiveness of of CSA initiatives (Lasco *et al*., 2010; Benjamin and Sauer, 2018). The implementation of PES can theoretically generate economic benefits. However, low credit price arising economic disincentive which discourages farmers from planting trees on their lands. This is evident in Community-based forest management projects in the Philippines (Flugge and Abadi, 2006; Lasco *et al*., 2010), and even in developed countries like USA, where carbon trading fails to motivate landowners in Missouri to adopt agroforestry practices because of lower returns compared to traditional agriculture (Holderieath *et al*., 2012). Studies indicate that a mandatory carbon price is essential in order to encourage engagement. For instance, the findings of a study conducted in Peru suggest that a minimum threshold of $US 50 per ton CO2e would offer a modest financial incentive for farmers to adopt agroforestry practices and expand the tree coverage on their agricultural land (Antle *et al*., 2007). Similarly, a recent study in Scotland exploring the integration of agroforestry with livestock grazing in hill and lowland areas suggests a credit price range of $US 170.7 - $US 1026.6 per ton CO_2e might be necessary to make agroforestry financially attractive for farmers, under the circumstances where traditional farming practices are unprofitable (yielding a return of -$US 371.1 per hectare) (Abdul-Salam *et al*., 2022). Insufficient utilization of land could result in substantial opportunity costs for farmers, particularly when credit prices are low (Antle *et al*., 2007; van Noordwijk *et al*., 2008). The delayed benefits of carbon credits lead to conflicts and confusion among farmers regarding their compensation, and discourage their participation in PES initiatives (Haile *et al*., 2019; Osewe *et al*., 2023). The prolonged wait for benefits can be ascribed to the extended production cycles involved in tree planting in agroforestry practices, thereby presenting farmers with the challenge of adapting to a lengthier cash flow cycle (Pollini, 2009). Ambiguities related to crop yields and the allocation of credit in CSA methods may result in disputes and misunderstandings among farmers

Table 4: Socio-cultural and political barriers related to PES implementation in smallholder agroforestry system

No.	Socio-culture and political barriers	Sources
1	Farmers' knowledge ■ Environmental benefit of PES ■ Incentive structure ■ Policy	Dumbrell *et al*., 2016; Zerssa *et al*., 2021; Pagdee and Kawasaki, 2021
2	Scepticism towards PES projects ■ Different practices compared to traditional farming ■ Cultural beliefs ■ Previous program failures ■ Poor design due to overlooking local cultural traits ■ Limited experience	Pollini, 2009; Aslam *et al*., 2017; Dutta *et al*., 2021; Dhyani *et al*., 2021
3	Demographic ■ Ages ■ Education levels ■ Gender roles	Chimoitaligare, 2014; Aslam *et al*., 2017; Nyberg *et al*., 2020; Dutta *et al*., 2021; Atsiaya *et al*., 2023
4	Lack of government knowledge	Zerssa *et al*., 2021; Suich *et al*., 2017
5	Lack of stakeholder engagement	Jacobi *et al*., 2017; Bamanyisa *et al*., 2019; Osewe *et al*., 2023
6	Small plots of land	Benjamin and Sauer, 2018; Dutta *et al*., 2021; Atsiaya *et al*., 2023
7	Land ownership rights	Suich *et al*., 2017; Benjamin and Sauer, 2018; Dhyani *et al*., 2021
9	Conflict of interest	Wunder *et al*., 2008; White *et al*., 2022; Osewe *et al*., 2023
10	Limited political interest from policymakers	Suich *et al*., 2017; Martino and Muenzel, 2018; Dhyani *et al*., 2021; Dutta *et al*., 2021; Zerssa *et al*., 2021; White *et al*., 2022

