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Ecosystem-Based Forestry Land Use for Flood Risk Mitigation and Socio-Livelihood Supports in Southwest Nigeria

Abstract. Despite huge government spending on concrete infrastructure, Nigeria still faces recurrent flooding issues. Therefore, the study was conducted to assess ecosystem-based forestry land use (EFLU) for flood risk mitigation and socio-livelihood supports in South West Nigeria. A multistage procedure was applied in this research. The initial two stages involved purposive sampling of Oyo, Ogun, and Lagos States, with two local government areas (LGAs) selected from each state, followed by a third stage of random selection of 22 communities in each of the LGA, based on past incidences of flood. In the fourth stage, households listing was used to systematically select 250 households. Questionnaire administration was adopted for data collection. Data analysis utilised descriptive statistics, ranking and chi-square test at $\alpha 0.05$. Findings showed extent of awareness on discouraging refuse and waste dump into drainages and rivers ranked 1st while other government's intervention were ranked below 1.5 mean scores benchmark. In addition, for EFLU; tree planting and conservation of trees were ranked 1st and the latter ranked 2nd, respectively. This suggested that tree planting and conservation are well-promoted initiatives, but other EFLU may require more attention to increase their impacts. Furthermore, there was a significant relationship between extent of awareness and trees conservation in upland areas. Therefore, the study recommends consistent promotion and support tree planting and conservation initiatives, with effective engagement of local communities to promote environmental awareness, to curb climate change disaster.

Keywords: climate change, disaster management, awareness, environmental protection, ecosystem services, forest trees

JEL Classification: Q15, Q56

Introduction

Flooding has resulted in extensive loss of lives and destruction of property in Nigeria, compelling successive governments to allocate substantial financial resources toward infrastructural repairs and flood control measures. According to Confor (2016), significant public expenditure was directed toward the construction of flood defences in vulnerable areas in 2007; however, many of these structures failed to deliver the expected outcomes during the heavy rainfall events of December 2015. This underscores the limitations of conventional flood mitigation approaches. Carrick et al. (2018) further observed that traditional hard-

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engineering solutions such as dams, reservoirs, and embankments are capital-intensive, time-consuming, and often unsustainable over the long term.

In contrast, nature-based solutions, including vegetation cover, reforestation, improved water channelisation, and waterway diversion, have been identified as effective and sustainable flood mitigation measures (Opperman & Galloway, 2022). The inadequate adoption and limited validation of forestry land-use strategies such as tree planting and other green mitigation practices have contributed to increased vulnerability, livelihood disruption, and material losses in flood-prone communities. While structural flood control measures widely implemented across Nigerian states remain costly and unsustainable, forestry-based land use strategies are comparatively affordable, environmentally sound, and resilient.

Beyond physical interventions, awareness creation by governments at all levels particularly regarding early flood warning systems, evacuation from floodplains, and proper waste management remain critical. However, evidence from South West Nigeria suggests that reliance on structural flood mitigation measures has yielded minimal success. This situation highlights the need for forestry managers and policymakers to integrate forestry land use strategies into flood management frameworks, especially in areas that experience recurrent flood disasters. This evolving research domain is essential for strengthening forestry land-use systems for effective flood management in South West Nigeria.

Empirical studies affirm that deforestation and unsustainable land use practices significantly reduce land capacity for water absorption and retention, thereby intensifying flood risks (Ali et al., 2021). Forest ecosystems play a vital role in regulating hydrological processes, enhancing sustainability, and supporting climate adaptation and mitigation efforts (Ellison et al., 2017). Forest trees can alter surface runoff dynamics by reducing flood peaks, delaying flood occurrence, and allowing communities more time to respond to flood warnings (Confor, 2016). Riparian vegetation slows water flow, reduces sedimentation, and enhances river channel capacity, while tree buffers across hills and streams trap sediments and reduce erosion.

Consistent with this, Lopes et al. (2018) emphasised that forest vegetation both in rural and urban landscapes enhances rainwater infiltration, particularly in flood-prone ecosystems. These insights support the global shift from purely structural flood control toward integrated, non-structural floodplain management strategies (Marapara et al., 2020). Forest soils are generally porous, promoting infiltration and reducing surface runoff (Zhu et al., 2025), although the effectiveness of plantation forests depends on management practices, understory presence, and site-specific conditions (Ashrafizadeh & Yousefpour, 2025).

Ecosystem-based forestry land use approaches are increasingly recognised as effective strategies for flood mitigation and livelihood sustainability, particularly in flood-prone regions. Globally and within Nigeria, sustainable forestry practices contribute significantly to environmental stability by enhancing ecosystem services such as soil conservation, watershed protection, and natural flood regulation. According to Adeoye et al. (2025), ecosystem services derived from well-managed forest landscapes help stabilise soils, reduce surface runoff and erosion, and function as natural buffers that moderate the intensity and impacts of flooding. In South West Nigeria, where seasonal rainfall and rapid urban expansion have heightened flood vulnerability, communities often adopt non-structural, ecosystem-based measures—including tree planting, riparian vegetation restoration, and streambank stabilisation—to reduce flood risks while sustaining local livelihoods. These practices reinforce the ecological capacity of landscapes to absorb excess water and protect settlements located in low-lying or flood-prone areas. Furthermore, the close relationship

between ecosystem services, food security, and economic sustainability in developing regions underscores the importance of integrating forestry-based land use strategies into flood management frameworks. As emphasised by Gupta et al. (2021), ecosystem-driven resource management provides a viable pathway for improving environmental resilience while supporting rural and peri-urban livelihoods. In this context, eco-based forestry land use systems represent a sustainable and cost-effective alternative to purely structural flood control measures.

However, despite the growing recognition of ecosystem-based forestry in flood management, empirical evidence on how communities perceive the benefits and practical impacts of such land-use systems remains limited, particularly in South West Nigeria. Existing studies have largely focused on the ecological or technical effectiveness of forestry practices, while relatively little attention has been given to local awareness of government-supported forestry interventions, community perceptions of their socio-economic benefits, and the extent to which these ecosystem-based strategies are viewed as viable tools for flood risk mitigation. This knowledge gap constrains the effective integration of ecosystem-based forestry approaches into local flood management policies and community-based adaptation strategies.

Against this background, this study evaluates the benefits and impacts of ecosystem-based forestry land use for flood mitigation in South West Nigeria, with particular emphasis on awareness of government interventions, household benefits from forestry practices, and the impact of ecosystem-based approaches on strengthening community resilience and reducing flood risks.

The general objective of this study is to assess perceived benefits of ecosystem-based forestry land use and impact for flood risk mitigation in South West Nigeria.

The specific objectives were to:

1. assess the extent of residents' awareness of government flood mitigation interventions in South West Nigeria;
2. evaluate the perceived benefits of EFLU for flooding mitigation; and
3. assess impact of ecosystem-based forestry land-use for flood risk mitigation.

The following null hypotheses were formulated and tested at an appropriate level of significance:

H₀₁: There is no significant relationship between residents' awareness of government flood intervention measures and impact of ecosystem-based forestry land-use (EFLU) strategies for flood mitigation in South West Nigeria.

Literature review

The Need for Ecosystem-Based Flood Mitigation and Socio-Livelihood Supports

Threats from incessant floods have been recurrent throughout many human civilisations, it has been an unavoidable event because residents live close to a water source (Cooper et al., 2021). The risk of fluvial flooding poses significant challenges to communities, yet it is important to recognise that flooding also plays a beneficial role by periodically rejuvenating and fertilising productive lands through the deposition of nutrient-rich sediments, an example of which is the River Nile in Egypt (Cooper et al., 2021). Traditionally, flood defence and

mitigation have relied on the construction of hard infrastructure such as dams, weirs, sluices, and barriers, or through river engineering methods like straightening and deepening channels to increase capacity (Peter & Fatuki, 2018). Similarly, levees and embankments, such as those built along the Mississippi River in the United States, have been employed to control floods (Olson & Speidel, 2021). While effective, these structural measures involve high costs for construction and maintenance, often have adverse environmental impacts, and may provoke unintended consequences. Recently, however, there has been a growing consensus that natural flood management approaches could provide more environmentally sustainable and cost-effective solutions to flood mitigation (Waylen et al., 2018).

Natural flood management (NFM) has been defined in various ways in the literature. According to Lane (2017), it involves the holistic application of general flood management and hydrological principles to develop techniques at any scale within a catchment that either replicate or enhance natural processes to reduce flood risk. The Environment Agency in England classifies several NFM techniques, including river restoration, floodplain restoration, leaky barriers, offline storage areas, catchment woodland, cross-slope woodland, floodplain woodland, riparian woodland, soil and land management, headwater management, and runoff management (Environment Agency, 2018).

Notwithstanding, forest ecosystem services showcase an imminent role in supporting livelihoods by providing essential resources such as food, fuelwood, and medicine (Ahhammad et al., 2019), which hinges on SDG 2 focusing on zero hunger, and they further regulate water cycles and climate, preventing soil erosion and offer income and employment opportunities, particularly for the rural poor communities. More so, the ecosystem free services are critical for both subsistence and economic development, yet they are often undervalued (Thammanu et al., 2021), but aggregately, successful community forest management enhances the provision of ecosystem benefits and contributes to sustainable agricultural production through effective regulation and stewardship of forest resources, and livelihood activities that engender economic prosperity in the rural setting. This underscores the importance of effective forest management policies to ensure the sustainability of these benefits and to support vulnerable populations.

Forest Trees and Water Control

Forest trees have long been recognised for their role in water regulation, dating back to the time of Pliny the Elder (Vaquero et al., 2025). Historical awareness of this relationship is evident in mediaeval France, where a decree issued in 1219 acknowledged the connection between forests and water systems (Cooper et al., 2021). According to Vaquero et al. (2025), the earliest recorded hydrological monitoring occurred in France during the mid to late 1800s. As scientific understanding of the global hydrological cycle has advanced, forests have increasingly been seen as critical components in maintaining this cycle. This recognition has led to the establishment of numerous monitoring and experimental initiatives worldwide, including the Long-Term Ecological Research (LTER) network in the United States and the Coalburn catchment studies (Gupta et al., 2021). Trees possess unique characteristics that distinguish them from other vegetation types, particularly in terms of water usage, due to their size, longevity, and structure. Hu et al. (2025) identify three main categories of factors influencing tree water use: (1) climatic factors, including solar radiation, air temperature, humidity, and wind; (2) water availability, such as rainfall, irrigation, soil water, and groundwater; and (3) tree-specific factors, including leaf area, rooting depth, maturity, and

overall size. The age, species composition, and spatial distribution of trees in a forest significantly affect the hydrological fluxes within that ecosystem.

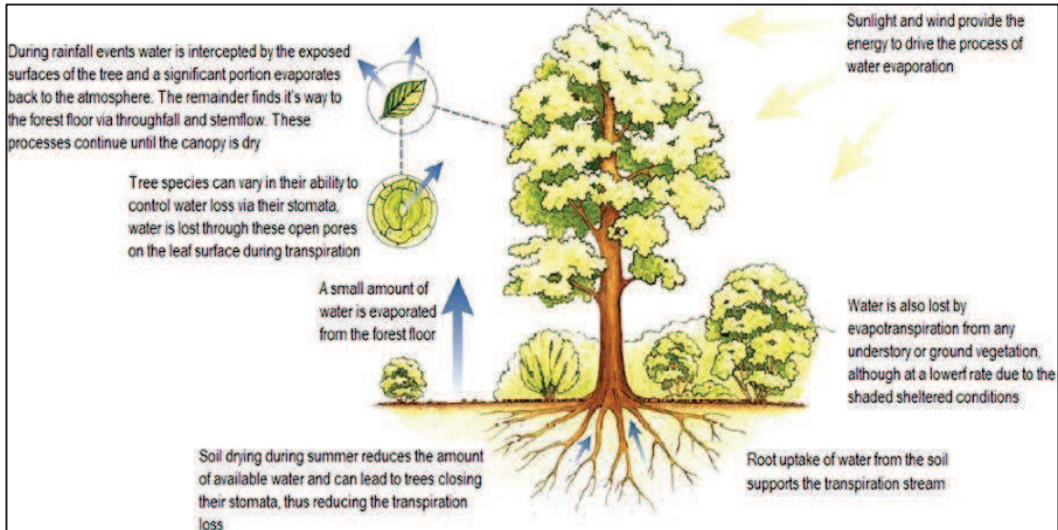


Fig. 1. How forest trees use water

Source: Adapted from an original illustration published in *Forestry and Natural Resources*, Purdue University (2021).

Beyond their direct impact on water uptake and evapotranspiration, trees also influence hydrological processes indirectly. They alter soil properties enhancing infiltration and water storage—modify surface roughness, which affects overland flow during flooding, and reduce erosion and downstream sedimentation (Firoozi & Firoozi, 2024). These functions collectively underscore the essential role forests play in managing water resources and mitigating flood risks. Figure 1 illustrates the processes through which trees influence the hydrological balance in forested landscapes.

Methodology

The study was conducted in South West Nigeria, focusing on residents in flood-prone communities. The South-West is one of Nigeria's six geopolitical zones and is predominantly inhabited by the Yoruba ethnic group. The population of South West Nigeria is 41,192,000 according to demographic statistics (2022). The region covers a land area of approximately 114,271 km² and comprises six states: Oyo, Osun, Ogun, Lagos, Ondo, and Ekiti. A four-stage sampling procedure was employed to select the households for the study.

Stage 1: Three states of Oyo, Ogun, and Lagos were purposively selected based on their history of frequent and severe flood events (Nnodim, 2023; Cirella et al., 2018).

Stage 2: Within the selected states, Local Government Areas (LGAs) and wards with the presence of water bodies and recurrent flooding were also purposively chosen. In Oyo

State, Ido and Oluyole LGAs were selected; in Ogun State, Obafemi Owode and Abeokuta South LGAs were chosen; and in Lagos State, Alimosho and Ikorodu LGAs were selected. The number of wards in each LGA is as follows: Ido – 10 wards, Oluyole – 10 wards, Obafemi Owode – 12 wards, Abeokuta South – 15 wards, Alimosho – 11 wards, and Ikorodu – 19 wards.

Stage 3: A total of 22 highly flood-prone communities were randomly selected from the wards. These include: Ido LGA (Oyo State): Apete/Awotan, Omi-Adio, Idi-Iya; Oluyole LGA (Oyo State): Odo-Ona Elewe/Ikereku, Odo-Ona Kekere, Odo-Ona Nla; Obafemi Owode LGA (Ogun State): Ofada/Mokoloki, Mowe, Ibafo, Asese; Abeokuta South LGA (Ogun State): Obantoko, Igbore/Itori/Ago-Oba, Ago-Ijsha/Ijeun Titun; Alimosho LGA (Lagos State): Shasha/Akowonjo, Egbe/Agodo, Ikotun/Ijegun; Ikorodu LGA (Lagos State): Ijede II, Ibeshe, Odogunyan, Agura/Iponmi, Isiu, Ipakodo

Stage 4: A household listing was conducted in each selected community to create a sampling frame. From this list, households were systematically sampled by selecting every 5th household. A total of 250 respondents were ultimately selected across the 22 communities as sample size. The test instrument used for collection of information from the respondents was a well-structured questionnaire and interview section. Data analyses were carried out with frequencies, simple percentages, chi-square and ranking of mean scores.

Analytical Tools

- i. Chi-square Analysis

$$\chi^2 = \sum \left[\frac{(f_o - f_e)^2}{f_e} \right] \dots\dots\dots (1)$$

Where:

- χ^2 = Chi-Square statistic;
- Σ = Summation symbol, indicating the total sum;
- f_o = Observed frequencies of the qualitative variables in the study;
- f_e = Expected frequencies of occurrence, derived from the distribution of response categories.

Ranking of Mean Scores

Residents were asked to indicate their extent of awareness, as well as perceived benefits, and the categorisation of the impact of ecosystem-based forestry land-use in flood-prone communities of South West Nigeria using a 4-point Likert scale of larger extent=3, lesser extent=2, rare extent=1, and not aware=0. Also, for perceived benefits, effectiveness was measured using a four-point rating scale as follows: very effective = 3; effective = 2; mildly effective = 1; not effective = 0. The benchmark was obtained as 3+2+1+0=6 divided by 4 =1.5. Hence, any point below 1.5 is low, and any point equal to and above 1.5 is high. These were used to rank the mean scores of extents of awareness and socio-livelihood support. Further, the same benchmark of 1.5 was used to operationalise impact of ecosystem-based forestry land-use (EFLU).

Results and Discussion

Extent of Awareness of Government Intervention

The results in Table 1 on the extent of government intervention among residents reveal that the extent of awareness on discouraging refuse and waste dumping into drainages and rivers (mean = 1.6) was the most popular level of awareness among residents and was ranked 1st. This infers that this information was the most accessible among residents and it suggests that the more informed residents are on refuse and waste dump management, the less flood overflow.