concerning their remuneration (Haile *et al*., 2019; Osewe *et al*., 2023). Critics of PES programs argue that they come at a cost to traditional ways of life for small-scale farmers. Studies by Bremer *et al*., (2014) and Haile *et al*., (2019) raise concerns that program participation might restrict access to vital resources like firewood and grazing areas. This could pose a significant disadvantage for low-income households who are already facing difficulties in fulfilling their fundamental requirements. Such families might be reluctant to embrace approaches like CSA or CF if they do not perceive immediate financial advantages, thereby risking their conventional means of livelihood for uncertain future gains (Jacobi *et al*., 2017). Limited initial capital due to low incomes poses a significant barrier to entry for small-scale farmers. These financial constraints hinder their ability to invest in essential program elements vital for successful participation in agroforestry initiatives, including land preparation, and acquiring tree seedlings (Haile *et al*., 2019) or compost, and irrigation projects (Zerssa *et al*., 2021). Insufficient investments in infrastructure worsen the difficulties encountered by small-scale farmers in effectively managing agroforestry products and attaining supplementary advantages (Jacobi *et al*., 2017; Saikanth *et al*., 2023). In countries without PES integrated policy, financial support favoring large-scale monoculture agriculture or livestock activities over agroforestry practice (Jacobi *et al*., 2017). Farmers are compelled to look for financial support from industries downstream that profit from the environmental services offered by agroforestry (Ranjan, 2021). Limited utilization of corporate social responsibility funds by these downstream such as private sectors to purchase PES credits showing a lack of awareness of environmental threats to their sustainability (Netter *et al*., 2022). This condition creates a long-term risk for the viability of PES programs (Osewe *et al*., 2023).

In addition to financial obstacles, the effective implementation of PES necessitates the consideration of socio-cultural and political factors, as illustrated in Table 4. The willingness of farmers to participate in PES programs cannot be ensured solely based on their knowledge of agroforestry practices. An understanding of climate change such as environmental benefits of PES programs (Pagdee and Kawasaki, 2021), incentive structure (Zerssa *et al*., 2021), and climate policy (Dumbrell *et al*., 2016) can significantly influence farmers' decision. Farmers in Missouri faced challenges in adopting carbon farming practices due to their limited knowledge of carbon credit mechanisms such as the Chicago CCX or the California carbon market. This lack of understanding led to skepticism regarding the suitability of carbon farming practices like silvopasture or alley cropping for their land (Holderieath *et al*., 2012). Scepticism towards PES projects can arise from the inherent differences between traditional farming practices and the proposed approach (Dhyani *et al*., 2021) coupled with cultural beliefs that create uncertainty regarding the income potential of ecosystem services offered by practices like CF (Dutta *et al*., 2021). Scepticism arises also from previous program failures, such as failed land productivity initiatives (Pollini, 2009) due to the poorly designed PES program considering local cultural context or stakeholder conditions and limited experience with new practices (Aslam *et al*., 2017). Generating additional obstacles and endangering the prospects of achieving sustained prosperity (Wunder *et al*., 2008; Hayes, 2012). Additional demographic factors such as age, education level, and gender complicate PES program adoption. Studies carried out in the Busia region of Kenya reveal a potential disparity between generations, as older farmers demonstrate a lower inclination towards adopting CSA practices when contrasted with their their younger counterparts (Atsiaya *et al*., 2023). This reluctance likely stems from the challenges associated with transitioning from established traditions to new farming methods (Aslam *et al*., 2017; Dutta *et al*., 2021). Education levels have a significant impact on the inclination towards sustainable farming. In Western Kenya, households with higher levels of education tend to be more attracted to non-farming occupations that are perceived to be more financially rewarding (Chimoitaligare, 2014). Gender dynamics further complicate PES implementation highlight by Nyberg *et al*. (2020) and Zerssa *et al*. (2021) where men are often prioritized for training and technology related to climate adaptation, while women face time constraints, such as due to household duties, which limit their project involvement. The role of the government in natural resource management is pivotal, as it involves providing training on carbon farming skills and technology to local communities. Notwithstanding the significant role it plays, the efficiency of knowledge transfer may face obstacles due to a lack of internal comprehension among government officials, as highlighted by Zerssa *et al*., (2021). The limited comprehension of ecosystem services can additionally hinder the transition from emphasizing land productivity to prioritizing environmental services (Suich *et al*., 2017). The concept of PES relies on collective participation for optimum benefits (Bamanyisa *et al*., 2019), however, the absence of stakeholder engagement is another crucial aspect of PES programs. This could be attributed to uncertainties surrounding the intricate project procedures and the program's reliability in delivering advantages, particularly to the nearby communities. Consequently, farmers have become detached from the stakeholders (Jacobi *et al*., 2017; Osewe *et al*., 2023). Besides stakeholders' roles, the benefits of PES programs are closely linked to the size of the land. It is important to consider that certain PES programs may be better suited for large farms, such as those that store carbon through planting trees, while many local farmers have small plots of land, which would make it harder for them to participate (Benjamin and Sauer, 2018; Dutta *et al*., 2021; Atsiaya *et al*., 2023).

Farmers' hesitation to invest in PES programs can be attributed to concerns about land ownership rights (Benjamin and Sauer, 2018). Long-term planning and investment in PES schemes heavily rely on the indispensability of these rights (Suich *et al*., 2017). Farmers commonly harbor feelings of uncertainty and insecurity when it comes to the benefits of PES programs, primarily stemming from the absence of secure land tenure (Suich *et al*., 2017). Competition could arise among farmers and other stakeholders from the difference in land use preferences, or from the incoherent of specific policies with ecosystem complexity and resource enhancement (Wunder *et al*., 2008; White *et al*., 2022; Osewe *et al*., 2023).

Table 5: Technical and biophysical barriers related to PES implementation in smallholder agroforestry system

No.	Technical and biophysical barriers aspect	Sources
1	Complexity of measurement of ecosystem services	van Noordwijk *et al*., 2008; Kearney, Coops, *et al*., 2017; Osewe *et al*., 2023
2	Complexity of designing PES program ■ Establishing baselines ■ Calculate carbon sequestration and project emission ■ Identifying and measuring the emissions leakage ■ Post-validation (monitoring) activities	De Jong *et al*., 2007; van Noordwijk *et al*., 2008; Waldén *et al*., 2020; Dutta *et al*., 2021; Kearney, Coops, *et al*., 2017
5	Biophysical conditions ■ Rainfall ■ Climate ■ Soil health	Flugge and Abadi, 2006; White *et al*., 2022; Liu and Chuang, 2023

Support is crucial for enhancing the execution of PES, as the absence of policies often arises from policymakers' limited political enthusiasm (Bamanyisa *et al*., 2019; Dhyani *et al*., 2021; Dutta *et al*., 2021). Current agricultural policies frequently overlook the environmental advantages of agroforestry, resulting in a lack of trust among farmers in government incentives and a decrease in their enthusiasm for participation (Dhyani *et al*., 2021; White *et al*., 2022). The uncertainty of policy arises from conflicting regulations or unclear interpretations, such as in the cases of Indonesia and the Natura 2000 Program in Romania, also increasing the risks for investors and project developers (Wicke *et al*., 2013; Suich *et al*., 2017; Martino and Muenzel, 2018). Technical obstacles, in addition to financial and social obstacles, are frequently encountered in numerous research instances (Table 5). Accurately measuring ecosystem services is a complex task that presents a notable challenge in addressing technical barriers. This endeavor calls for the utilization of specialized skills and allocation of adequate resources (Osewe *et al*., 2023). The statistical differentiation of agroforestry ecosystem services is hindered by the limited availability of specific and accurate measurement approaches for predicting the distribution of environmental services, such as carbon sequestration (van Noordwijk *et al*., 2008; Kearney, Coops, *et al*., 2017). Designing a PES program such as establishing baselines and monitoring plan, also estimating carbon sequestration and project emissions, particularly in small-scale agriculture becomes an intricate challenge (De Jong *et al*., 2007; Waldén *et al*., 2020; Dutta *et al*., 2021). Establishing a baseline for PES programs in Ethiopia proves to be a challenging task due to the scarcity of research, especially in the realm of monoculture farming (Waldén *et al*., 2020). Identifying and measuring emissions outside project areas (leakage) in dynamic landscapes like agroforestry systems also pose challenges (De Jong *et al*., 2007; van Noordwijk *et al*., 2008). Subsequent to validation, the implementation of post-validation activities, specifically program monitoring, is imperative to uphold the concept of additionality in the delivery of environmental services. This is in line with the overarching goal of the project, which includes the conservation of carbon stored in above-ground biomass. The monitoring incurs significant costs and requires technical expertise. While satellite imagery or remote sensing can assist in monitoring, it also poses a challenge, particularly for small-scale projects. Small-scale agricultural practices tend to span various landscape gradients that complicate remote sensing analysis to identify project areas. The monitoring of carbon storage changes is complicated by the diverse range of management practices and shifts in land use. Multicollinearity in regression analysis for mapping carbon stored or increased can also affect data accuracy (Kearney, Coops, *et al*., 2017). The implementation of agroforestry within PES schemes is hindered by technical challenges arising from biophysical conditions like rainfall and climate (Flugge and Abadi, 2006; Liu and Chuang, 2023). Weather directly influences program success and brings the aspect of uncertainty. In regions with low intensity of rainfall, like Australia's great southern and eastern wheatbelt areas, implementing agroforestry for carbon farming may not be attractive due to slow