Table 1. Extent of Awareness of Government Intervention (N= 250)

Government's Interventions	Extent of Awareness				Mean	Rank
	Not Aware	RrE	LsE	LgE		
Dumping of refuse and waste into drainages and rivers is discouraged in our community.	39 (15.6)	89 (35.6)	67 (26.8)	55 (22.0)	1.6	1 st
Government has warned many residents living in the floodplain to relocate	53 (21.2)	154 (61.6)	18 (7.2)	25 (10.0)	1.1	2 nd
Upland area of floodplain must be restricted to cattle grazing to avoid soil compactness	229 (91.6)	17 (6.8)	3 (1.2)	1 (0.4)	1.0	3 rd
Sensitisation and early warning systems are essential components of effective flood management.	65 (26.0)	135 (54.0)	26 (10.4)	24 (9.6)	1.0	3 rd
Both government and non-governmental organisations (NGOs) have critical roles to play in mitigating flood risks and enhancing community preparedness.	86 (34.4)	124 (49.6)	26 (10.4)	14 (5.6)	0.9	4 th
Prohibition of building construction on the floodplain is enforced.	118 (47.2)	74 (29.6)	32 (12.8)	26 (10.4)	0.9	4 th
De-silting of the river must be carried out frequently to allow free flow of water.	145 (58.0)	52 (20.8)	34 (13.6)	19 (7.6)	0.7	5 th
Upland area must be engaged with reforestation where deforestation has occurred.	189 (75.6)	22 (8.8)	36 (14.4)	3 (1.2)	0.4	6 th
Adequate sensitisation on land-use strategies is environmental best natural practice to control flood.	183(73.2)	49 (19.6)	2 (0.8)	16 (6.4)	0.4	6 th
The importance of conservation of existing trees and shrubs in flood management.	182 (72.8)	45 (18.0)	17 (6.8)	6 (2.4)	0.4	6 th
Tree planting (reforestation) and agroforestry as effective flood management.	179 (71.6)	46 (18.4)	22 (8.8)	3 (1.2)	0.4	6 th
Adequacy of tree planting as means of preventing flood.	198 (79.2)	26 (10.4)	16 (6.4)	10 (4.0)	0.4	6 th

NB* Figures in parentheses are percentages; RrE = Rare Extent; LsE = Lesser Extent; LgE = Larger Extent

Source: Field survey.

Government's warning to many residents living in the floodplain or flood-prone areas to relocate (mean = 1.1) was ranked 2nd most level of awareness of government intervention. Sensitisation and early warnings about flooding being useful in flood management (mean = 1.0) was ranked 3rd most popular level of awareness of government intervention among residents for flood risk mitigation. This corroborates with Vaquero et al. (2025) and Cooper et al. (2021) that it is an awareness of forest trees which plays a role in water regulation, and awareness of this relationship is evident in mediaeval France, where a decree issued in 1219 acknowledged the connection between forests and water systems. However, awareness on government and non-government organisation's roles in combating flood (mean = 0.9), the necessity for regular desilting of the river to ensure the free flow of water (mean = 0.7), and agroforestry as effective flood risk mitigation practices, adequacy of tree planting as a means of preventing flood, conservation of existing trees and shrubs for flood management and adequate sensitisation on land-use strategies being environmental best natural practices to control flood and vulnerability of people (mean = 0.4) were ranked 4th, 5th, and 6th, respectively, most popular level of awareness of government intervention among residents. This implies that the higher the extent of awareness among residents on government intervention, the more flood risk is averted. This corroborates Ellison et al., (2017) that forest ecosystems play a vital role in regulating hydrological processes, enhancing sustainability, and supporting climate adaptation and mitigation efforts. Furthermore, extent of awareness on government interventions about ecosystem services was ranked 6th. This suggests residents showed limited awareness of ecosystem services, ranking knowledge of these practices like reforestation, conservation, and agroforestry as low, indicating a significant knowledge gap.

Perceived Benefits of Ecosystem-based Land Use

Table 2 shows the distribution of benefits of ecosystem-based forestry land use (EFLU) in the study area. The results reveal EFLU enhances carbon sequestration which contributes to global efforts on reduction of greenhouse gas emission supporting sustainable development ranked 1st. This indicates that EFLU has a positive impact on the environment by enhancing carbon dioxide from the atmosphere, mitigating climate change and enforcing sustainable development and a healthier environment. This aligns with Sustainable Development Goal (SDG) 13 on Climate Action, as it directly contributes to combating climate change by facilitating the removal of greenhouse gases from the atmosphere (Dagnachew et al., 2021). The findings also show that environmental benefits from EFLU support agriculture, fisheries and other livelihoods enhancing food security and nutrition ranked 2nd. This implies that EFLU has a positive impact on food availability and nutrition by supporting key sectors like production of arable crops, permanent crops, animals and fish as more important socio-livelihoods activities. This concurs with Sustainable Development Goal (SDG) 2 on Zero Hunger, as forest ecosystem services directly support food security, enhance nutrition, and promote sustainable agriculture by providing essential resources and maintaining the health of ecosystems critical for food production (Food and Agriculture Organization of the United Nations, 2015). In addition, findings reveal increased resilience by EFLU in reducing vulnerability to floods, droughts, and other climate-related shocks ranked 3rd. This indicates that EFLU approach enhances community resilience, enabling them to better withstand and adapt to climate-related challenges. This corroborates SDG 15 on life on land which focuses on protecting, restoring, and sustainably using terrestrial ecosystems, including forests which align with SDG 13 on climate action entrench on

strengthening resilience and adaptive capacity on climate-related hazards as forests are crucial for mitigating climate change and building resilience (Bowyer et al., 2018). To sum-up, EFLU has positive impacts generally on sustainable development for ensuring a healthier environment, lands, soils, and water supply for agricultural and fisheries production, overall livelihood supports, total food safety net combating hunger, and enforcing resilience to floods, droughts, and climate-related hazards.

Table 2. Perceived Benefits of Ecosystem-based Forestry Land Use (N= 250)

Ecosystem-Based Forestry Land Use	Highly Effective	Effective	Mildly Effective	Not Effective	Mean Scores	Rank
Flood mitigation from ecosystem-based forestry land-use (EFLU) protects home, agricultural lands and infrastructure enhancing food safety and stable income	35 (14.0)	115 (46.0)	75 (30.0)	25 (10.0)	1.6	5 th
Sustainable livelihoods from EFLU generate income and employment opportunities improving overall well-being	30 (12.0)	125 (50.0)	68 (27.2)	27 (10.8)	1.6	5 th
Environmental benefits from EFLU support agriculture, fisheries and other livelihoods enhancing food security and nutrition	50 (20.0)	130 (52.0)	70 (28.0)	0 (0.0)	1.9	2 nd
Increased restoration reduces vulnerability to floods, droughts, and other climate-related shocks	45 (18.0)	132 (52.8)	65 (26.0)	8 (3.2)	1.8	3 rd
EFLU improves food security which increases access to nutrition, better health, and well-being	32 (12.8)	141 (56.4)	60 (24.0)	17 (6.8)	1.7	4 th
EFLU enforces carbon sequestration which contributes to global efforts to reduce greenhouse gas emission supporting sustainable development	75 (30.0)	120 (48.0)	41 (16.4)	14 (5.6)	2.0	1 st
EFLU supports community empowerment which enhances community capacity to manage natural resources	28 (11.2)	117 (46.8)	85 (34.0)	20 (8.0)	1.6	5 th

NB* Figures in parentheses are percentages

Source: Field survey.

Impact of Ecosystem-based Forestry Land Use for Flood Risk Mitigation

Table 3 presents the ecosystem-based forestry land-use (EFLU) practices employed in the study area for flood risk mitigation. Tree planting, with a mean score of 1.8, was the most extensively utilised EFLU and ranked first. It was partially practiced by most residents (98.4%) in Lagos, Oyo, and Ogun States, respectively. Following this, the conservation of trees and shrubs in upland areas (mean = 1.6) ranked as the second most prominent EFLU, with partial use among majority of residents (78.0%). Similarly, stream bank stabilisation through re-vegetation, also with a mean of 1.6, shared the second rank, with partial utilisation among majority of residents (77.6%) in South West Nigeria. Additionally, de-silting of streams and rivers, with a mean score of 1.0, ranked third, with partial use reported by 49.2% residents who never used EFLU and about 50.4% of residents who partially used EFLU in

South West Nigeria. This corroborates with Hu et al. (2025) and Firoozi & Firoozi, (2024) that forest trees have significant use for mitigating flooding by influencing hydrological processes indirectly and altering soil properties to enhance infiltration of running waters. Furthermore, sustenance of the natural environment (mean = 0.7) ranked as the fourth most popular EFLU, with partial adoption rates of EFLU never used by residents (64.8%) and partially used by residents (35.2%). Similarly, landscaping, planning, and beautification of the environment (mean = 0.7) attracted residents who never used EFLU(65.6%) and residents who partially used EFLU (34.4%), respectively. These findings indicate that tree planting, tree conservation, and streambank stabilisation were the most practiced forest land-use strategies with relatively high utilisation. This corroborates Ellison et al., (2017) that forest ecosystems play a vital role in regulating hydrological processes, enhancing sustainability, and supporting climate adaptation and mitigation efforts. In contrast, other approaches such as desilting of streams, sustenance of the natural environment, and environmental landscaping exhibited lower levels of use in South West Nigeria. Overall, this suggests that ecosystem-based forestry land-use (EFLU) practices are generally underutilised in the region.

Table 3. Impact of Ecosystem-Based Forestry Land Use for Flood Risk Mitigation (N= 250)

Ecosystem-Based Forestry Land Use	Category of Utilisation				Mean	Rank
	NU	US	PU	FU		
Planting of trees	4 (1.6)	-	246 (98.4)	-	1.8	1 st
Conservation of trees	55 (22.0)	-	195 (78.0)	-	1.6	2 nd
Streambanks stability by revegetation	56 (22.4)	-	194 (77.6)	-	1.6	2 nd
Desilting of rivers and culverts in vulnerable communities	123 (49.2)	-	126 (50.4)	1 (0.4)	1.0	3 rd
Sustenance of the natural environment	162 (64.8)	-	88 (35.2)	-	0.7	4 th
Landscaping and beautification planning of the environment	164 (65.6)	-	86 (34.4)	-	0.7	4 th
Agroforestry practices	250 (100.0)	-	-	-	0.0	5 th
Green fencing with trees and shrubs in the floodplain	250 (100.0)	-	-	-	0.0	5 th

Note: Never used: NU; Used but stopped: US; Partially in use: PU; Fully in use: FU

Figures in parentheses are percentages

Source: Field survey.

Hypothesis testing for a relationship between extent of awareness and impact of EFLU

Ho1: There is no significant relationship between extent of awareness of government interventions and impact of ecosystem-based forestry land use (EFLU)

The study (Table 4) revealed no significant relationship between the extent of residents’ awareness of government and non-governmental organisations’ roles in flood combat and several specific interventions, including desilting of rivers ($\chi^2 = 1.09, p = 0.777$), prohibition of construction on floodplains ($\chi^2 = 4.54, p = 0.208$), sensitisation and early warning of flooding ($\chi^2 = 1.72, p = 0.631$), government warnings on relocation from floodplains ($\chi^2 = 2.37, p = 0.498$), refuse prohibition into drainage and rivers ($\chi^2 = 2.06,$

$p = 0.558$), and tree planting as an ecosystem-based forestry land use (EFLU). This suggests that these government interventions may not be effectively enforced, making it difficult to assess their influence on tree planting as an EFLU strategy. This concurs with Lopes et al. (2018) who emphasised that forest vegetation both in rural and urban landscapes enhances rainwater infiltration, particularly in flood-prone ecosystems.

Table 4. Chi-square Analyses of Extent of Awareness of Government's Interventions and Impact of Ecosystem-based Forestry Land Use

Extent of Awareness of Government's Interventions	Ecosystem-Based Forestry Land Use [df=(6-1) (6-1)]					
	Tree planting	Conservation of trees	Sustenance of natural environment	Stream bank stabilisation	Desilting of streams and rivers	Landscaping and environment
Government and non-government organisation role in combating flood	0.93 (0.816) ^{ns}	18.31 (1×10 ⁻⁴)*	20.28 (1.2×10 ⁻⁴)*	19.19 (1×10 ⁻⁴)*	5.01 (0.542) ^{ns}	22.66 (1.1×10 ⁻⁴)*
Desilting of river frequently	1.09 (0.777) ^{ns}	22.07 (1×10 ⁻⁴)*	11.88 (0.01)*	22.85 (1×10 ⁻⁴)*	18.40 (0.01)*	12.43 (0.01)*
Prohibition of building construction on floodplain	4.54 (0.208) ^{ns}	52.19 (1×10 ⁻⁴)*	10.40 (0.02)*	51.67 (1.1×10 ⁻⁴)*	71.84 (1×10 ⁻⁴)*	10.07 (0.02)*
Sensitisation and early warning of flooding	1.72 (0.631) ^{ns}	18.92 (1×10 ⁻⁴)*	27.88 (1.1×10 ⁻⁴)*	19.06 (1.3×10 ⁻⁴)*	21.81 (1×10 ⁻³)*	28.12 (1×10 ⁻⁴)*
Government warning on relocation from flood-prone areas	2.37 (0.498) ^{ns}	14.64 (2×10 ⁻³)*	33.42 (1×10 ⁻⁴)*	15.05 (1×10 ⁻⁴)*	29.85 (1.2×10 ⁻⁴)*	36.53 (1×10 ⁻⁴)*
Prohibiting Dumping of refuse into drainages and rivers	2.06 (0.558) ^{ns}	27.89 (1×10 ⁻⁴)*	20.37 (1.2×10 ⁻⁴)*	27.24 (1×10 ⁻⁴)*	6.31 (0.389) ^{ns}	23.05 (1.1×10 ⁻⁴)*

Note: χ^2 - values outside parentheses, p-values are in parentheses, Degree of Freedom (df) = 25, ns - not significant and *Significant $p \leq 0.05$

Source: Field survey.

However, there was a significant relationship between the extent of residents' awareness of the roles of government and non-governmental organisations in combating flooding and the utilisation of tree conservation in upland areas ($\chi^2 = 18.31$, $p = 1 \times 10^{-4}$); sustenance of natural environment ($\chi^2 = 20.28$, $p = 1.2 \times 10^{-4}$); stream bank stabilisation by vegetation ($\chi^2 = 19.19$, $p = 1 \times 10^{-4}$); and landscaping of environment ($\chi^2 = 22.66$, $p = 1 \times 10^{-4}$). This indicates that that government's efforts to combat flooding are closely linked to tree conservation which helps absorb excess rainwater and reduce flood risk; sustaining natural environment which preserves natural habitats and mitigates flood impacts; streambank stabilisation reduces sedimentation and flood risk; while well-designed landscaping could absorb rainwater, reduce runoff and flood risk, thereby promoting ecosystem health. This corroborates Zhu et al., (2025) that forest soils are generally porous, promoting infiltration and reducing surface runoff. It also aligns with Adeoye et al. (2025) that ecosystem services derived from well-managed forest landscapes help stabilise soils, reduce surface runoff and erosion, and function as natural buffers that moderate the intensity and impacts of flooding.

Furthermore, there was a significant relationship between extent of residents' awareness of river desilting and utilisation of tree conservation practices in upland areas ($\chi^2 = 22.07$, $p = 1 \times 10^{-4}$); sustenance of natural environment ($\chi^2 = 11.88$, $p = 0.01$); streambank stabilisation ($\chi^2 = 22.85$, $p = 1 \times 10^{-4}$); and landscaping of environment ($\chi^2 = 12.43$, $p = 0.01$). This suggests that when river desilting is combined with these ecosystem-based forestry land-use practices, it helps reduce sediment load, improve water quality, and enhance ecosystem health through preservation of natural habitats and promoting biodiversity.

In addition, the study found a significant relationship between the extent of residents' awareness of the prohibition on building in flood-prone areas and several ecosystem-based forestry land-use (EFLU) practices: tree conservation in upland areas ($\chi^2 = 52.19$, $p = 1 \times 10^{-4}$), sustenance of the natural environment ($\chi^2 = 10.40$, $p = 0.02$), stream bank stabilisation ($\chi^2 = 51.67$, $p = 1.1 \times 10^{-4}$), desilting of streams and rivers ($\chi^2 = 71.84$, $p = 1 \times 10^{-4}$), and landscaping of the environment ($\chi^2 = 10.07$, $p = 0.02$). This suggests that effective flood risk management in the study area requires a holistic approach that integrates environmental conservation with sustainable land-use practices.

By enforcing the prohibition of construction on flood-prone areas, the risk of flooding can be mitigated while simultaneously protecting the natural environment. In conclusion, the significant relationships observed between residents' awareness of institutional interventions by government agencies and the adoption of EFLU practices indicate a positive impact on flood risk mitigation in flood-prone communities of South West Nigeria.

Conclusions and Recommendations

The findings of this study demonstrate that residents in flood-prone communities of South West Nigeria possess varying levels of awareness regarding government interventions for flood risk mitigation. The highest level was awareness regarding the discouragement of refuse dumping into drainages and rivers, followed by relocation warnings from flood-prone areas and sensitisation on early flood warnings. However, awareness of broader ecosystem-based forestry land-use (EFLU) strategies such as agroforestry, tree conservation, and reforestation remained relatively low, indicating a substantial knowledge gap in understanding nature-based approaches to flood mitigation. Despite this limited awareness, residents perceived significant environmental and socio-economic benefits from EFLU practices, particularly in terms of carbon sequestration, support for agriculture and livelihoods, and enhancement of resilience to climate-related hazards such as floods and droughts. These perceived benefits highlight the potential contribution of ecosystem-based land use to sustainable development and climate adaptation within the region. Furthermore, the results reveal that tree planting, conservation of trees and shrubs, and stream bank stabilisation were the most practiced EFLU strategies, although overall adoption levels remain moderate to low. A further analysis showed that while some government interventions had no significant relationship with certain ecosystem-based forestry land-use (EFLU) practices, institutional awareness was significantly associated with practices such as tree conservation, natural environmental sustenance, stream bank stabilisation, and environmental landscaping.

Based on the findings of this study, the following policy measures are recommended:

1. Enhance public awareness of the flood-mitigation benefits of ecosystem-based forestry practices.
2. Encourage community participation in tree planting and riparian vegetation restoration.
3. Integrate forestry land use into land-use planning for natural flood regulation.
4. Highlight livelihood benefits such as improved ecosystem services and local resource security.
5. Promote reforestation in flood-prone areas to strengthen natural flood buffers.
6. Provide capacity building on ecosystem-based flood management practices.
7. Offer incentives to encourage adoption of forestry land use strategies.
8. Monitor community perceptions of the effectiveness of ecosystem-based forestry for flood risk reduction.

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High Value Crops and Their Role in Financing the Needs of Smallholder Farming Households in Central Uganda

Abstract. In Central Uganda, farmers are investing in high value crops, such as hot pepper (*Capsicum annum*), French beans (*Phaseolus spp.*), and okra (*Abelmoschus esculentus*) to meet household needs. Based on data from 273 adopters, this study identified priority household needs, assessed profitability of the crops, and evaluated the extent to which the crops address household objectives. School fees emerged as the foremost priority, followed by, among others, trade investment, liquidity, land acquisition, and healthcare. A gross margin analysis confirmed profitability, with French beans yielding the highest, (US\$ 1,003 ha⁻¹), followed by hot pepper (US\$ 816 ha⁻¹) and okra (US\$ 783 ha⁻¹). Despite contributing about one-third of household income, production of these crops remains constrained by small land parcels (0.03–0.10 ha), high input costs, and limited advisory services, meaning only school fees were fully met. The findings highlight the need for interventions that strengthen market access, stabilise prices, and enhance productivity through irrigation, fertilisers, mechanisation, and improved varieties. Linking agricultural income to education financing is critical, while extension services, climate-smart practices, crop insurance, and public–private partnerships can reduce risks and improve access to inputs. Scaling up production and diversifying activities will enable households to meet a broader range of needs.

Keywords: priority household needs, high-value crops

JEL Classification: Q15, Q56

Introduction

Development interventions must be consciously structured, planned and implemented with an aim of conferring the highest possible benefits to the target group in line with the intended development path (Belcher and Palenberg, 2018). This can be attained since economic growth is highly ranked among the farmers' objective set (Amir et al., 2020). Farmers in Central Uganda are increasingly embracing production of non-traditional horticultural export crops of High Value such as hot pepper (*Capsicum annum*), French beans (*Phaseolus spp.*), and okra (*Abelmoschus esculentus*), albeit slowly (Technoserve, 2024). Many studies have not adequately considered farmers' specific circumstances and priority

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objectives which are very crucial for the development of successful intervention programmes. Agricultural development programmes must take this into account (Diallo & Wouterse 2023).

As noted by Sibanda (1999), smallholder resource users are described as having objectives and decisions (Adolph et al., 2021) and therefore represent an organised decision-making unit. These activities are carried out with the purpose of satisfying the household needs as derived from objectives and priorities set. Farm-level operations are upheld as a typical objective-oriented system in which farmers' decisions must be understood in the prevailing environment and constraints.

This work is premised on the observation that in many economic-decision situations, households differ in their aspirations, choices and preferences (Mukerjee et al., 2023). Households are decision-making units (Hillesland & Doss, 2024, ;Chandrasa et al., 2021) whose objectives tend to form a hierarchical structure with food and nutritional security among the priorities (Kakaei, 2022). Households also venture into other livelihood objectives such as liquidity and profit assurance and asset accumulation. It follows that household economic portfolios are influenced by household needs. Farm and non-farm strategies undertaken by a household are shaped by several variables operating at different scales and levels in macro- and microeconomic environment.

The identification of farming objective(s) is a key decision affecting the choice of a farming strategy adopted by the respective households. Conceptually, resource allocation has some basic assumptions concerning the objective function of farmers. These assumptions include: (i) farmers have preferences revealed in utility functions; (ii) farmers' needs are many and conflict; (iii) the objectives are functions of the decision model variables; and (iv) the objective of production is to achieve satisfactory levels of income subject to limitations imposed by the environment. Household investment decision-making is a function of personality, household, regional and village factors. These include endowments of physical, human, social, financial and natural capital (Kefeng et al., 2021).

Following a decision to undertake farming activities, the choice of and number of crops, livestock, forestry enterprises and their combinations become important and influence household investment strategies. The inclusion of high-value crops is perceived from the costs and benefits involved (Murekezi et al., 2004). However, all farmers' objectives are not equally important, so the act of prioritising them helps indicate the choice preferences of a particular farmer. This paper discusses the priority problems that farmers strive to address by including the perceived HVCs in their production plans and assesses the extent to which the needs are achieved.

Sætra (2021) argues that human goals can be categorised. Firstly, there are those goals that relate to family, marriage, sex and romance. Second are interpersonal goals that are related to interactions with people in general, which are divided into subsets such as physical goals including health and appearance, and goals related to friendship, belonging, social recognition and social belonging. Other interpersonal goal subsets are related to receiving from others, avoiding rejection, general positive social qualities such as being honest, teaching and helping others, and leadership. The third main group of goals relates to intrapersonal issues which are also divided into subsets. One of these subsets contains values relating to freedom, ethics, social awareness and religion; another includes values relating to aesthetics, creativity, entertainment and openness to experience; another contains values relating to psychological well-being, safety and stability, personal growth, achievement and

self-determination; and another includes values relating to finances, career, education and intellect.

Objectives or needs, by implication, determine how farmers respond to any stimuli. Concern for the complexity and multiple nature of farmers' objectives dates back to the work of Ashby (1926). He asserted that: "... if we want to know how or why a farmer acts in a certain way or how to induce him to act in a certain way, we have to inquire especially why men act as they do when they live in the sort of social environment and general circumstances in which farmers live." However, the factors Ashby (1926) described as "motives" are more commonly treated by social psychologists as "values". To understand, therefore, why and how an individual acts in a certain way, his or her values must be explored. An understanding of these values, that is what is important to an individual, leads to an appreciation of the motives and rationale of the actions taken by that individual, i.e. their behaviour. In the literature on farmers' motives and their relationship with behaviour, the terms objectives, goals, needs and values are quite commonly used interchangeably (Ogbewi, 2021). The intrinsic nature of the value concept tends to be disregarded and the fact that objectives and goals have a means-end relationship in that "objectives set the goals, and strategy sets the path to the goals" is often obscure. In an attempt to address issues in this background, this study was designed with three objectives; (i) to identify the priority household needs that drive farmers in central Uganda to adopt High Value Crops (HVCs), (ii) to assess the profitability of the selected HVCs, and to evaluate the extent to which adoption of the HVCs enables farmers to meet their priority household needs.

Methods

This study was conducted in the banana-coffee farming system that constitutes one of Uganda's farming systems (Mayanja et al., 2013). The study districts were: Luwero, Masaka, Mpigi, Mukono, Rakai and Wakiso⁵ located in Central Uganda. It is in these districts that the study crops are mainly grown in Uganda (Masika et al., 2022), partly due to the high market access (Ddamulira et al., 2021) and conducive agroecological conditions in these districts. Multi-stage purposive sampling was used at the farming system and district levels using production figures of the crops under study. A total of 273 households that had adopted (and were growing) any of the three crops at least 3 years prior to the survey, were randomly selected (Table 1).

Both primary and secondary data were used in the study. Primary data were collected through administering structured pre-tested questionnaires in face-to-face interviews to cover farm activities and physical resources of the second season of 2018 (2018B), first season of 2019 (2019A) and the second season of 2019 (2019B). This quantitative approach was supplemented with qualitative approaches that included: community and key informant interviews and focus group discussions as well as observations made during village transect walks. Variables that were captured included; (i) socio-demographic variables (such as age, education, marital status of the household head); and (ii) variables related to the decision and choice of enterprise, and the costs and revenues of the study crops. Priority needs were

⁵ Luwero (0°50'N 32°30'E), Masaka (0°18'46"S 31°42'47"E), Mpigi (00°13'48"N 32°19'48"E), Mukono (0°21'12"N 32°45'19"E), Rakai (00°42'36"S 31°24'18"E) and Wakiso (00°23'53"N 32°28'41"E).

elicited by asking the respondents to rank what they seek to solve by growing any of the HVCs being studied, how much money they were to commit to achieving the needs, how much they had actually committed, and their opinions about the profitability of the crops. Although, the farmers provided several priority problems, only the top ranked eight that constituted the statistically accepted frequency was used for the analysis.

Table 1. Sample size by district and status of adoption of the HVCs

District	Respondents	Percent
Luwero	46	16.8
Masaka	41	15.0
Mpigi	37	13.6
Mukono	59	21.6
Rakai	48	17.6
Wakiso	42	15.4
Total	273	100.0

Source: survey data.

Secondary data were obtained from several official sources including publications, journals, Government reports and newsletters of the district. Most of the secondary information were also used to triangulate the primary data and discuss the findings. Data were analysed using MS Excel (windows 2013), SPSS (version PASW 18) and STATA (version 14) computer software. Analytical procedures included: estimation of frequencies, descriptive statistics, weighted averages and paired samples t-tests. Gross Margin Analysis was used to determine profitability (Saimon et al., 2016), and it was computed as follows (equation 1):

$$GM_i^s = Y_i^s P y_i^s - \sum_{x=1}^n VI_x^s P_x^s \dots\dots\dots (1)$$

Where:

GM is the gross margin (US\$ ha⁻¹)⁶ of the ith crop enterprise during the sth season;
 Y_i^s the production (Kgs ha⁻¹) for the ith crop enterprise during the sth season,
 P y_i^s the market price (US\$ ha⁻¹) of the ith crop produced in the sth season,
 VI_x^s refers to the quantity of variable inputs (units vary by nature of input, for example labour was in mandays, fertilisers were measured in kgs, liquid chemicals in litres) for the ith crop enterprise during the sth season,

P_x^s is the unit cost of variable inputs (US\$ unit⁻¹) for the ith crop enterprise during the sth season, i is an index for crop enterprises, and x the variable inputs. A weighted ranking approach, as used by Nakiganda *et al.* (2006), was employed.

The eight major household needs that drive farmers to adopt the study crops were captured. From the ranks, a total weight was calculated, and a weighted average was obtained as indicated in equation 2 below:

$$WAG_1 = (\Psi_{1,1} * \omega_8) + (\Psi_{1,2} * \omega_7) + (\Psi_{1,3} * \omega_6) + \dots\dots\dots (\Psi_{1,8} * \omega_1) / 8 \dots\dots (2)$$

⁶ At the time of the study the Exchange rate between Ushs per US Dollar was.

Suppose the needs are arbitrarily labelled 1, 2,, 8 (not necessarily ordered), further: (i) Weighted averages for the needs (WAG) can be denoted by WAG_1, \dots, WAG_8 ; (ii) Let the percentage of respondents that rank Objective 1 first be denoted $\psi_{1,1}$, that of those who rank it second,, eight be $\psi_{1,2}, \dots, \psi_{1,8}$; (iii) Let the number of ranks for Objective 1 be denoted $\omega_1, \omega_2, \dots, \omega_8$. Then, the WAG values were ranked in ascending order.

The gross margins were compared pairwise (hot pepper vs French beans, hot pepper V_s okra and okra V_s French beans by seasons) and season-wise (2018B & 2019A, 2018B & 2019B and 2019A & 2019B by the HVCs) using paired t-tests samples. Finally, Analysis of Variance (ANOVA) was used to compare the “before” and “after” situations to ascertain whether farmers achieved their needs. The “before” period analysed the monetary value of needs (in Ushs) before producing the crops (beginning of season 2018B). These values were compared with the monetary values (in US\$) of what was actually spent on each of the aforementioned household needs “after” the study period (end of season 2019B). Data were analysed using Analysis of Variance (ANOVA).

Results and Discussion

The socio-demographic and economic profile of the surveyed households ($n = 273$) shows that household heads were relatively young, averaging 37.4 years, with 15.4 years of farming experience and 7.2 years of formal education (Table 2), which is higher than the national average of 6 years, and that of the Central region averages 7 years. Most households (61%) reported children enrolled in school (the national figure being 60 – 65% according to UBoS (2024), while 45% received remittances, reflecting the growing importance of non-farm income streams in rural Uganda (World Bank, 2022). Agricultural diversification was evident, with 30% cultivating bananas, 27% coffee, and 83% keeping livestock which was dominated by poultry, goats, pigs and dairy cattle, underscoring the role of mixed farming systems in resilience strategies (Etana et al., 2022).

Land access averaged 1.5 hectares, consistent with smallholder conditions, while farm income contributed US\$441.37 annually, complemented by off-farm earnings of US\$157.93. These findings highlight the dual reliance on farm and non-farm sources of livelihood, a pattern increasingly documented in East Africa (Mubangizi & Adekanla, 2024). The relatively high livestock ownership suggests adaptive strategies for food security, while modest education and income levels point to structural constraints requiring policy interventions (Oyet et al., 2025).

Table 2. Selected Socio-demographic and economic variables of the Respondents

Variable	Result (n=273)
Age of household head (years)	37.4
Farming experience of head (years)	15.4
Education of household head (years)	7.2
Households with children in school (%)	61.0
Households receiving remittances (%)	45.0
Households cultivating bananas (%)	30.0
Households cultivating coffee (%)	27.0
Households owning livestock (%)	83.0
Total land accessed (hectares)	1.5
Farm income (US\$/year)	441.4
Off-farm income (US\$/year)	157.9

Source: survey data.

Results show that some of the considerations taken into account by farmers prior to adopting the HVCs were diverse. As for hot pepper, farmers consider market access (20.7% of the 273 adopters) as the major aspect (Table 3). Access to remunerative markets is a major challenge faced by smallholder farmers in Uganda (Ninsiima et al., 2025). High product prices were also a major consideration (13.1%) as they embody the level of incentive for investment. The short turnover period was also a major consideration (10.6% of the adopters) since many farmers do not have access to alternative cash sources or credit so they prefer investing in crops where their limited funds can be recouped within a short period. Peer influence by fellow farmers (10.6% of the adopters) was also crucial, reflecting the importance of social capital (Wardhana et al., 2021). It partly improves their belief and confidence to grow the crops, learning from the experience of fellow farmers.

Table 3. Reasons given by smallholder farmers for growing the HVCs

Factor considered	Hot pepper		French beans		Okra	
	n	%	n	%	n	%
Easy market access	88	20.7	43	16.2	41	17.7
High product prices	56	13.1	22	8.3	30	13.0
Early maturing/quick turnover	46	10.8	47	17.7	43	18.6
Peer influence	45	10.6	37	13.9	26	11.3
Pays well/good income	36	8.5	14	5.3	19	8.2
Low production cost	35	8.2	14	5.3	19	8.2
Low labour requirement	29	6.8	25	9.4	9	3.9
Access to advisory services	23	5.4	17	6.4	18	7.8
Regular income	17	4.0	0	0.0	0	0.0
High yields	14	3.3	12	4.5	6	2.6
Stable price	11	2.6	0	0.0	8	3.5
Easy to produce	9	2.1	6	2.3	0	0.0
Others	17	4.0	29	11	12	5.3
Total	426	100.0	266	100.0	231	100.0

Source: survey data.

French beans farmers also considered the same factors, albeit in a slightly different order of ranking. The only factor among the top five mentioned by French beans farmers that was not among the ones considered by hot pepper farmers was low labour requirement. Access to labour is a major household constraint (Tennhardt et al., 2024). The okra farmers considered similar factors as those taken into account by hot pepper and French bean farmers. Other dominant considerations were the ability to bring good income, access to advisory services, good yields and stable prices, while others included household consumption, ease of production, experience, health reasons, access to inputs (seeds, fertilisers), regular income and social prestige.

The areas dedicated to the HVCs were analysed to ascertain level of interest in and commitment to the crops as compared to available resources. It is clear that farmers tend to allocate small hectares towards the HVCs. This is approximately 33.6% of their total land, for a household that adopted all the three crops, and about one third of this for those adopting only one out of the three crops (Table 4). This could be attributed to the high cost of inputs and the labour-intensive nature of these crops. However, such small areas also compromise efficiency levels partly due to diseconomies of scale.

Table 4. Acreage under production of the HVCs over a period of three seasons

Season	Hot Pepper		French Beans		Okra	
	n	Area (hectares)	n	Area (hectares)	n	Area (hectares)
2018B*	176	0.05	107	0.05	115	0.05
2019A**	176	0.08	86	0.04	114	0.04
2019B***	126	0.05	124	0.03	109	0.03
Mean	159	0.20	105	0.13	112	0.13

* 2018B season refers to the second season of 2018 that runs from July to December, 2018;

** 2019A refers to the first season of 2019 that runs from March to June, 2019;

*** 2019B is the second season of 2019 that runs from July to December, 2019.

Source: survey data.

Farmers were asked to express their views on the profitability of hot pepper, French beans, and okra. The results show that most respondents regarded these high value crops (HVCs) as profitable (Table 5). Out of 165 farmers who answered the question on hot pepper, 95.2% reported that the crop provides financial returns. For French beans, 94.4% of respondents considered the crop profitable, while 91.4% expressed the same opinion about okra. These findings suggest that farmers cultivate these crops with confidence in their ability to generate income, which helps them meet essential household needs such as school fees, medical expenses, and farm investments. This outcome is consistent with evidence from Uganda showing that the HVCs enhance smallholder profitability and market participation (Mugisha & Diiro, 2021), and with regional studies indicating that adoption of high value horticultural crops contributes positively to household income and welfare in East Africa (Okello & Sindi, 2022). Very few farmers claimed that the crops are not profitable, while some, e.g 1.8% for hot pepper, 3.2% for French beans and 6.9% for Okra, were not sure of the level of profitability of these crops.