Table 6: Risk of permanent issues from PES in smallholder agroforestry

No.	Risks aspect	Sources
1	Market risks	Antle *et al.*, 2007; Otto, 2019; Jacobi *et al.*, 2017; Waldén *et al.*, 2020; Dhyani *et al.*, 2021
2	Internal risks ▪ Difficult to maintain the commitment ▪ Labour displacement (emission leakage) ▪ Inequitable benefit sharing ▪ Financial resource limitations	De Jong *et al.*, 2007; van Noordwijk *et al.*, 2008; *et al.*, 2016; Haile *et al.*, 2019; Nyberg *et al.*, 2020; Grima *et al.*, 2016
3	Program design ▪ Inappropriate training ▪ Lack of additionality ▪ Monitoring competency ▪ Inadequate methodology	Bremer *et al.*, 2014; Grima *et al.*, 2016; Kearney, Fonte, *et al.*, 2017; Kearney, Coops, *et al.*, 2017; Osewe *et al.*, 2023
4	Nature risks ▪ Changes in temperature ▪ Extreme weather ▪ Pest and diseases ▪ Fires ▪ Groundwater availability	Lasco *et al.*, 2010; Wicke *et al.*, 2013 Flugge and Abadi, 2006; Jacobi *et al.*, 2017 Dhyani *et al.*, 2021

carbon absorption rates and unsuitable species for specific biophysical conditions, such as biosaline land (Flugge and Abadi, 2006). To optimize the chances of achieving successful tree growth in PES programs, it is essential to give due attention to the evaluation of soil health conditions right from the outset of the program (White *et al.*, 2022).

Risks affected to permanence issue

Over time, the quantity of carbon stored in diverse land use types may seem unchanging. However, it is important to note that this stability can be disrupted by human activities and environmental fluctuations, particularly climate variations. These disruptions, referred to as leakage and permanence aspects, can cause fluctuations in the carbon content stored in different land use categories (Roshetko *et al.*, 2007; Leifeld, 2023). The stringent requirement for permanence is viewed as a major hurdle in project implementation because it cannot be guaranteed. Ecosystems possess a dynamic nature, wherein the exchange of carbon (alongside other greenhouse gases) occurs in both directions, forming an integral part of these systems (Leifeld, 2023). As shown in Table 6, market risks such as unsecured or delayed credit payments will be a hurdle in program participants' financial cycle (Antle *et al.*, 2007; Jacobi *et al.*, 2017; Waldén *et al.*, 2020; Dhyani *et al.*, 2021). For instance, the Scolel Te´ program in Chiapas, Mexico, saw a decline in carbon credit sales post-2008 global financial crisis, with buyers shifting focus to greener regions (Otto, 2019). Causing delayed payments that discourage farmers after a long period of waiting for full compensation for their agroforestry implementation (Otto, 2019). Although most of the risks of PES programs are identified from the aspect of market risk, internal factors such as farmers' commitment, labour displacement, inequitable benefit sharing, and financial resources limitation contribute to the risk of program sustainability. In the Kenya Agriculture sustainability program, the participant farmers have difficulty maintaining their engagement and commitment in voluntary to implement Sustainable agriculture land management (SALM) practices. (Nyberg *et al.*, 2020). This lack of understanding can decrease commitment to future PES programs (Hayes, 2012). In small-scale farming, labour displacement can lead to emission leakage beyond project boundaries, resulting in carbon reduction effectiveness (De Jong *et al.*, 2007; van Noordwijk *et al.*, 2008). For example, in the Scolel Te´ program, shifts in activities like logging outside project areas can negate carbon sequestration benefits (De Jong, 2006). The unequal distribution of benefits poses a considerable social injustice risk for farmers with lower incomes (Grima *et al*., 2016; Haile *et al*., 2019). Higher-income farmers may benefit more from PES contracts, while those with high risks may require higher PES payments to achieve similar levels of benefits (Antle *et al*., 2007; Liu and Chuang, 2023). Despite the economic advantages that PES programs bring, their adoption by small-scale farmers can jeopardize the project's long-term viability. This is primarily due to the limitations in financial resources, which contribute to stakeholder misunderstandings and ultimately result in project failure (Netter *et al*., 2022). The elevated risks encountered by small-scale farmers can be attributed to their limited asset ownership and low income (Haile *et al*., 2019; Nyberg *et al*., 2020). The long-term viability of PES programs also hinges on program design. Several factors of poor program design can create risks to the sustainability of PES programs. Inappropriate training, as evidenced in the Socio Páramo program of Ecuador, can lead to certification disapproval, hindering project success (Bremer *et al*., 2014). Projects that fail to provide concrete proof of their supplementary environmental or social advantages may face challenges in enticing investors, thereby endangering their long-term financial feasibility (Grima *et al*., 2016; Kearney, Fonte, *et al*., 2017). Implementing complex monitoring plans, like carbon offset tracking, in diverse small-scale farming systems without proper training can also increase project risks (Kearney, Coops, *et al*., 2017; Osewe *et al*., 2023). Insufficient conservation efforts in PES frameworks could lead to a failure in mitigating ongoing ecosystem stressors, thereby jeopardizing the environmental targets and overall sustainability of the program (Grima *et al*., 2016). These risks highlight the importance of well-designed, well-implemented PES programs to ensure their long-term success. Climate change-induced extreme weather events pose a significant challenge to the effectiveness of PES initiatives, particularly impacting farmers who do not possess adequate sustainable farming practices (Lasco *et al*., 2010) which impacts on tree growth, biomass, carbon sequestration, and crop productivity (Wicke *et al*., 2013). This condition further accelerates the development rates of pathogens (disease-causing organisms), increasing their overall population size and potential damage. Specific pests and diseases can pose a threat to the productivity and stability of the system by targeting certain tree and crop species that are susceptible to their detrimental effects (Dhyani *et al*., 2021). Certain species of vegetation in agroforestry may become vulnerable to fires, or groundwater availability particularly in low rainfall intensity areas (Flugge and Abadi, 2006; Jacobi *et al*., 2017).