Table 5. Farmers' perceptions about profitability of hot pepper, French beans and okra

Response	Hot Pepper		French Beans		Okra	
	n	%	n	%	n	%
HVCs are profitable to produce	157	95.2	117	94.4	106	91.4
HVCs are not profitable to produce	5	3.0	3	2.4	2	1.7
Not sure of profitability of HVCs	3	1.8	4	3.2	8	6.9
Total	165	100.0	124	100.0	116	100.0

Source: Field survey.

The above analysis would be incomplete if it relied solely on farmers' perceptions. To substantiate these views, profitability was further examined through gross margin analysis, with results presented in Table 6. The findings corroborate farmers' opinions, showing that the high value crops (HVCs) under study are indeed profitable. Gross margin values were highest for French beans, followed by hot pepper and okra. In the short run, farmers can cover the variable costs associated with producing all three crops, confirming their profitability. An additional analysis was conducted to compare gross margins across crops and within production seasons, using both pairwise comparisons among the HVCs and season-wise assessments. These results align with recent evidence from Uganda, where short cycle horticultural crops have been shown to generate favourable gross margins for smallholder farmers (Tumwine et al., 2023). Similar findings from Kenya demonstrate that French beans production consistently yields positive gross margins, reinforcing the conclusion that short-cycle HVCs provide reliable income streams for smallholders (Mwangi & Otieno, 2024).

Table 6. Mean Gross Margins (US\$ ha⁻¹) of the HVCs over a period of 3 seasons

Season	Hot Pepper		French Beans		Okra	
	n	Gross margin	n	Gross margin	n	Gross margin
2018B	176	604	107	720	115	378
2019A	176	653	86	615	114	549
2019B	126	370	124	851	109	590
Mean	159	541	105	727	112	507

Source: survey data.

Seasonal comparisons of gross margins revealed statistically significant differences across crops and production periods. For hot pepper, gross margins were significantly higher in 2018B compared to 2019A ($p < 0.05$), and similarly higher in 2018B relative to 2019B ($p < 0.10$) (Table 7). In contrast, French beans showed no significant differences between the seasons examined. For okra, gross margins were significantly higher in 2018B compared to 2019A ($p < 0.10$), and the same trend was observed between 2018B and 2019B, with the latter recording higher margins ($p < 0.05$). These variations reflect shifts in yields and market prices across seasons, partly influenced by climatic variability and market dynamics. Such fluctuations underscore the production and income risks faced by smallholder farmers, consistent with evidence on seasonal profitability volatility in high value crops in East Africa (Ariho et al., 2024; Ndyetabula & Jeckoniah, 2025; Tumwine & Kansiime, 2024).

Table 7. Season-wise comparison of the HVCs gross margins (US\$ ha⁻¹)

Crop	Seasons 2018B & (2019A)			Seasons 2018B & (2019B)			Seasons 2019A & (2019B)		
	Mean	St.dev	P-value	Mean	St.dev	P-value	Mean	St.dev	P-value
Hot pepper	604 (370)	2.58 (1.58)	0.02**	604 (653)	2.56 (2.80)	0.69	650 (370)	2.80 (1.58)	0.08*
French Beans	720 (851)	3.09 (3.65)	0.39	720 (612)	3.09 (2.64)	0.43	615 (851)	2.64 (3.65)	0.11
Okra	375 (549)	1.62 (2.36)	0.07*	375 (590)	1.61 (2.53)	0.03**	549 (590)	2.35 (2.53)	0.72

NB: ***, ** and * denote significance at 1%, 5% and 10%. Figures in parentheses refer to the season in parentheses. It should also be noted that the Gross Margins are based on a hectare, but none of the farmers kept these crops on a full hectare as reported in Table 3 above.

Source: survey data.

French beans recorded higher gross margins (US\$ ha⁻¹), overall, but these were accompanied by larger standard deviations, indicating greater variability and risk. Okra, in contrast, showed relatively lower standard deviations, suggesting more stable income streams. Seasonal differences in gross margins were mixed, with no consistent pattern favouring either season one or season two across the high value crops (HVCs) analysed. Pairwise comparisons revealed that French beans and hot pepper margins did not differ significantly in 2018B and 2019A, but French beans were significantly higher in 2019B ($p < 0.01$) (Table 8). Hot pepper margins were significantly higher in 2018B ($p < 0.05$) but significantly lower in 2019B ($p < 0.05$). Across all seasons, French beans consistently outperformed okra in terms of gross margins. These findings highlight the dual nature of profitability and risk in the HVC production, reflecting seasonal variability in yields and market prices. Recent studies confirm that such fluctuations are common in horticulture, where climate variability and market dynamics drive both profitability and risk exposure (Kansiime and Wambugu, 2020; Nabirye & Musoke, 2019; Ochieng et al., 2017).

Table 8. Pairwise comparison of the HVCs gross margins (US\$ ha⁻¹) by crop and seasons

Pairwise comparison	2018B			2019A			2019B		
	Mean	St.dev	p-value	Mean	St.dev	p-value	Mean	St.dev	p-value
Hot pepper & French beans	604	2.59		653	2.80		369	1.58	
	720	3.09	0.38	612	2.64	0.76	851	3.65	0.00***
Hot pepper & Okra	604	2.59	0.02**	653	2.80	0.38	369	1.58	
	378	1.62		549	2.35		590	3.65	0.03**
French beans & Okra	720	3.09	0.03**	632	2.64	0.57	851	3.65	
	378	1.62		549	2.35		590	2.53	0.07*
Overall comparison for three seasons									
	Mean	Standard deviation		P value					
Hot pepper & French beans	540	2.32		0.14					
	728	3.12							
Hot pepper & Okra	540	2.32		0.75					
	507	2.18							
French Beans & Okra	728	3.12		0.08*					
	507	2.18							

***, ** and * denote significance at 1%, 5% and 10%.

Source: survey data.

A significant difference in gross margins was observed between French beans and okra ($p < 0.10$), while no significant differences were found between hot pepper and French beans or between hot pepper and okra. Variations in gross margins can be explained by shifts in input and output prices and yield performance, which are strongly influenced by agroclimatic conditions and seed quality (Mang'ana et al., 2023). Farmers' technical capacity, particularly their ability to apply agronomic practices on schedule, also shapes profitability outcomes (Msangi et al., 2023). Beyond production factors, the limited domestic market for these high value crops necessitates reliance on export destinations in Europe and Asia, where stringent quality standards heighten both marketing risks and costs (Kagorora et al., 2021).

Farmers ranked the needs that they seek to address by producing the HVCs. Education, proxied by securing school fees, was the highest ranked objective of households as evidenced by the rankings (Table 9; Rank 1 refers to the most important objective followed by ranks 2, 3, 4, 5 and 6). In order of priority, other household needs that farmers intend to address by taking on production of the HVCs were to: invest in trade, ensure steady cash flows for ploughing back into crop production, buy more land, cover health care expenses and invest in livestock farming, buy a car or motorcycle and allocate for household consumption.

Farmers in different countries exhibit a different hierarchy of motives and goals. In Uganda, education for children has been reported as a key objective of farming households (L'Roe et al. (2022) and Juma et al., (2024). In Poland, short-term goals of economic security particularly dominate farmers' attitudes (Ministry of Agriculture and Rural Development (Poland, 2025). The results of the study corroborate earlier findings which conjecture that the practical behaviour of farming households cannot be explained by the optimisation of a single goal but by a compromise between multiple goals (Uhlenbrook et al., 2022).

Education ranks at the top of household priorities among farming families in the study area, because it is widely recognised as the most reliable pathway out of poverty and a foundation for resilience. Schooling equips individuals with the ability to access and apply information, improving productivity and decision-making in both farm and non-farm activities. Households headed by more educated individuals are significantly more likely to escape poverty, while those with low human capital remain vulnerable (Mwesigye & Matsumoto, 2024). Longer periods of schooling further increase upward mobility, expand income opportunities, and strengthen resilience to shocks, making education a decisive factor in household welfare outcomes (Balojja & Sebbowa, 2024). Results show that on average 3 children are in school (Table 8), about 60% of the total household size, which conforms to the results of UBoS (2024). A total of 61.1% of the Households had at least one person in school.

This priority comes at a heavy cost. Families often dedicate a large share of their budgets to school fees and related expenses, straining limited rural incomes. Gender disparities intensify the challenge: although boys and girls enrol, girls are more likely to drop out at critical stages such as primary and A Level due to financial constraints, cultural expectations, or early marriage. Yet, female education yields especially strong returns, reducing poverty, improving child health, and empowering households socially and economically (Nanyonjo, 2025). To meet these costs, farming households increasingly turn to high value crops, as a means of generating the funds needed for school fees. Diversification into such crops provides higher income streams compared to subsistence farming, enabling families to sustain educational investments. This linkage between agriculture and education highlights the importance of policies that expand access to markets, credit, and extension services, ensuring that farming can effectively finance schooling (Okello & Mugisha, 2024).

Table 9. Mean number of children in the study Households at different school levels compared by gender

Education Level	n	Male	Female	t-Statistic	p-value
Nursery	38	0.4	0.3	0.55	0.58
Primary	99	0.5	0.3	2.00	0.05
O Level (Senior 1–4)	29	0.4	0.2	1.95	0.06
A Level (Senior 5–6)	8	0.3	0.1	2.15	0.04
College/Tertiary/University	8	0.2	0.1	1.95	0.06
Total Across All Stages		2.0	1.0	0.90	0.36
Total Children in Household		2.5	2.2	1.16	0.25

Source: survey data.

Investment in trade, ranked second among farmers' objectives, reflects diversification into non-farm activities, a strategy increasingly common in agrarian economies (Table 10). Diversification is widely recognised as a risk mitigation measure, enabling households to buffer against agricultural uncertainties while enhancing resilience (Kansiime & Wambugu, 2022). Steady income, ranked third, is equally critical, as liquidity ensures farmers can meet operational expenses and reinvest in crop production cycles. Access to credit and financial flows has been shown to significantly improve productivity among smallholder farmers in Sub-Saharan Africa (Khan & Kim, 2025). Purchase of land, ranked fourth, underscores its role as a fundamental factor of production. For many households, securing adequate land remains central to sustaining agricultural livelihoods. Moreover, land tenure systems in Africa are often complex and fragmented, reinforcing the urgency for farmers to secure ownership early to safeguard long-term investment (Holden, 2021).

Currently, only 10% of the land in Uganda is titled, many alterations of titles are being made, and this is leading to several disputes (Rugadya & Nsamba-Gayiiya, 2022) that cause uncertainty and frustration among farmers. Further, land is a fixed resource with an increasing population having a growing pressure on it and land fragmentation. Health care ranked fifth, and this implies recognition by farmers of the importance a healthy household that plays a role in providing the much-needed family labour to supplement hired labour (Christiaensen, 2021). Further, one of the causes of poverty is ill health (Alkire et al., 2023). Investing in livestock to further diversify farming activities ranked sixth. Livestock possession is widely used as an indicator of wealth and wealth differentiation (FAO, 2024). Acquiring a car or a motorcycle to improve mobility of people and produce transportation was ranked seventh. Meeting household consumption needs such as purchase of food crops that are not raised by the households for food security, sugar, salt, beef and other sauce types came last among the priority problems that the farmers intended to solve through adoption of the HVCs. The ranking of steady income above food security implies that the HVCs are grown primarily for cash income.

Table 10. Ranking of Household needs based on weighted averages

Household Needs	Ranks (1-5)					Weighted total	No. of ranks	Weighted average	Overall rank
	1	2	3	4	5				
School fees	70.9 (166)	21.8 (51)	7.3 (17)	0.0 (0)	0.0 (0)	463.7	3	154.6	1 (n=234)
Investment in trade	38.7 (12)	12.9 (4)	48.4 (15)	0.0 (0)	0.0 (0)	390.3	3	130.1	2 (n=31)
Steady cash inflows for HVCs operations	67.9 (55)	22.2 (18)	6.2 (5)	3.7 (3)	0.0 (0)	454.3	4	113.6	3 (n=81)
Buying land	64.9 (24)	10.8 (4)	21.6 (8)	2.7 (1)	0.0 (0)	437.8	4	109.5	4 (n=37)
Health care expenditure	24.7 (21)	44.7 (38)	27.1 (23)	3.5 (3)	0.0 (0)	390.6	4	97.6	5 (n=85)
Investment in livestock	16.1 (5)	58.1 (18)	3.2 (1)	22.6 (7)	0.0 (0)	367.7	4	91.9	6 (n=31)
Buying a car/ motorcycle	23.1 (9)	23.1 (9)	23.1 (9)	30.8 (12)	0.0 (0)	338.5	4	84.6	7 (n=39)
Household consumption	16.3 (25)	52.9 (81)	22.9 (35)	6.5 (10)	1.3 (2)	376.5	5	75.3	8 (n=153)

Figures in parentheses represent weighted percentages of responding farmers per rank, unless otherwise indicated.

Source: Field survey.

A further analysis of the level achievement of the household needs for producing the HVCs reveal that the school fee objective was fully achieved since the funds that were planned for this objective were allocated to it fully and even beyond (Table 11). There was no significant difference between the funds that the households planned to spend on fees and what was actually spent ($P > 0.05$). This attests to the importance that farming households attach to education. No funds were allocated to land acquisition and purchase of cattle. These findings emphasise an important fact that, given the current dismal sizes of operation as evidenced by the area under each of the HVCs (0.05, 0.05 hectares and 0.1 for okra, French beans and hot pepper respectively during the season of 2018B), farmers cannot depend on the HVCs to achieve their needs. However, it is also noteworthy that even though the prioritised needs were not fully achieved, the HVCs contributed about 36.5% towards the needs. A case in point is about funds (US\$ 7) that were allocated to purchase of pigs, but whose planned expenditure was US\$ 69. This shows a significant difference ($p < 0.01$) between what was planned and what was spent. Likewise, other objectives are allocated funds according to household priorities (health and household consumption needs) whose planned expenditures are significantly higher ($p < 0.01$) than the actual expenditure. The benefits that are aspired are linked to various life goals (or values) farmers aspire for namely, respect, security, achievement, and happiness (Sumberg et al., 2023).

Table 11. An analysis of level of achievement of farmers' financing needs using funds from the HVCs. An analysis of the "before" and "after" scenarios using ANOVA

Objective	Frequency (n)	Planned expenditure (US\$) ("before" scenario)	Actual expenditure (US\$) ("after" scenario)	p-value
Purchased Land	78	1337	0	0.000***
Cattle	101	827	0	0.000***
Pigs	57	69	7	0.000***
Health	34	55	13	0.000***
Fees	226	193	199	0.350
Consumption needs	83	138	26	0.000***

***, ** and * denote significance at 1%, 5% and 10%.

Source: survey data.

Among the top eight priority needs addressed by the studied households, investing in trade and securing steady income for reinvestment in high value crops (HVCs) was not mentioned when evaluating achieved needs. This omission can be attributed to overwhelming household goals relative to the limited income generated from the HVCs. Peer-reviewed studies confirm that smallholder farmers in Uganda often rely on external financing sources to support agriculture and trade activities, reflecting the structural mismatch between household aspirations and agricultural returns (Orwothwun & Qutieshat 2022; Rijksdienst voor Ondernemend Nederland, 2022, and Economic Policy Research Centre, 2022).

Income from the HVCs was utilised in diverse ways beyond the set household priorities. While a significant share was directed toward recurrent expenses such as school fees, household consumption, and healthcare, expenditure on tangible assets was also substantial. Of the total yearly household income, estimated at US\$ 742, the HVCs contributed US\$ 245, representing 33% of the total. This finding underscores the significant role of the HVCs in household welfare and suggests that scaling up production could further enhance their contribution. Recent peer-reviewed evidence shows that rural households in Uganda strategically allocate agricultural income across education, health, and asset accumulation, reinforcing the importance of the HVCs in poverty reduction and resilience building (Okello & Mugisha, 2024).

Conclusions and Policy Recommendations

The study establishes that high value crops (HVCs), such as hot pepper, French beans, and okra, are central to financing household needs among smallholder farmers in Central Uganda. Education, particularly the payment of school fees, is the foremost driver of adoption, with households prioritising schooling as a pathway out of poverty. Farmers also consider market access, high product prices, quick turnover, and peer influence when deciding to grow the HVCs. Profitability is widely acknowledged, with gross margins averaging US\$ 1,003 ha⁻¹ for French beans, US\$ 816 ha⁻¹ for hot pepper, and US\$ 783 ha⁻¹ for okra, though seasonal fluctuations and variability in returns are evident.

Despite contributing about one-third of household income, production is constrained by small land parcels (0.03–0.10 ha), high input costs, and limited advisory services. As a result, while school fees are consistently covered, other household priorities such as land acquisition, livestock investment, and healthcare remain only partially achieved, with households relying on other crops, livestock, and off-farm activities to bridge the gap.

To address these constraints, interventions should prioritise strengthening market access and stabilising prices, while enhancing productivity through improved varieties, irrigation, fertilisers, and mechanisation. Policies that link agricultural income to education financing are critical, given that school fees are the primary motivation for the HVC adoption. Expanding extension and advisory services will improve technical capacity, while climate-smart practices and crop insurance can mitigate seasonal risks. Partnerships between farmers, the private sector, and public institutions should be reinforced to ensure timely access to affordable planting materials and inputs. Scaling up production to benefit from economies of scale, coupled with diversification into both farm and non-farm activities, will enable households to meet a broader range of needs. Ultimately, a rigorous yield enhancement agenda, supported by research and policy, is essential to unlock the full potential of the HVCs as a sustainable financial lifeline for smallholder households in Central Uganda.