Maintain the sustainability of agroforestry in pes program

PES programs hold immense potential for promoting sustainable land management practices like agroforestry (Le et *al.,* 2024). Environmental benefits such as carbon sequestration, biodiversity enhancement, and soil conservation are made possible through the incentivization of farmers to integrate trees into their agricultural landscapes by PES programs (Rode *et al.,* 2023). The application of Payment for PES within small-scale agroforestry setups has encountered backlash for its intricate nature attributed to practical hurdles. These hurdles entail addressing barriers across financial, socio-cultural, political, and technical realms, alongside biophysical factors. This is further exacerbated by the perceived risks linked to PES schemes, which are influenced by various factors such as market context, internal elements, program design, and the inherent nature of these schemes. Diversification strategies to mitigate barriers and risks associated with PES schemes can be done by adaptation, collective action, cooperation, and strengthening institutional arrangements. Several financial barriers such as high implementation costs, opportunity costs, low carbon credit prices, and delayed benefits can act as disincentives, impede farmer participation. Overcoming these issues, requires the adjusted carbon prices to be higher to motivate farmers to adopt new practices like agroforestry (Bremer *et al*., 2014; Haile *et al*., 2019). Ensuring a stable agricultural income remains crucial on PES program, particularly for keeping carbon sink effectively. This can be addressed by offering multiple income streams beyond carbon credits, including the sale of carbon-neutral products derived from agroforestry practices (Netter *et al*., 2022). Involvement in developing credit mechanisms that promote sustainable activities such as the Gold Standard could amplify the benefits of Payment for Ecosystem Services (PES) projects for small-scale agricultural producers (Parnphumeesup and Kerr, 2015). Alternatively, programs can incentivize participation by providing legal land ownership, as a strategy used in Bolivia (Jacobi *et al*., 2017). Farmers will be emboldened to preserve and potentially amplify carbon storage in agroforestry over an extended period due to the security offered by legally recognized land ownership rights (Roshetko *et al*., 2007). Tailoring compensation to local needs, such as offering food in areas with limited market access, ensures that the benefits of agroforestry programs are directly relevant (Haile *et al*., 2019). By broadening the range of revenue-generating possibilities and tailoring approaches to suit the unique characteristics of different regions, Payment for ecosystem services (PES) schemes can present farmers with a more enticing prospect, leading to increased uptake of agroforestry methods as environmentally-friendly land utilization strategies. Unlike forest PES programs typically involve private sector entities working dominantly, building successful PES programs for agroforestry requires a multifaceted approach that fosters trust and collaboration among all stakeholders. The active participation of farmers is of utmost importance in promoting agroforestry. To ensure their engagement, it is essential to clearly illustrate the long-term benefits of agroforestry, including improved soil fertility, enhanced drainage, and the provision of shade for plants. Additionally, offering ongoing support throughout the program is crucial in overcoming the challenges that may arise during the implementation of agroforestry practices (Dhyani *et al.,* 2021; Atsiaya *et al.,* 2023; Osewe *et al.,* 2023). PES thrives on collective participation (Bamanyisa *et al.,* 2019). Effective coordination between diverse stakeholders – government bodies, NGOs, local communities, and private enterprises – is crucial for addressing the unique needs and perspectives of each group (Osewe *et al.,* 2023). Collaboration poses a considerable obstacle, yet it remains crucial for the success of the program. The involvement of farmer cooperatives and active engagement from all stakeholders can effectively tackle the infrastructure and capital constraints frequently encountered in PES implementation (Jacobi *et al.,* 2017; Bamanyisa *et al.,* 2019). Stakeholders must consider the broader landscape-scale impacts and community livelihood needs. Program design should empower farmers by encouraging thorough evaluation of program elements like ecosystem service value, affordability, and fairness before participation (Netter *et al.,* 2022; Osewe *et al.,* 2023), because unresolved stakeholder issues have been shown to contribute to project collapse (Otto, 2019; Nyberg *et al.,* 2020). To establish trust and ensure the long-term viability of programs, it is imperative to adopt a transparent and farmer-centric approach. By involving local communities in the design, implementation, and management of agroforestry projects, a sense of ownership is cultivated, social cohesion is enhanced, and the systems are customized to suit the unique needs and contexts of the community. This inclusive approach paves the way for sustainable outcomes and enduring success. Beyond program design, successful implementation of PES in agroforestry hinges on several key pillars. Training in best practices on Implementing sustainable land management practices within agroforestry systems, such as minimal tillage, organic farming, and agroecological approaches (Gui *et al.,* 2024) is essential to promote soil carbon sequestration and reduce carbon loss through erosion and degradation (Jacobi et al., 2017; Zerssa *et al.,* 2021). Equipping farmers with the requisite knowledge and competencies to effectively maneuver through the intricacies of agroforestry practices is pivotal in upholding soil health and fertility. Consequently, this contributes significantly to the long-term sequestration of carbon and the maximization of economic advantages. Moreover, the realization of cost-efficient and precise carbon storage monitoring can be accomplished by leveraging high-resolution satellite imagery and employing appropriate statistical methods on larger landscape scales, including watersheds, communities, or cities (Kearney, Fonte, *et al*., 2017). This approach not only reduces uncertainty but also provides valuable data to guide farmers toward optimal practices that enhance carbon benefits and unlock access to incentives. Finally, establishing collaborative security and monitoring mechanisms is paramount for addressing potential issues and preventing project failure (van Noordwijk *et al.,* 2008; Holderieath *et al.,* 2012; Grima *et al.,* 2016). The sustainability of PES programs and the environmental advantages they provide are safeguarded through the promotion of collaboration and openness by these mechanisms. In order for PES programs to effectively advance agroforestry practices, it is imperative to have supportive policy frameworks in place. Local participation in policy-making is key to efficient program design. Integrating PES policies into community development plans promotes decision prioritization and enhances farmer involvement, ultimately leading to ensuring the sustainability practice of agroforestry delivers outcomes (Roshetko *et al.,* 2007; Benjamin and Sauer, 2018; White *et al.,* 2022). The implementation of binding policies is vital in ensuring the enduring commitment to agroforestry, a method that necessitates a considerable timeframe for both implementation and the realization of benefits (Dhyani *et al.,* 2021). Adequate policy support fosters greater farmer compliance with land use practices, empowering them with control and allowing for project adaptation (Hayes, 2012). Addressing potential conflicts of interest among stakeholders through policy formulation is crucial. Overcoming obstacles such as land rights and the exploitation of resources is a key aspect of the approach (Roshetko *et al.,* 2007; Pollini, 2009). By fostering local participation, ensuring long-term commitment, and mitigating potential conflicts, well-designed policy becomes the cornerstone for unlocking the full potential of PES programs in promoting sustainable agroforestry practices.