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Understanding Drivers and Risks for Policy: A Comparative Assessment of Cassava Production Systems in Africa

Abstract. Cassava is a critical staple crop for food security and livelihoods across sub-Saharan Africa, yet its production dynamics vary significantly between major producing nations. This study conducts a comparative analysis of cassava production trends, drivers of change, and sources of instability from 1993 to 2024 in five leading African producers: Angola, Congo, Ghana, Nigeria, and Tanzania. Utilising a decomposition analysis framework on FAO time-series data, the research quantifies the contributions of area expansion and yield improvement to production growth and identifies the statistical components of output volatility. The results reveal two distinct models: Ghana exemplifies a productivity-led intensification path, where rising yields contributed most to growth, while Nigeria and Tanzania followed an area-driven extensification model, where massive land expansion offset declining yields and introduced higher instability linked to volatile area allocation. Angola and Congo demonstrated more balanced growth. The primary sources of instability differed: Nigeria's risk was dominated by fluctuations in cultivated area, while Ghana's was driven by increasing yield variance. The study concludes that sustainable growth in the cassava sector requires a strategic shift from extensification to intensification. Policy implications advocate for differentiated national strategies prioritising investment in yield-enhancing technologies, climate-resilient practices, and stabilised land-use policies to ensure long-term productivity and reduced volatility.

Keywords: cassava, extensification, intensification, production, trend, Africa

JEL Classification: Q01, Q17, Q18

Introduction

Cassava (*Manihot esculenta* Crantz) is a vital staple crop and a cornerstone of food security for over 800 million people globally, with sub-Saharan Africa accounting for approximately 60% of worldwide production (Aigbokie et al., 2025; Gmakouba et al., 2024; FAO, 2022; Fu, 2021; Szyniszewska, 2020). Its resilience to drought, ability to thrive in

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marginal soils, and versatile uses for human consumption, animal feed, and industrial starch make it a critical crop for rural livelihoods and economic development across the continent (Omodara et al., 2023; Ngongo et al., 2022; Acheampong et al., 2021; Amelework et al., 2021; Acheampong et al., 2018). In recent decades, concerted efforts have been made to transform cassava from a subsistence food crop into a competitive commodity, driven by national policies, research into high-yielding and disease-resistant varieties, and growing market demand (Dankwa et al., 2025; Gmakoubaet et al., 2024; Udochukwu, 2024; Otun et al., 2023; Tafesse et al., 2021; Pipitpukdee et al., 2020; Darko-Koomson et al., 2020). Understanding the dynamics of its production is therefore essential for guiding agricultural policy, ensuring nutritional security, and fostering inclusive economic growth in Africa.

Despite its importance, cassava production systems in Africa face persistent and evolving challenges. Production trends are characterised by significant spatial and temporal variability, with growth patterns differing markedly between major producing nations. While some countries have achieved substantial gains through improved yields, others have relied predominantly on expanding cultivated area, often with implications for sustainability and stability (Ikuemonisan et al., 2020a&b). Furthermore, production remains highly vulnerable to an array of biotic and abiotic stresses, including cassava mosaic and brown streak diseases, fluctuating climate patterns, and volatile market prices, leading to considerable instability in output (Sakadzoet al., 2025; Enesi et al., 2022; Becerra-Lopez Lavalle et al., 2021). This instability threatens household income and regional food supply chains. A nuanced comparative analysis of the sources of production growth and instability is currently lacking, limiting policymakers' ability to design targeted, context-specific interventions that enhance both productivity and resilience.

This study is justified by the urgent need to move beyond aggregate production statistics and dissect the underlying components of change and risk in Africa's cassava sector. A comparative assessment of top-producing countries can reveal successful models of sustainable intensification and highlight systemic vulnerabilities. Such an analysis provides critical evidence for informing strategic investments in agricultural research, extension services, climate-smart practices, and infrastructure development. By identifying whether production increases are driven by yield improvements or area expansion, and by pinpointing the key sources of volatility, stakeholders can prioritise interventions that maximise long-term, stable benefits for farmers and consumers alike.

The primary objective of this research is to conduct a detailed comparative analysis of cassava production trends, drivers of change, and sources of instability across five major African producing countries: Angola, Congo, Ghana, Nigeria, and Tanzania, from 1993 to 2024. Specifically, the study aims to: (1) analyse and compare the long-term production, area, and yield trends across these nations; (2) decompose the causes of changes in production between the periods 1993-2008 and 2009-2024; (3) quantify the contributions of area expansion, yield enhancement, and their interaction with changes in average production; and (4) identify and compare the fundamental sources of instability in cassava production within each country's context..

Theoretical Framework

This study is anchored in the "Theory of Production" from agricultural economics, which posits that output is a function of inputs such as land, labour, capital, and technology

(Heady, 1952). To analyse cassava production dynamics, we apply a “Decomposition Analysis Framework”, a methodological approach that disentangles changes in total output into distinct, quantifiable components. Specifically, we adopt an “Output Decomposition Model” where changes in total production ($P = \text{Area} * \text{Yield}$) are attributed to variations in the mean cultivated area, changes in mean yield (representing technological and efficiency improvements), and the interaction between these two factors (Ikuemonisan & Akinbola, 2021; Ikuemonisan *et al.*, 2020). This is expressed as:

$$\Delta P \approx \Delta A \bar{Y} + \Delta Y \bar{A} + \Delta A * \Delta Y$$

where A is area and Y is yield. Furthermore, to understand volatility, the analysis extends to decomposing the variance of production, identifying sources of instability stemming from fluctuations in area, yield, their covariance, and mean shifts. This framework, supported by the conceptual models of Minot (2014) for agricultural growth decomposition, allows for a systematic, comparative assessment of whether production growth is driven by land expansion (extensification) or productivity gains (intensification), and what factors underpin production risks in different national contexts.

Conceptual Framework

This study is guided by a conceptual framework that posits total cassava production (P) as the central outcome variable, determined by the interactive components of cultivated area (A) and yield per hectare (Y). Changes in production over time are therefore conceptualised as stemming from variations in area, yield, or their synergistic interaction. These components are themselves influenced by a set of external factors categorised into environmental, policy/technological, and socioeconomic domains, which include climate, research & development, market forces, and agricultural policies. This framework allows for the systematic decomposition of production trends and instability into these core elements, facilitating a comparative analysis of growth drivers and risk sources across different national contexts, as adapted from decomposition models used in agricultural economics (Minot, 2014; Ikuemonisan *et al.*, 2020).

Key Elements:

1. External factors: Environmental (climate, soil), Policy/Technological (R&D, policies), and Socioeconomic (markets, labour) factors that influence production components.
2. Core components: Cultivated Area (A) and Yield per Hectare (Y) as the fundamental production factors.
3. Production function: Total Production (P) determined by the multiplicative interaction of A and Y.
4. Analytical framework: Systematic decomposition approach to compare growth drivers and instability sources across countries.

This visualisation shows how external factors influence the fundamental production components (Area and Yield), which combine to determine total output, enabling a comparative analysis of production dynamics across different agricultural contexts.

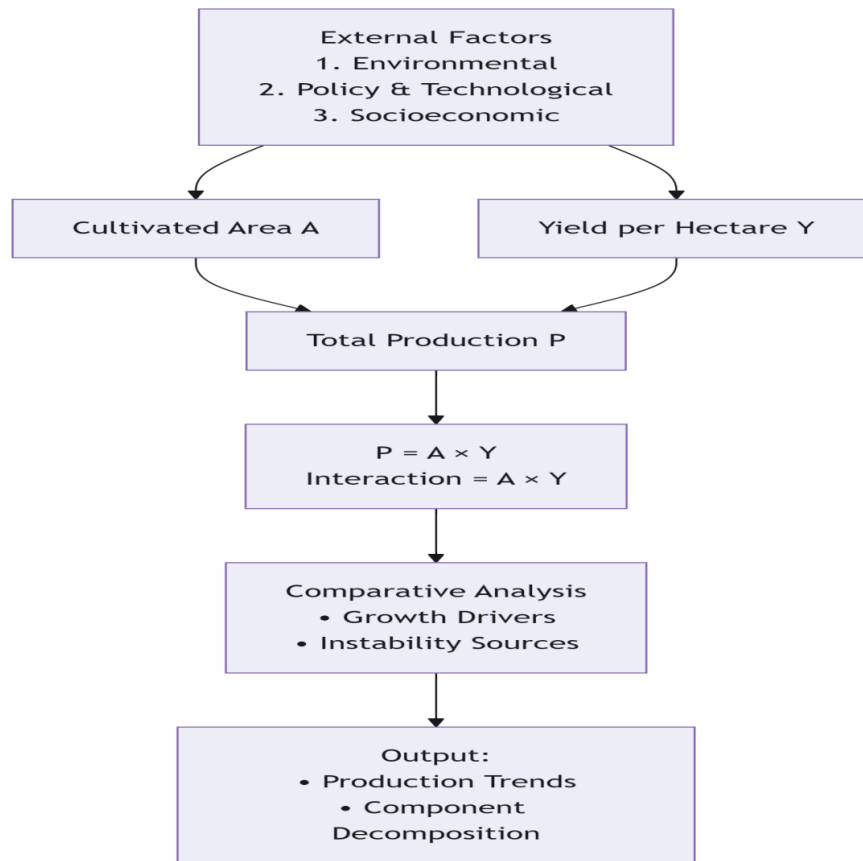


Fig. 1. Conceptual framework

Source: own study.

Empirical Review

Empirical research on cassava production in Africa has extensively documented varied growth patterns and underlying drivers. Studies on Nigeria, the global leading producer, consistently identify area expansion as the primary driver of output growth, with yield stagnation or decline being a major concern. Ikuemonisan et al. (2020) confirmed this through a decomposition analysis for 1970-2018, finding that area contributed over 80% to production increases, while yield growth was minimal and unstable. Conversely, Ghana is often highlighted as a success story for productivity-led growth. Research by Acheampong et al. (2021) attributes this to the successful adoption of improved, high-yielding varieties supported by effective extension services and market linkages, a finding corroborated by Pauw (2022) in their evaluation of national input subsidy programmes.

Comparative studies reveal these divergent models. Liverpool-Tasie et al. (2015) note that while land expansion offers a quick path to increased output, it often involves cultivating less suitable lands, leading to lower average yields and greater environmental pressure—a pattern evident in Nigeria and Tanzania. In contrast, the intensification model, as seen in Ghana, relies on enhanced technical efficiency but may introduce new vulnerabilities, such as greater sensitivity of modern varieties to climate shocks, as discussed by Abotbina et al. (2022).

As for instability, the empirical literature points to multiple sources. Sakadzo et al. (2025) emphasise climate variability as a critical destabilising factor, particularly in East African countries like Tanzania. Other studies, including Minot (2014), identify volatile input and output prices, pest and disease outbreaks (notably cassava mosaic and brown streak diseases), and policy inconsistencies as key contributors to production variance. The decomposition of instability into area and yield components, as applied in this study, is less common but builds upon the methodological foundations laid by earlier agricultural economic analyses to provide a nuanced understanding of risk sources (Jayne et al., 2018).

Beyond the established literature on production decomposition, recent empirical studies have provided deeper insights into the micro-level dynamics and external factors shaping cassava production across Africa. A comprehensive panel analysis of 37 African countries from 1961 to 2020 by Adebayo (2023) revealed that approximately 95.6% of the variability in cassava production is explained by changes in area harvested, while yield variability accounts for merely 1.1%, with consumer price index (27.6%) and temperature changes (1.8%) also playing significant roles. This finding corroborates the extensification narrative observed in Nigeria and Tanzania while highlighting the limited contribution of productivity gains continent-wide.

In Eastern Africa, recent research on cassava response to weather variability using panel regression across 15 countries from 1961 to 2023 found that while rainfall impacts on yields are insignificant, temperature effects are significantly positive, indicating yield and area increases with warming climate (Bacsi & Jarso, 2026). However, the study cautioned that expansion of cassava-growing areas coupled with growing rural populations contributed to declining yields due to the spread of smallholder subsistence farming constrained by limited resources. This suggests that even if climate change may benefit cassava production, other factors create severe limitations on improving yields.

For Ghana, micro-level evidence from field surveys in the Ashanti and Volta regions documents a local-level agricultural transformation characterised by growing farm sizes, adoption of new technologies, higher productivity, expanding market opportunities, and shifting labour structures (Andersson et al., 2024). The study observed that medium-sized farms (5-100 ha) are increasing in number, driven by reinvestment of incomes by local farmers rather than foreign investment. Average cassava yields in these regions increased substantially from 10-14 t/ha to 22-24 t/ha between 2008 and 2018, demonstrating the tangible outcomes of Ghana's productivity-led approach.

In Tanzania, disease stress and climate shock remain critical constraints. Masisila et al. (2025) found that among smallholder cassava producers in the Mtwara and Lindi regions, 84% suffered from insufficient rainfall, 65% experienced late onset rainfall, and 58% faced high temperatures and prolonged dry spells. Crucially, 76% of farmers reported poor root quality and 88.5% reported reduced yields due to Cassava Mosaic Disease (CMD) and Cassava Brown Streak Disease (CBSD). Similarly, research by Aregbesola et al. (2021) revealed that 66.8% of Tanzanian farmers produce cassava primarily for food, relying on

friends (43.8%) and their own farms (41.9%) for planting materials, with significantly more farmers controlling viruses (38.1%) than whiteflies (19.7%), highlighting critical gaps in pest management capacity.

For Nigeria, emerging evidence points to growing industrial opportunities alongside persistent structural barriers. The Nigeria Cassava Initiative reports that while Nigeria produces over 60 million metric tons annually, it captures only 2% of the \$180 billion global cassava processing market (Edike et al., 2025; Ikejamba & Brock, 2024). National yields remain low at approximately 6 t/ha, far below the global benchmark of 25 t/ha. However, pilot projects demonstrate that yields can double or triple with consistent access to improved stems, soil inputs, and agronomic support. Recent international partnerships, such as the collaboration between the Chinese Academy of Tropical Agricultural Sciences and Nigeria's National Root Crops Research Institute established in 2023, aim to introduce new cassava varieties and advanced farming techniques across over 500,000 hectares, potentially transforming productivity through germplasm exchange, technology transfer, and capacity building (Onyediako & Adiele, 2022; Oluwabiyi & Duruji, 2021).

Research Methodology

This study employs a quantitative decomposition analysis using secondary time-series data (1993–2024) from the FAO database for five major African cassava producers: Angola, Congo, Ghana, Nigeria, and Tanzania. The methodology follows output decomposition frameworks (Sadiq et al., 2020; Sadiq et al., 2021; Minot, 2014). The change in mean production between two periods (I: 1993–2008 and II: 2009–2024) is disaggregated into components attributable to changes in mean cultivated area, mean yield, and their interaction. Subsequently, the variance of production is decomposed to identify the statistical sources of instability, including variance in area and yield, their covariance, and changes in mean values. Key limitations of the methodology include reliance on the accuracy of reported FAO data, the model's inherent assumption that production is a direct product of area and yield, and its inability to causally attribute the observed changes to specific external factors like climate or policy shifts.

Empirical model

The empirical analysis employs a two-stage decomposition model. First, the change in average production between Period I and Period II is decomposed as follows (Sadiq et al., 2025a&b):

$$\Delta \bar{P} = \Delta A * \bar{Y}_1 + \Delta Y * \bar{A}_1 + \Delta A * \Delta Y \dots\dots\dots (1)$$

Where:

$\Delta \bar{P}$ - Change in mean production;

ΔA - Change in mean area ($\bar{A}_2 - \bar{A}_1$);

ΔY - Change in mean yield ($\bar{Y}_2 - \bar{Y}_1$);

\bar{A}_1, \bar{Y}_1 - Mean area and yield in Period I.

This attributes the total change to contributions from area expansion ($\Delta A * \bar{Y}_1$), yield improvement ($\Delta Y * \bar{A}_1$), and their interaction ($\Delta A * \Delta Y$).

Second, the change in the variance of production (instability) is decomposed using the general formula for the variance of a product:

$$\text{Var}(P) = \text{Var}(A * Y) \approx \bar{A}^2 * \text{Var}(Y) + \bar{Y}^2 * \text{Var}(A) + 2 * \bar{A} * \bar{Y} * \text{Cov}(A, Y) + \text{higher - order - terms} \dots(2)$$

The change in Var(P) between periods is then statistically attributed to changes in Var(A), Var(Y), Cov(A,Y), and the squared means (\bar{A}_2, \bar{Y}_2). This follows the decomposition methodology outlined by Sadiq *et al.* (2025a&b), Sadiq *et al.* (2021), Sadiq *et al.* (2020), and Minot (2014) for analysing agricultural output volatility.

Results and discussion

Production Trend of Cassava across the Selected Countries

The analysis of cassava production trends from 1993 to 2024 across Angola, Congo, Ghana, Nigeria, and Tanzania reveals distinct growth patterns and productivity levels (Figure 2). Nigeria consistently dominated in absolute production volume, with an average of 45.3 million tonnes, far surpassing other nations (Figure 2d). This aligns with its status as the world's largest cassava producer, a position supported by extensive land allocation, despite exhibiting lower average yield (9,362 kg/ha) compared to its potential, as noted by earlier studies which attribute this yield gap to predominant smallholder farming and limited adoption of improved varieties (Sadiq *et al.*, 2025c; FAO, 2022). Ghana demonstrated the most impressive growth trajectory, with average production reaching 14.1 million tonnes and achieving the highest average yield (16,252 kg/ha) among the group (Figure 2c). This significant increase, particularly post-2008, reflects successful agricultural modernisation efforts, including the promotion of high-yielding, disease-resistant varieties, which has been documented as a key driver of Ghana's root and tuber crop revolution (Acheampong *et al.*, 2021). In contrast, Angola showed volatile but generally increasing production, averaging 8.1 million tonnes, with notable peaks and troughs linked to post-conflict agricultural recovery and later climatic shocks (Figure 2a). Congo and Tanzania presented more moderate production scales, averaging 1.2 million and 6.3 tonnes, respectively (Figure 2b&e). Tanzania's trend was marked by high instability, particularly in yield, which remained the lowest on average (6,820 kg/ha), indicating persistent challenges such as variable rainfall and pest pressures, consistent with findings by Sakadzo *et al.* (2025) on climate vulnerability in Eastern African cassava systems. Congo, while small in scale, displayed steady growth, suggesting incremental improvements in a stable but constrained agricultural environment.