CONCLUSION

The results of the systematic literature review underscore the scientific value added of the findings. Through a deliberate selection process, we identified 40 studies that provided comprehensive coverage while maintaining depth and rigor in our analysis. Various aspects, scopes, and focuses have been explored in these studies, shedding light on the barriers and risks that have an impact on the implementation of Payment for ecosystem services for climate change mitigation through agroforestry practices. The attainment of successful outcomes in payment for ecosystem services initiatives is impeded by a multitude of barriers, as evidenced by selected studies. These barriers encompass financial, socio-cultural, political, technical, and biophysical aspects, all of which pose significant challenges to the execution of such initiatives. Financial barriers emerge as a formidable hurdle, underscoring the substantial economic burden faced by smallholders engaging in Payment for ecosystem services programs. Estimates implementation costs from \$US 150 per ton CO_2e, illuminating the daunting financial landscape that often discourages farmer participation. Furthermore, the prevalence of low credit prices (around \$US 50 per ton CO_2e), exacerbates economic disincentives, compounding the challenges faced by smallholder farmers. Gender dynamics, traditional beliefs, and generational disparities play significant roles in shaping farmers' perspectives on the adoption of Payment for Ecosystem Services within the socio-cultural context. Shed light on the unequal distribution of training and technology related to climate adaptation, with men often prioritized over women. The existence of generational disparities brings to light the difficulties that arise when shifting from long-standing traditions to modern farming techniques. Traditional beliefs and scepticisms towards Payment for ecosystem services initiatives, further contribute to the complexity of socio-cultural barriers, requiring targeted interventions to foster trust and promote community acceptance. From a technical standpoint, the precise measurement of ecosystem services and the complexities involved in monitoring them present considerable challenges. It is crucial to underscore the intricacies associated with establishing baselines, estimating carbon sequestration, and monitoring program efficacy, as these factors pose formidable hurdles. Biophysical conditions, including rainfall patterns and soil health, further influence program success. Addressing these technical barriers necessitates innovative solutions and robust methodologies to ensure the reliability and accuracy of data collection and analysis. While risks associated with Payment for ecosystem services programs are complex and multifaceted, encompassing market uncertainties, internal factors, program design, and nature challenges. Market risks, such as delayed or unsecured credit payments, pose significant hurdles to program participants' financial stability, as evidenced by experiences from programs like Scolel Te´ in Chiapas, Mexico. Internal factors, including farmers' commitment, labour displacement, and inequitable benefit sharing, further compound the risk of program sustainability. The Kenya Agriculture Sustainability Program exemplifies the obstacles encountered in fostering farmers' involvement and dedication to sustainable methods. Furthermore, disparities in benefit allocation can heighten the social injustice vulnerabilities of impoverished farmers. Moreover, the long-term viability of Payment for ecosystem programs hinges on effective program design and implementation. Poorly designed projects, lacking clear evidence of additional environmental or social value, may struggle to attract investors and face certification disapproval. Inadequate conservation measures within Payment for ecosystem schemes can also undermine environmental goals and program sustainability. The effectiveness of programs is further jeopardized by the challenges posed by nature, such as extreme weather events driven by climate change. This is particularly true for farmers who do not possess sustainable farming knowledge. As a result of these environmental impacts, there is a decline in tree growth, biomass, and carbon sequestration, while the vulnerability to pests, diseases, and environmental stressors increases. To maintain the sustainability of agroforestry in Payment for ecosystem programs, it is essential to recommend the diversify income streams for farmers beyond carbon credits, adapt to local contexts, and incentivize participation through strategies like adjusted carbon prices and multiple income opportunities. Collaborative efforts involving diverse stakeholders, such as government bodies, NGOs, local communities, and private enterprises, are crucial to proposed for successful program implementation. Encouraging farmer participation through long-term benefits demonstration, ongoing support, and farmer empowerment is key. The establishment of trust and the promotion of long-term sustainability heavily rely on the incorporation of transparency, farmer-focused methodologies, and the active participation of local communities in the planning and execution of programs. Highlight the need for training in best practices, cost-effective monitoring methods, and collaborative security mechanisms play pivotal roles in successful agroforestry implementation within Payment for ecosystem services programs. Supportive policy environments that integrate Payment for ecosystem services policies into community development plans, prioritize local participation in policy-making, and address conflicts of interest among stakeholders are fundamental for promoting sustainable agroforestry practices through Payment for Ecosystem Services programs. The collective exertions will ultimately support the continuity of agroforestry practices, with a particular emphasis on its ability to offer vital environmental services, such as sustainable carbon storage. The significance of the 40 research studies emphasizes the urgent requirement for inventive approaches to address the technical challenges associated with precise measurement of ecosystem services and guaranteeing the dependability of data within Payment for ecosystem services initiatives. It advocates for supportive policy frameworks that prioritize local participation, mitigate conflicts of interest, and integrate Payment for ecosystem services policies into community development plans to foster sustainable agroforestry practices. Moreover, the study highlights the necessity of boosting climate resilience via adaptive approaches in agroforestry, resolving market uncertainties to secure financial stability for program recipients and draw in investors, and fortifying conservation strategies to realize supplementary environmental and social perks while mitigating climate change risks. These findings highlight promising avenues for future research and action aimed at advancing both environmental conservation and socioeconomic development agendas.