Causes of Changes between Period I (1993-2008) vs. Period II (2009-2024)

The decomposition of changes between the two 16-year periods highlights divergent strategies and outcomes (Table 1). For Angola, Congo, and Ghana, the second period (2009-2024) was characterised by simultaneous increases in both mean cultivated area and mean yield (Tables 1a, b & c). Ghana's performance was particularly striking, with a mean yield increase of 8,057 kg/ha, the largest absolute gain, coupled with substantial area expansion (Table 1c). This synergy between area and yield growth underscores the effectiveness of integrated national programmes focusing on input access and extension services, a success factor echoed in studies on Ghana's Planting for Food and Jobs initiative (Pauw, 2022). Nigeria and Tanzania, however, followed a different path. Nigeria witnessed a massive 4.1-million-hectare expansion in mean area but suffered a significant decline in mean yield (-

2,694 kg/ha) (Table 1d). This inverse relationship suggests an extensification strategy where production growth was achieved primarily by bringing more land under cultivation, often at the expense of yield per hectare, potentially due to cultivation on marginal lands or dilution of management intensity, a pattern observed in studies on Nigerian agricultural land use (Awotide et al., 2016). Similarly, Tanzania expanded its mean area but experienced a yield decline (-1,452 kg/ha) (Table 1e). The variance in area increased dramatically in Nigeria and Tanzania in Period II, pointing to greater volatility in land committed to cassava, possibly due to price fluctuations or competing land uses. The covariance between area and yield turned increasingly negative for Nigeria, indicating that higher area years were associated with lower yields, reinforcing the extensification narrative.

Sources of Change in Average Production of Cassava across the Selected Countries

The contribution analysis of changes in average production clearly distinguishes between yield-led and area-led growth models (Table 2). In Ghana, the change in mean yield was the predominant source, contributing 49.3% to the total production increase, followed by area expansion (29.6%) and their positive interaction (19.5%) (Table 2c). This demonstrates a productivity-intensive growth model. Similarly, in Angola and Congo, area expansion was the largest contributor (63.5% and 62.8%, respectively), but yield increases also played a substantial role (26.2% and 25.8%), showing balanced growth (Table 2a&b). The situation was reversed for Nigeria and Tanzania. In Nigeria, the massive area expansion contributed 211.9% to the mean production change, but this was severely offset by negative contributions from yield change (-42.7%) and the negative interaction between area and yield (-53.3%) (Table 2d). This results in a net increase where area expansion compensated for falling productivity, a pattern of unsustainable extensification that raises concerns about long-term land degradation, as cautioned by research on sub-Saharan Africa's crop production frontiers (Jayne et al., 2018). Tanzania's pattern mirrored this, with area expansion contributing 183.4% but being counteracted by large negative yield and interaction effects (Table 2e). The positive change in area and yield covariance in Tanzania (14.2%) was a minor mitigating factor, suggesting some weak alignment between area and yield gains in the latter period.

Sources of Instability in the Production of Cassava across Selected Countries

The sources of instability, derived from changes in production variance, reveal the underlying risk factors in each country's cassava sector (Table 3). Nigeria exhibited the most complex and extreme sources of instability (Table 3d). The overwhelming positive contribution came from the change in area variance (2,311.3%), indicating that fluctuations in the amount of land planted are the primary driver of production volatility. This is compounded by a huge negative contribution from changes in area and yield covariance (-1,108.4%), meaning that in years of high area, yields were disproportionately low, amplifying production risk. This aligns with studies identifying land tenure insecurity and erratic input supply as key sources of volatility in Nigerian agriculture (Liverpool-Tasie et al., 2015). For Tanzania, the main positive contributors to increased variance were changes in area variance (92.9%) and area and yield covariance (77.1%), while yield variance change was strongly negative (-72.3%) (Table 3e). This suggests that Tanzania's instability is less about fluctuating yields per se and more about unpredictable area allocation and its inconsistent relationship with yield, likely tied to climatic variability and market signals. Ghana's

increased production variance was primarily driven by positive changes in yield variance (27.6%), mean yield (19.2%), and area and yield covariance (16.7%) (Table 3c). This indicates that as Ghana intensified production, it also introduced new vulnerabilities, potentially related to greater sensitivity of high-yielding varieties to climate shocks or pests, a trade-off noted in high-input agricultural systems (Acheampong et al., 202; Tambo & Abdoulaye, 2012). Angola and Congo showed more mixed component contributions (Tables 3a&b, respectively), with negative contributions from changes in mean area and yield dominating in Angola, suggesting a dampening of earlier volatility, possibly due to post-war stabilisation.

Conclusions, Recommendations and Policy Implications

Conclusions

The analysis reveals two distinct cassava production models in Africa: a sustainable, productivity-led intensification model exemplified by Ghana, and a less stable area-driven extensification model dominant in Nigeria and Tanzania. While all countries increased average production, Ghana achieved this through significant yield gains, whereas Nigeria and Tanzania relied on land expansion accompanied by yield decline and higher instability, primarily from volatile area allocation.

Recommendations

For Nigeria and Tanzania, policy must urgently shift from extensification to sustainable intensification by prioritising improved seed systems, soil fertility management, and irrigation. Ghana should focus on consolidating gains by enhancing climate resilience and value chain development. Angola and Congo should continue their balanced path with strengthened research and extension services.

Policy Implications

National agricultural policies must be differentiated based on each country's dominant growth driver and source of instability. Investment should target yield-enhancing technologies and climate adaptation to de-risk production. Regional cooperation is vital to share best practices from Ghana's success, promoting a continental shift towards resilient and productive cassava systems that ensure long-term food security without ecological degradation.

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Appendix

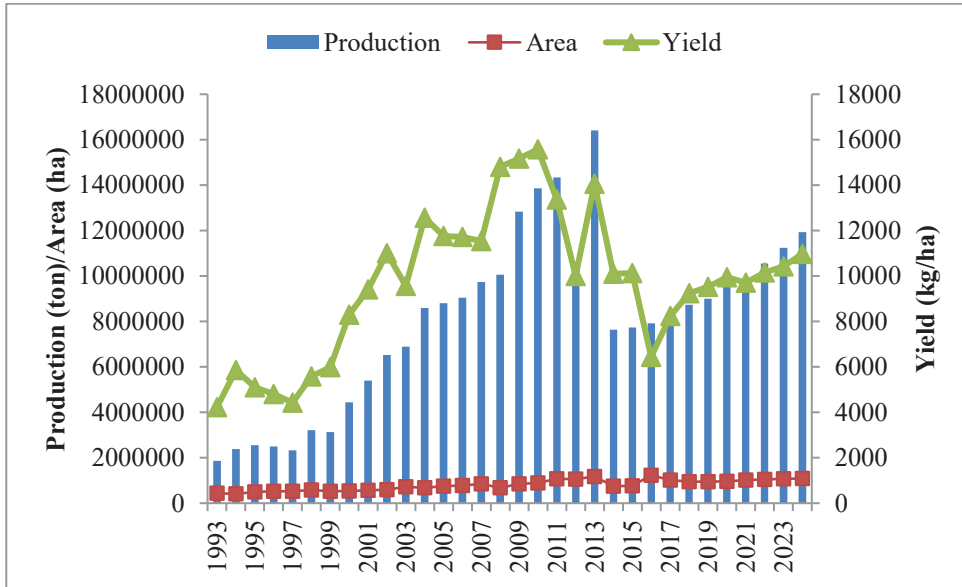


Fig. 2a. Production trend of cassava in Angola

Source: FAO, 2026.

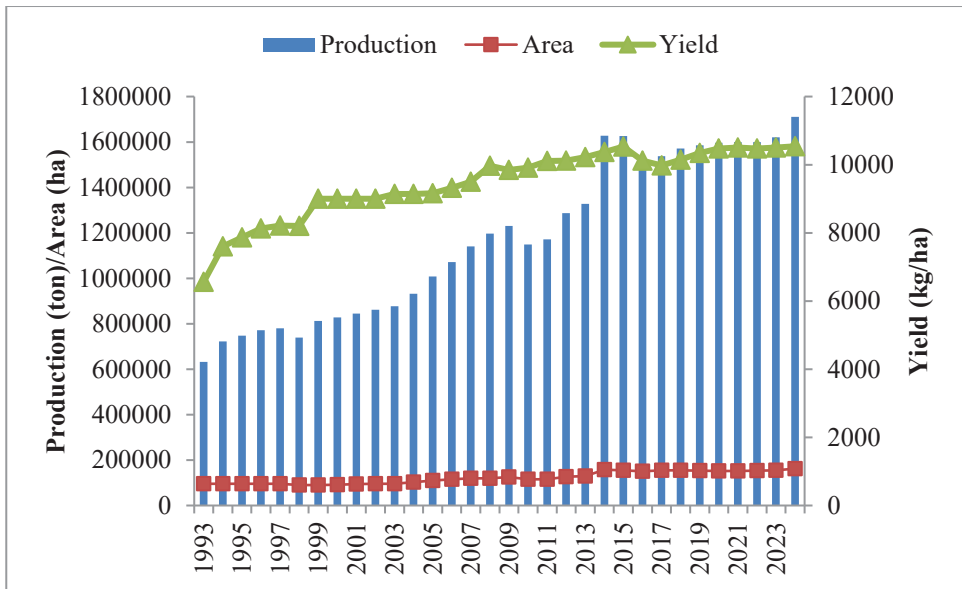


Fig. 2b. Production trend of cassava in Congo

Source: FAO, 2026.

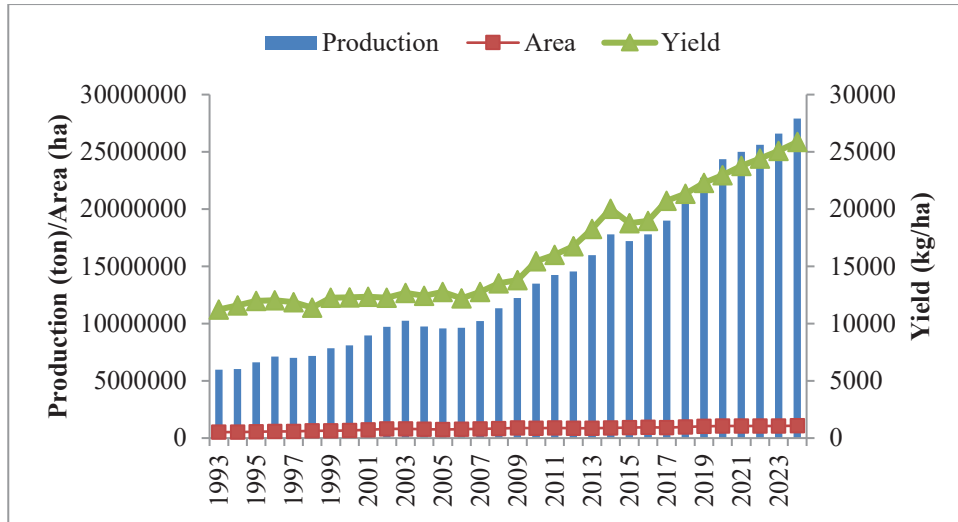


Fig. 2c. Production trend of cassava in Ghana

Source: FAO, 2026.

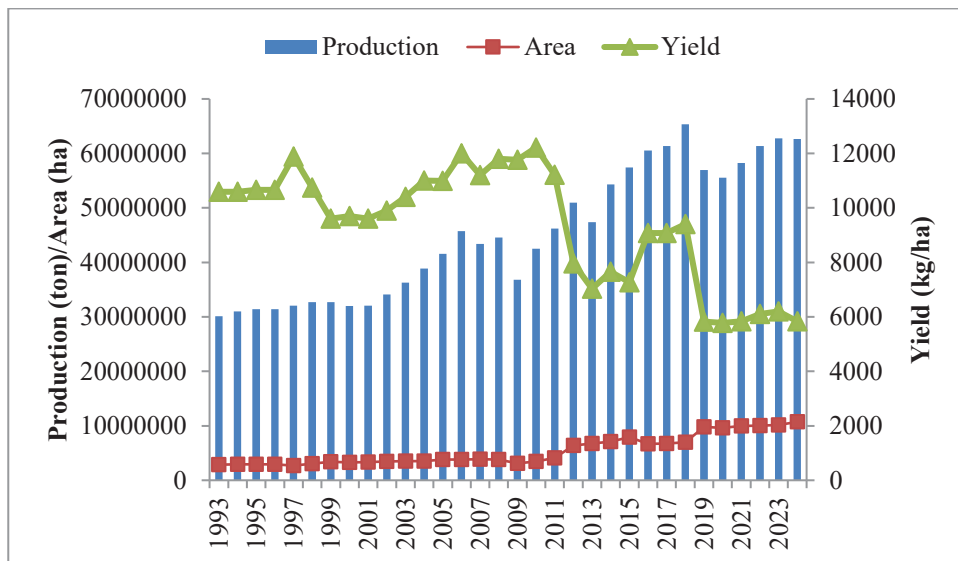


Fig. 2d. Production trend of cassava in Nigeria

Source: FAO, 2026.

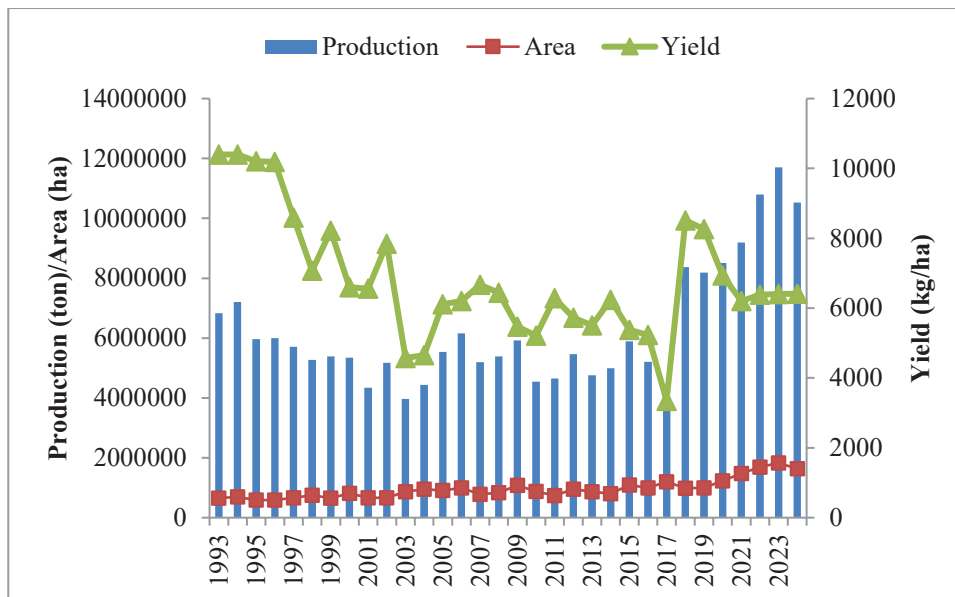


Fig. 2e. Production trend of cassava in Tanzania

Source: FAO, 2026.

Table 1a. Causes of changes between period I (1993-2008) versus period II (2009-2024) for cassava in Angola

Items	Period	Area	Yield	Area-Yield interaction
Mean	I	602371.4	8540.181	5.45E+09
	II	991998.4	10816.57	1.07E+10
Change		389627	2276.388	5.24E+09
Variance	I	1.12E+10	9533489	7.73E+18
	II	1.14E+09	1734107	8.87E+17
Change		-1E+10	-7799382	-6.8E+18
Covariance	I	2.02E+08		
	II	-4.2E+07		
Change		-2.4E+08		

Source: FAO, 2026.

Table 1b. Causes of changes between period I (1993-2008) versus period II (2009-2024) for cassava in Congo

Items	Period	Area	Yield	Area-Yield interaction
Mean	I	100064.8	8675.594	8.7E+08
	II	144544.4	10261.52	1.49E+09
Change		44479.56	1585.925	6.15E+08
Variance	I	8899899	648079.7	1.13E+16
	II	1.45E+08	28788.79	2.19E+16
Change		1.36E+08	-619291	1.06E+16
Covariance	I	1483362		
	II	1915372		
Change		432009.9		

Source: FAO, 2026.

Table 1c. Causes of changes between period I (1993-2008) versus period II (2009-2024) for cassava in Ghana

Items	Period	Area	Yield	Area-Yield interaction
Mean	I	687871.4	12223.48	8.45E+09
	II	959630	20280.52	1.97E+10
Change		271758.6	8057.038	1.12E+10
Variance	I	1.22E+10	201718.9	2.75E+18
	II	5.06E+09	11450554	2.2E+19
Change		-7.1E+09	11248835	1.93E+19
Covariance	I	30587678		
	II	2.26E+08		
Change		1.95E+08		

Source: FAO, 2026.

Table 1d. Causes of changes between period I (1993-2008) versus period II (2009-2024) for cassava in Nigeria

Items	Period	Area	Yield	Area-Yield interaction
Mean	I	3322431	10709.07	3.55E+10
	II	7469700	8015.519	5.65E+10
Change		4147269	-2693.55	2.1E+10
Variance	I	1.12E+11	11989.96	1.04E+19
	II	4.65E+12	2777070	3.29E+19
Change		4.53E+12	2765080	2.25E+19
Covariance	I		-2.3E+07	
	II		-3.4E+09	
Change			-3.3E+09	

Source: FAO, 2026.

Table 1e. Causes of changes between period I (1993-2008) versus period II (2009-2024) for cassava in Tanzania

Items	Period	Area	Yield	Area-Yield interaction
Mean	I	753441.3	7545.875	5.48E+09
	II	1152834	6093.863	7.13E+09
Change		399392.4	-1452.01	1.64E+09
Variance	I	1.03E+10	4575475	7.51E+17
	II	6.68E+10	170326.5	4.21E+18
Change		5.65E+10	-4405148	3.46E+18
Covariance	I		-1.3E+08	
	II		99967754	
Change			2.34E+08	

Source: FAO, 2026.

Table 2a. Sources of change in average production of cassava in Angola

Components of change in average production			
S/No.	Source of change	Components of change	Percent
1	Change in mean yield	1.37E+09	26.18365
2	Change in mean area	3.33E+09	63.53833
3	Interaction between changes in mean area and mean yield	8.87E+08	16.93616
4	Change in yield and area covariance	-2.4E+08	-4.65820
	Total Change in mean production	5.24E+09	100

Source: FAO, 2026.

Table 2b. Sources of change in average production of cassava in Congo

Components of change in average production			
S/No.	Source of change	Components of change	Percent
1	Change in mean yield	1.59E+08	25.81305
2	Change in mean area	3.86E+08	62.76753
3	Interaction between changes in mean area and mean yield	70541250	11.47410
4	Change in yield and area covariance	432009.9	0.07027
	Total Change in mean production	6.15E+08	100

Source: FAO, 2026.

Table 2c. Sources of change in average production of cassava in Ghana

Components of change in average production			
S/No.	Source of change	Components of change	Percent
1	Change in mean yield	5.54E+09	49.33932
2	Change in mean area	3.32E+09	29.57255
3	Interaction between changes in mean area and mean yield	2.19E+09	19.49258
4	Change in yield and area covariance	1.95E+08	1.736563
Total Change in mean production		1.12E+10	100

Source: FAO, 2026.

Table 2d. Sources of change in average production of cassava in Nigeria

Components of change in average production			
S/No.	Source of change	Components of change	Percent
1	Change in mean yield	-8.9E+09	-42.696
2	Change in mean area	4.44E+10	211.8949
3	Interaction between changes in mean area and mean yield	-1.1E+10	-53.2959
4	Change in yield and area covariance	-3.3E+09	-15.9589
Total Change in mean production		2.1E+10	100

Source: FAO, 2026.

Table 2e. Sources of change in average production of cassava in Tanzania

Components of change in average production			
S/No.	Source of change	Components of change	Percent
1	Change in mean yield	-1.1E+09	-66.5781
2	Change in mean area	3.01E+09	183.4091
3	Interaction between changes in mean area and mean yield	-5.8E+08	-35.2924
4	Change in yield and area covariance	2.34E+08	14.23845
Total Change in mean production		1.64E+09	100

Source: FAO, 2026.

Table 3a. Sources of instability in the production of cassava in Angola

Components of change in variance of production		
S/No.	Source of change	Components of change
1	Change in mean yield	-37.6613
2	Change in mean area	-106.243
3	Change in yield variance	41.36734
4	Change in area variance	10.77443
5	Interaction between changes in mean yield and mean area	-5.24423
6	Change in area and yield covariance	36.11586
7	Interaction between changes in mean area and yield variance	70.82182
8	Interaction between changes in mean yield and area variance	6.509367
9	Interaction between changes in mean area and yield and change in area and yield covariance	39.83559
10	Change in residual	43.72381
Total change in variance of production		-6.8E+18

Source: FAO, 2026.

Table 3b. Sources of instability in the production of cassava in Congo

Components of change in variance of production		
S/No.	Source of change	Components of change
1	Change in mean yield	26.81982
2	Change in mean area	77.3244
3	Change in yield variance	-58.5022
4	Change in area variance	96.63669
5	Interaction between changes in mean yield and mean area	1.974399
6	Change in area and yield covariance	7.062657
7	Interaction between changes in mean area and yield variance	-63.5686
8	Interaction between changes in mean yield and area variance	38.56027
9	Interaction between changes in mean area and yield and change in area and yield covariance	5.014187
10	Change in residual	-31.3216
Total change in variance of production		1.06E+16

Source: FAO, 2026.

Table 3c. Sources of instability in the production of cassava in Ghana

Components of change in variance of production		
S/No.	Source of change	Components of change
1	Change in mean yield	19.17192
2	Change in mean area	1.521602
3	Change in yield variance	27.59134
4	Change in area variance	-5.49806
5	Interaction between changes in mean yield and mean area	0.694362
6	Change in area and yield covariance	16.74535
7	Interaction between changes in mean area and yield variance	26.10763
8	Interaction between changes in mean yield and area variance	-9.63678
9	Interaction between changes in mean area and yield and change in area and yield covariance	22.35449
10	Change in residual	0.948148
Total change in variance of production		1.93E+19

Source: FAO, 2026.

Table 3d. Sources of instability in the production of cassava in Nigeria

Components of change in variance of production		
S/No.	Source of change	Components of change
1	Change in mean yield	-32.3283
2	Change in mean area	-6.5605
3	Change in yield variance	135.6615
4	Change in area variance	2311.259
5	Interaction between changes in mean yield and mean area	2.250025
6	Change in area and yield covariance	-1108.37
7	Interaction between changes in mean area and yield variance	550.0651
8	Interaction between changes in mean yield and area variance	-1016.44
9	Interaction between changes in mean area and yield and change in area and yield covariance	-722.357
10	Change in residual	-13.1777
Total change in variance of production		2.25E+19

Source: FAO, 2026.

Table 3e. Sources of instability in the production of cassava in Tanzania

Components of change in variance of production		
S/No.	Source of change	Components of change
1	Change in mean yield	-49.9110
2	Change in mean area	77.3167
3	Change in yield variance	-72.2549
4	Change in area variance	92.9064
5	Interaction between changes in mean yield and mean area	4.4906
6	Change in area and yield covariance	77.0986
7	Interaction between changes in mean area and yield variance	-96.9068
8	Interaction between changes in mean yield and area variance	-32.3149
9	Interaction between changes in mean area and yield and change in area and yield covariance	18.1151
10	Change in residual	81.4602
Total change in variance of production		3.46E+18

Source: FAO, 2026.

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Temporary Associations of Undertakings in Agrivoltaic Projects in Italy: Structural, Authorisation, and Contractual Profiles

Abstract. This article examines the use of temporary associations of undertakings (*associazioni temporanee di imprese*, ‘ATI’) in Italian agrivoltaic projects, a contractual architecture increasingly adopted to integrate energy generation with continued agricultural activity under the PNRR incentive scheme. The study reconstructs the private-law structure of the ATI and tests its operational resilience against the MiTE Guidelines of 27 June 2022 and the binding framework introduced by Ministerial Decree of 22 December 2023, No 436, as implemented through the GSE Operational Rules. Methodologically, the analysis combines doctrinal and systematic interpretation of the Italian Civil Code’s agency/representation tools with a regulatory reading of the incentive requirements and their documentary conditionality. The article shows that agrivoltaic ATIs cannot be meaningfully framed through the ‘horizontal/vertical’ categories of public procurement, because energy and agriculture are interdependent and equally necessary components of project qualification. It concludes that bankability and compliance depend on drafting an ‘Agency Arrangement’, internal governance rules, technical annexes and an agricultural management plan capable of ensuring continuity of farming, traceability, and allocative clarity of responsibilities, including for changes in participating entities. Finally, it identifies minimum contractual safeguards to align permitting titles with incentive entitlement and to manage ATI–SPV transitions without jeopardising eligibility.

Keywords: agrivoltaics; temporary associations of undertakings (ATI); permitting and authorisation procedures; PNRR incentives; GSE Operational Rules; contractual drafting and governance

JEL Classification: K12; K23; Q15; Q42; Q48; L94

Introduction

This study examines the legal and operational use of temporary associations of undertakings (*associazioni temporanee di imprese*, ‘ATI’) in Italian agrivoltaic projects. The purpose is to clarify how an ATI can be contractually structured to coordinate the energy and agricultural components while maintaining regulatory compliance under the PNRR incentive scheme and the GSE Operational Rules.

In the Italian agrivoltaic market, the ATI has become relevant not merely as a legal technique of cooperation, but as a practical governance tool for combining two business sectors that are structurally distinct yet legally interdependent: electricity generation and agricultural production. This relevance is explained by the regulatory architecture of agrivoltaic incentives, which requires both the technical development of an energy installation and the demonstrable continuity of agricultural activity on the same land. More broadly, agrivoltaics has been described in recent literature as a multifunctional land-use system aimed at combining photovoltaic generation and agricultural production within a single integrated spatial and operational framework (Maity et al, 2025). In practice, many projects are promoted by energy developers that need to combine their technical and financial

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capacities with the land availability, agricultural status, and operational know-how of farmers or agricultural undertakings. The ATI has therefore emerged in Italy as a flexible intermediate structure capable of concentrating external representation, coordinating documentary compliance, and preserving the separate legal identities of the participating operators during the development and permitting phase. For this reason, the ATI is increasingly discussed not only in legal scholarship, but also in professional and transactional practice, where it is used as a bridge between early-stage project development and the later incorporation of a project company.

The specific objectives are fourfold: (i) to reconstruct the private-law architecture of the ATI outside public procurement, focusing on agency, representation and internal governance; (ii) to analyse how the MiTE/MASE Guidelines and the Agrivoltaic Decree frame the 'subjective' qualification of agrivoltaic projects; (iii) to identify the contractual safeguards required to ensure documentary traceability, continuity of the agricultural component and stability of incentive entitlement throughout the project lifecycle; and (iv) to assess the ATI–SPV transition as a critical moment for permitting, incentives and bankability.

Against this background, the article addresses the following research problem: whether and under what conditions the temporary association of undertakings (ATI) constitutes a legally coherent and functionally efficient organisational model for the development, authorisation, and initial structuring of agrivoltaic projects within the Italian regulatory framework.

More specifically, the paper investigates whether the ATI is capable of ensuring continuity of the agricultural function, stability of the authorisation pathway, and compliance with the requirements of the incentive system, and how this model interacts with alternative forms of cooperation and with the subsequent transition to a project company (SPV).

The research gap addressed by the article lies in the limited legal literature on ATI structures tailored to agrivoltaics, where energy generation and agricultural activity are interdependent and equally necessary conditions for qualification. Existing contributions typically discuss ATIs either within public procurement or in general private-law terms, without translating those categories into the compliance and bankability constraints imposed by the PNRR/GSE framework.

The article's novel contribution is to propose a 'functional' model of agrivoltaic ATI and to derive a set of replicable drafting coordinates – governance, land title design, documentary flows, and contingency mechanisms – capable of reducing misalignment risks between permits and incentive status.

Literature Review & Research Data and Methods

The research adopts a doctrinal and analytical legal methodology, based on the systematic interpretation of statutory provisions, administrative practice, and the regulatory framework governing agrivoltaic projects in Italy. This approach is complemented by a practice-oriented analysis of contractual structures and recurrent project configurations emerging in the agrivoltaic sector, with particular attention to the interaction between private law arrangements, authorisation procedures, and incentive schemes.

The combination of normative analysis and practice-based reconstruction allows the paper to assess the functional suitability of the ATI in comparison with alternative forms of

cooperation and to identify the contractual and organisational conditions required to ensure legal robustness, regulatory compliance, and project bankability.

ATI and Other Legal Forms of Cooperation in Italian Agrivoltaics

The role of the ATI in agrivoltaic projects can be more accurately understood when placed within the broader spectrum of legal forms of cooperation available in the Italian agricultural sector.

The functional relevance of the ATI becomes clearer when it is compared with other legal forms of cooperation available in the Italian agricultural sector, each of which reflects a different degree of organisational integration and temporal stability. Agricultural cooperatives, governed by Articles 2511–2548 of the Italian Civil Code, represent a paradigmatic model of institutionalised cooperation based on the principle of mutuality, aimed at satisfying the economic and social needs of members through the collective management of agricultural activities and resources. In the Italian system, cooperatives constitute a structural pillar of the agri-food economy, combining entrepreneurial strategies with solidarity-based governance and long-term organisational stability. Their function is not limited to project-specific coordination, but extends to market integration, value-chain organisation, and the collective valorisation of agricultural production. (Tedioli, 2025a)

Against this background, the ATI operates on a structurally different plane. Unlike cooperatives, which presuppose a stable organisational framework and a long-term integration of members' activities, the ATI is conceived as a project-specific and functionally temporary coordination mechanism, lacking both legal personality and a segregated patrimony. Its purpose is not to integrate production and market activities in a stable organisational form, but to coordinate heterogeneous operators – typically energy developers and agricultural undertakings – within a defined transactional framework aimed at obtaining authorisations and accessing incentive schemes. In this sense, while cooperatives embody a model of institutional cooperation, the ATI reflects a model of transactional cooperation, oriented towards the implementation of a specific project rather than the long-term organisation of economic activity.

A further alternative is represented by the agricultural network contract, which enables multiple undertakings to cooperate on the basis of a common programme while preserving their legal and operational autonomy. This instrument is characterised by a high degree of contractual flexibility and may also take a 'subjective' form with limited legal autonomy. However, its primary function lies in enhancing innovation capacity and market competitiveness through shared activities, rather than in concentrating representation and ensuring a unified interface with public authorities and incentive operators. As a result, while network contracts are particularly effective for horizontal cooperation among agricultural enterprises, they are less suited to contexts – such as agrivoltaics – where regulatory compliance, documentary traceability, and the centralisation of external relations play a decisive role.

From a functional perspective, therefore, the choice among these legal forms depends on the phase and objectives of the agrivoltaic initiative. Cooperative and corporate structures are better suited to long-term operation, collective management, and value-chain integration, especially where agricultural producers aim to retain stable control over the project. By contrast, the ATI proves particularly effective in the development and authorisation phase, where the need to combine land availability, agricultural qualification, technical expertise, and regulatory compliance requires a flexible yet coordinated structure. It follows that, in the

current Italian framework, the ATI should be regarded not as a substitute for other forms of cooperation, but as a complementary instrument, positioned upstream of more stable organisational models such as cooperatives or project companies.

Functional Efficiency of Cooperation Models in Italian Agrivoltaics

From a functional perspective, the legal structuring of agrivoltaic initiatives in Italy cannot be reduced to the identification of a single optimal organisational model. Different forms of cooperation display different degrees of efficiency depending on the specific phase of the project and on the balance sought between agricultural control, technical specialisation, and financial sustainability. In this respect, a meaningful comparison may be conducted across three dimensions: financing, implementation, and operation.

As regards the development and authorisation phase, the ATI appears particularly effective. Its contractual nature allows the aggregation of heterogeneous actors – typically agricultural undertakings and energy operators – without requiring immediate incorporation into a single legal entity. This flexibility is especially relevant where the project must combine land availability, agricultural continuity, technical design, and compliance with the incentive framework. In addition, the concentration of representative powers in the mandatory undertaking facilitates the management of relations with public authorities and with the GSE, thereby making the ATI especially suitable for the initial phase of project structuring.

Other forms of cooperation may perform different functions. Agricultural cooperatives are potentially effective where agricultural producers intend to retain a strong and stable role in the management of the farming activity and in the economic valorisation of the project. However, they do not necessarily offer the same degree of flexibility in combining agricultural and energy-sector operators, nor do they always ensure the technical and financial specialisation required by more complex agrivoltaic initiatives. Purely contractual arrangements, based for example on land titles and service agreements, may regulate specific relationships, but they tend to provide a lower level of organisational integration and are therefore less suitable where the regulatory framework requires a stable and verifiable coordination between the agricultural and the energy components.

From the standpoint of long-term financial sustainability and operational stability, more structured corporate solutions may prove more efficient than the ATI alone. Yet this does not diminish the role of the ATI within the Italian agrivoltaic sector. Rather, it confirms that the ATI is best understood as a functionally selective instrument: particularly efficient in the development and authorisation phase, but not necessarily exhaustive of the project's entire legal organisation. Its distinctive advantage lies in enabling the coordinated participation of different operators at the stage where regulatory compliance, documentary traceability, and the integration of agricultural and energy functions are most critical.

Accordingly, the most effective model for agricultural producers in Italian agrivoltaics cannot be identified in abstract terms. Where the priority is to preserve stable farmer control over the initiative, cooperative or other stable associative structures may be preferable. Where, by contrast, the project requires the coordinated participation of agricultural and energy operators for the purposes of permitting, incentive access, and initial implementation, the ATI appears to be the most efficient organisational solution. Its practical relevance therefore lies not in its universal superiority, but in its specific aptitude for governing the phase in which agrivoltaic projects are legally and administratively formed.

The Temporary Association of Undertakings: Legal Framework of the Institution

The temporary association of undertakings (*associazione temporanea di imprese*, 'ATI') is a contractual cooperation arrangement among economic operators in Italy, structured for the implementation of a specific transaction, without the incorporation of a new legal entity and without the constitution of a segregated patrimony (Mazzone, 2012; Durante, 2017; Corapi 1983). From a structural standpoint, an ATI is typically articulated into (a) the Agency Arrangement, which grants the lead undertaking (*mandataria*) authority to represent the participants and serves as the single point of contact for relations with third parties, and (b) an internal agreement/regulation intended to specify the object of the initiative, the allocation of activities, decision-making rules, information flows, and internal remedies and security arrangements. In systematic terms, the ATI functions as an internal 'organisational scheme': external representation tends to be concentrated in the *mandataria*, while the participating undertakings (*mandanti*) retain their separate legal and asset autonomy, remaining responsible for the performance of the tasks assigned to them under the agreed allocation.