AUTHOR CONTRIBUTIONS

A. Ibrahim was involved in conceptualizing the article, literature searching, selection and screening, data extraction, synthesis, and analysis, and writing the manuscript. S. Withaningsih was involved in obtaining funding, interpreting research results, reviewing the manuscript, revising the final manuscript, and providing final approval. R. Kinseng was involved in conceptualization, conceiving, and designing the analysis, and providing final approval. Parikesit was involved in conceptualization, conceiving, and designing the analysis. D. Muhamad was involved in supervising and reviewing the manuscript.

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CONFLICT OF INTEREST

The authors declare that there are no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy, were observed by the authors.

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ABBREVIATIONS

$US	United States dollar
%	Percent
AI	Artificial intelligence
CA	Conservation agriculture
CCX	Chicago Climate Exchange
CDM	Clean development mechanism
CF	Carbon farming
CO_2e	Carbon dioxide equivalent
COMAP	Comprehensive mitigation assessment process
CSA	Climate-smart agriculture
DOI	Digital object identifier
FALLOW	Forests, agroforests, low-value-landscape, or, wastelands
Fig.	Figure
KACP	Kenya Agriculture Carbon Project
LDSF	Landscape Degradation Surveillance Framework
MIDAS	Model of an Integrated Dryland Agricultural System
NGOs	Non-government organizations
PES	Payment for ecosystem services
PICO	Participant, Intervention, Comparators, and Outcome
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analysis
PSALSAR	Protocol, Search, Appraisal, Synthesis, Analysis, Reporting
SALM	Sustainable Agriculture Land Management
SLR	Systematic Literature Review
TESSA	Toolkit for Ecosystem Service Site-based Assessment
USA	United States of America

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AUTHOR (S) BIOSKETCHES

Ibrahim, A., M.I.L., Ph.D. Candidate, Doctoral Program on Environmental Sciences, Postgraduate School, Universitas Padjadjaran, Bandung City, West Java, Indonesia.
- Email: *ibrahimasni@gmail.com*
- ORCID: 0009-0005-1776-9507
- Web of Science ResearcherID: NA
- Scopus Author ID: NA
- Homepage: https://jentara.id/tim-kami/

Withaningsih, S., Ph.D., Associate Professor, Master Program on Sustainability Science, Postgraduate School, Universitas Padjadjaran, Bandung City, West Java, Indonesia.
- Email: *susanti.withaningsih@unpad.ac.id*
- ORCID: 0000-0002-5893-0222
- Web of Science ResearcherID: AAB-6734-2021
- Scopus Author ID: 57195276031
- Homepage: https://biologi.unpad.ac.id/dosen/

Kinseng, R., Ph.D., Professor, Departement of Communication and Community Empowerment, Faculty of Human Ecology, Bogor Agricultural University, Bogor City, West Java, Indonesia.
- Email: *rilus@apps.ipb.ac.id*
- ORCID: 0000-0002-9921-4601
- Web of Science ResearcherID: ADJ-0698-2022
- Scopus Author ID: 57194580921
- Homepage: https://skpm.ipb.ac.id/departement/dosen/detil/6

Parikesit, Ph.D., Professor, Departement of Biology, Faculty of Mathematics and Natural Sciences, Padjadjaran University, Sumedang, West Java, Indonesia.
- Email: *parikesit@unpad.ac.id*
- ORCID: 0000-0001-8214-7126
- Web of Science ResearcherID: AAC-9331-2021
- Scopus Author ID: 55934491300
- Homepage: https://biologi.unpad.ac.id/dosen/

Muhamad D., Ph.D., Indonesia Research Institute Japan, Shibuya Tokyo, Japan.
- Email: *muhamaddendi@gmail.com*
- ORCID: 0000-0001-8882-6322
- Web of Science ResearcherID: N-8781-2013
- Scopus Author ID: 36182969100
- Homepage: https://irij-jakarta.com/about-us/

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