Outside the perimeter of public procurement, however, the ATI is not a legislatively regulated institution in the strict sense (Galgano, 1994; Tedeschi et al., 1993): legal scholarship (Di Sabatino, 2006) has underscored the difficulty of subsuming the aggregation within a single category [unrecognised association, tertium genus, atypical associative contract (Corte di Cassazione, 1975, Decision No 681)], to the point of emphasising the characterisation of the private-law ATI as a multilateral contract and, at the same time, a normative (framework) contract, designed to coordinate and regulate the cooperation. From this perspective, the internal agreement is not a mere 'formal shell', but the source of each participant's obligation to align future conduct and external contracts with the common programme [*pactum de modo contrahendi*, Di Sabatino, 2006; Messineo 1962, Guglielmetti, 1969)], with the consequent implications in terms of contractual liability and internal remedies.

Consistently with this reading, the applicable discipline tends to be reconstructed 'by way of cross-references': (i) to agency agreement/relationship (Article 1703 of the Italian Civil Code) as the cornerstone of external representation and of the *mandataria/mandanti* relationship; (ii) to the contract (or contracts) which, on a case-by-case basis, constitutes the economic operation carried out through the ATI (in the classical experience, the works contract: Article 1655 of the Italian Civil Code), without prejudice to the fact that, on the internal plane, the general rules on multilateral contracts (Articles 1420, 1446, 1459, and 1466 of the Italian Civil Code) also become relevant when the performance of one participant becomes essential or non-fungible vis-à-vis the common purpose.

A methodological corollary follows, which in the agrivoltaic sector becomes immediately operational: the 'ordinary private-law' ATI must be made contractually self-sufficient, precisely because the public-law 'crutches' typical of groupings in public procurement are absent (*lex specialis*, statutory rules on changes in membership, and a legal framework of liabilities). In public procurement, indeed, the temporary grouping is a legislatively regulated institution governed by special rules (today: Legislative Decree of 31 March 2023, No 36, Article 68), whereas outside that domain, the practical viability of the ATI rests on private autonomy and on the ability of the internal regulation to govern liabilities, powers, and remedies.

Within this framework, alongside the ATI, a competing model of inter-firm cooperation – particularly relevant in agriculture – is the network contract [*contratto di rete* (Tedioli, 2025b and 2026a)], which allows forms of productive coordination and functional integration without necessarily creating a new legal entity. In the agrivoltaic perimeter, however, the regulatory choice has favoured the ATI scheme: it makes it possible to integrate different value chains (energy and agriculture) while keeping the participating undertakings separate; it concentrates representation and compliance duties in a single mandatary; and it thereby stabilises the interface with the incentive system – so much so that Ministerial Decree of 22 December 2023, No 436 expressly includes it among the subjects relevant for the PNRR measure. This design choice also aligns with governance patterns typical of EU-funded instruments, where concentrating accountability on a single interlocutor facilitates auditability, traceability, and the ex-post verification of conditionality. The implications of this choice in terms of compliance and bankability are addressed in the following sections.

The MiTE Guidelines of 27 June 2022: Subjective Qualification of Agrivoltaic Projects Between Agricultural Undertakings under Article 2135 of the Italian Civil Code and an ATI

The MiTE Guidelines of 27 June 2022 (Ministry for the Ecological Transition, 2022), prepared within the Ministry with technical support from CREA and GSE, are not a binding legal source in the strict sense; rather, they constitute a technical guidance instrument (soft law) describing the minimum features expected for a project to qualify as agrivoltaic and, at an applicative level, orienting the construction of technical-agronomic requirements and monitoring safeguards. The framework has, however, evolved: the notion of an ‘agrivoltaic installation’ is now also anchored to a primary statutory definition, introduced by Article 4(f-bis), of Legislative Decree of 25 November 2024, No 190 [Testo Unico FER (Tedioli, 2026b)], as amended by Law of 15 January 2026, No 4, and centred on preserving the continuity of crop-growing and pastoral activities at the installation site. The Guidelines remain relevant as a technical-interpretative benchmark and, above all, as an applicative reference for ‘advanced’ qualification and for administrative practice in the assessment phase, thereby making the linkage with support mechanisms predictable. In the event of a misalignment, the subsequent positive law prevails; the Guidelines retain, at most, an interpretative and supplementary role to the extent compatible with implementing sources and with the Operator’s regulatory framework (Tedioli, 2025c).

From the subjective standpoint, the document adopts a binary classification, with immediate effects on the structuring of the transaction. On the one hand, an agricultural undertaking (whether individual or associated) within the meaning of Article 2135 of the Italian Civil Code; on the other, a ‘mixed’ ATI between energy operators and one or more agricultural undertakings, required (on the basis of a specific agreement) to ensure the availability of the land and the continuity of agricultural activity. The distinction is not merely descriptive: within the Guidelines’ model, the ATI is treated as an organisational architecture capable of making the co-existence between electricity generation and agricultural activity ‘structural’, and thus of supporting – also from an evidentiary perspective – the qualification of the intervention.

The reference to an ATI, however, raises a problem of classification. The category is developed in public procurement contracting and presupposes a tender, a contracting authority, and a single unitary bid. None of these elements is present in the agrivoltaic context, where the ATI is not the instrument for submitting an offer in a competitive

procedure, but rather the contractual mechanism through which two value chains are coordinated in managing the authorisation pathway and in accessing the incentive scheme.

For this reason, the function of the typical instruments also changes: the Agency Arrangement serves to stabilise the interface with the Operator; the internal regulation must allocate the powers, obligations, and liabilities necessary to render the agricultural component verifiable throughout the entire lifecycle of the incentive. It follows that the ‘horizontal/vertical’ categories have, here, only a descriptive value: energy and agriculture are both conditions for the project’s qualification, and it is not useful to reconstruct them according to a ‘principal/accessory’ hierarchy. On this assumption rests the discussion that follows.

PNRR Incentives and Positive Law: Ministerial Decree of 22 December 2023, No 436, and the Operational Perimeter of ATIs

Ministerial Decree of 22 December 2023, No 436 (the ‘Agrivoltaic Decree’) constitutes the main binding regulatory framework governing access to Italy’s PNRR incentives (Investment 1.1) and, from a subjective standpoint, expressly includes ATIs among the eligible beneficiaries (Ministry of the Environment and Energy Security, 2023). Article 4 encompasses, alongside agricultural undertakings within the meaning of Article 2135 of the Italian Civil Code (letter a), ‘mixed’ ATIs that include at least one agricultural participant (letter b). This choice also affects bankability, since – where an ATI is involved – economic and financial requirements may be evidenced through a bank statement relating to only one of the participants (Article 5(3)). The incentive scheme is further structured as a combination of a capital grant and a tariff applied to the energy produced, in accordance with the architecture set out in the Decree (Articles 1 and 10).

The subjective composition conditions the access channel to the measure and, with it, the configuration of the transaction. The registers (300 MW quota) are reserved for installations up to 1 MW held by the ‘agricultural’ subjects referred to in Article 4(1)(a); the auction procedures (740 MW quota), by contrast, are open to installations of any capacity held either by agricultural subjects or by the ‘mixed’ ATIs referred to in letter (b) (Article 5).

This imposes a structural constraint on the transaction: the choice of the subjective arrangement and of the ATI’s composition determines the procedural trajectory (register/auction) and conditions sizing, bankability, and the internal allocation of functions.

From the objective standpoint, the Decree presupposes an agrivoltaic system integrating energy infrastructure with continuity of agricultural activity (Article 2, definitions). This requirement must now be read in coordination with the primary statutory definition of ‘agrivoltaic installation’ introduced by Article 4(f-bis), of Legislative Decree No 190/2024, as amended by Law No 4/2026, which anchors the qualification of the intervention to the effective and verifiable preservation of crop-growing and pastoral continuity, elevating it to a sanction-triggering parameter pursuant to Article 11(8) of the same legislative decree.

On the implementing side, the GSE Operational Rules allocate unified external responsibility by concentrating on the mandatary the PNRR obligations of a documentary nature, and in particular the reporting of expenditure. The point is decisive from a contractual perspective: traceability, monitoring activities, and documentary flows cannot remain in the background, but must be regulated as essential internal obligations. In this perspective, the statement attested by a qualified professional introduced by Law No 4/2026 – confirming the installation’s suitability to preserve at least 80% of the gross saleable production (*produzione lorda vendibile*, ‘PLV’) – is integrated into the documentary system that the mandatary is

required to manage and report to the GSE: any deficiency or inconsistency in its preparation or updating may affect the entire relationship with the Operator, impacting the disbursement of the incentive. Similarly, the five-year municipal post-installation check introduced by the same law extends documentary risk beyond the authorisation phase, requiring that the ATI regulations include traceability safeguards for the agricultural component that are functional also at the operational stage.

More generally, such ex-post verification mechanisms mirror accountability patterns commonly associated with EU-funded measures, where continued eligibility is conditioned on the ongoing, documentable fulfilment of project-specific commitments.

Finally, the incentive tariff operates through a differential mechanism reflected in the standard-form contract, with potential balancing payments depending on the trend of the market price vis-à-vis the tariff. Although this is an economic rule, the legal implication is immediate: the ATI regulations must expressly govern (i) the allocation of balancing amounts and (ii) transparent management of the related financial and informational flows.

Research Methodology

Configuring the ATI in the Agrivoltaic Context: The ‘Functional’ Model and Liability Vis-à-Vis Third Parties

The Guidelines’ reference to the ATI scheme of public-procurement origin raises a qualification issue that is not merely taxonomical: in the agrivoltaic sector, questioning whether the ATI is ‘horizontal’ or ‘vertical’ serves above all to clarify which elements of the ATI scheme can be adapted to the ordinary private-law context (agency, representation, internal allocation, recourse) and how this affects the construction of the external title and, consequently, the regime of liability towards third parties.

A horizontal ATI presupposes homogeneous competences and performances belonging to the same functional category; in the energy–agriculture grouping, participants contribute heterogeneous and non-interchangeable competences. A vertical ATI aggregates differentiated competences but presupposes a hierarchy between a main performance and severable ancillary performances: in agrivoltaics, such a hierarchy is not workable, because energy production and agricultural activity operate as interdependent and equally necessary conditions for qualifying the intervention. The outcome is a ‘functional’ or ‘integrated’ model, not fully overlapping with the categories of the Public Contracts Code.

The immediate consequence concerns liability vis-à-vis third parties. In an ordinary private-law ATI, the external regime is not laid down by statute and depends on how the relationship is structured. The *mandanti* qualify as co-obligors only if the external contract contemplates them as parties, or if the Agency Arrangement confers on the *mandataria* authority capable of producing direct legal effects in their legal sphere: only in that case do the participants assume the status of co-obligors of the same obligation and, absent a different express arrangement accepted by the third party, the presumption of joint and several liability under Article 1294 of the Italian Civil Code applies, with internal allocation clauses remaining irrelevant as against third parties.

The operational point, therefore, is not to choose between horizontal and vertical, but to design: (i) the structure of the external title – determining who is a party, for which obligations, and with what effects on the *mandanti*’s legal sphere – and (ii) the internal

safeguards of recourse and indemnity, as well as the mandatary's effective powers, bearing in mind that limitations agreed internally are not opposable to third parties who have not expressly accepted them. To these two profiles, in post-Law No 4/2026 agrivoltaics, a third axis of design must be added: (iii) the internal regulation of agricultural sanctioning risk, with an express allocation of responsibility for any failure to maintain crop-growing continuity and for the documentary safeguards required to support both the PLV statement attested by a qualified professional and the five-year municipal check. This internal allocation also serves an external-facing function of risk governance, in line with the compliance architecture typically expected for projects supported through EU-derived funding streams, where ongoing eligibility is tied to continuous, documentable performance.

Contractual Architecture of the Agrivoltaic ATI: Grouping Agreement, Agency Arrangement, and Land Title

Once the classificatory issue is set aside, the robustness of the agrivoltaic ATI depends on the quality of its internal contractual arrangement. Because the ATI does not constitute an autonomous centre of legal attribution and has no segregated assets, the internal cooperation (grouping) agreement performs a function that is constitutive in substance: it defines the object and operational perimeter of the initiative, governance, the allocation of activities, and the coordination rules between the energy component and the agricultural component, as well as the safeguards that make the grouping 'performable' and verifiable in dealings with counterparties and public authorities.

Within the PNRR framework, this function is further intensified by the concentration on the ATI (and, in practical terms, on the mandatary) of the duties of interface and compliance vis-à-vis the GSE, including those triggered by reorganisations of the grouping during the incentive period.

From a documentary standpoint, the minimum structure tends to consist of two coordinated instruments: (i) a special-purpose Agency Arrangement in favour of the *mandataria*, serving as the pivot of external representation and the unitary management of relationships with third parties and (ii) an internal regulation (grouping agreement) setting out in analytical terms the relationships among participants, the allocation of activities, information flows, decision-making mechanisms, controls, and remedies. Agrivoltaic practice, for reasons of verifiability and bankability, often adopts a 'package' structure: alongside the two core documents, (iii) technical annexes (plant configuration, agronomic lay-out, management and maintenance plan, timetable) and (iv) a deed or annex specifically devoted to agricultural management (cropping plan/agricultural management plan and related obligations), in order to avoid relegating the agricultural component to generic clauses.

This documentary articulation is consistent with the broader understanding of agrivoltaics as a socio-technical system whose feasibility and long-term performance depend not only on engineering and agronomic parameters, but also on the legal and policy frameworks governing project design and implementation (Jamil et al., 2026). In Italian transactional practice, this interdependence is reflected in a number of recurring ATI configurations. A first model involves an energy developer and an agricultural undertaking, where the former manages technical design, authorisation strategy, and relations with suppliers, while the latter ensures land availability and the continuity of agricultural activity. A second model involves a developer, an EPC-oriented industrial operator, and an agricultural undertaking, with a more explicit internal allocation between development, construction, and farming functions. A third model, less frequent but increasingly relevant,

involves several agricultural operators acting jointly in order to preserve direct control over the agricultural dimension while relying on specialised technical partners for the energy component. These recurring patterns confirm that the ATI is used in practice not as a generic associative form, but as a project-specific governance arrangement intended to allocate functions, documentary responsibilities, and risk in a manner compatible with the incentive framework.

Upstream, a declaration of commitment to constitute an ATI (*ATI costituenda*) is not infrequently used: it identifies the lead undertaking as the ‘producer’, grants representative powers to the future *mandataria*, and formalises the joint signature of the application, thereby ensuring a single interface with the GSE already at the filing stage.

Consistently with the Operational Rules, the constitutive deed and the internal regulation must also be drafted to be producible to the GSE as ‘enabling’ documentation, especially where changes in the participating entities occur, while ensuring internally the prompt availability and verifiability of the documentary evidence that the mandataria is required to transmit and report.

The internal regulation must define the object of the common initiative with precision, avoiding elastic formulations incapable of sustaining either the allocation of tasks or the remedial framework. It is advisable to distinguish, already at the contractual level, between a development phase (design, due diligence, preparation of documentation and technical-administrative interactions), a construction phase (procurement/EPC and management of performance), and an operational phase (O&M, agricultural management, and coordination of interferences). Phase-based sequencing allows the construction of verifiable objectives and intermediate deliverables (also in PNRR terms), the allocation of operational responsibilities, and the effective activation of contractual remedies, by anchoring information and reporting duties to clearly defined and measurable deliverables rather than to generic duties of cooperation.

Governance is the second turning point. In agrivoltaics, the principal risk is not mere decisional inefficiency, but misalignment between the energy component and the agricultural component, with external spillovers (authorisations, incentives, controls). It follows that the agreement should provide for a coordination body and for rules on ‘reserved matters’, i.e. decisions that affect the interdependence and equal necessity of the two components (plant lay-out, choice of compatible crops, scheduling of farming operations and maintenance, access management, technical changes impacting cultivation), including those choices capable of affecting the monitoring and reporting obligations under the implementing framework. The most efficient technique is to separate external signature power (entrusted to the *mandataria*, to preserve a single interface) from internal rules requiring prior authorisation for ‘sensitive’ acts, with decision traceability, specific information duties, and audit/document-verification powers over agricultural performances, functional to supporting externally the ongoing fulfilment of requirements.

The third profile, specific to the energy–agriculture ATI, concerns the legal basis for land availability. Law of 15 January 2026, No 4, converting Decree-Law No 175/2025, by amending Legislative Decree of 25 November 2024, No 190 (Testo Unico FER), has strengthened crop continuity as a definitional and sanction-relevant requirement for agrivoltaics, making the choice of the land title even more significant from a compliance perspective. The Operational Rules require the agricultural undertaking to secure the availability of the area through a specific agreement, without prescribing any particular legal instrument. The choice is not neutral: each title entails different implications in terms of

duration, enforceability against third parties, transferability, the regime governing works and improvements, and compatibility with the continued performance of agricultural activity – a requirement now also protected through sanctioning mechanisms under Article 11(8) of Legislative Decree No 190/2024.

The right of superficies (Article 952 of the Italian Civil Code) is the most widespread instrument in energy practice, as it allows the separation of ownership of the installation from ownership of the land and is enforceable against third parties upon registration. However, if not adequately tailored, the right of superficies confers on the superfiary an exclusive power incompatible with continuous agricultural activity and may result in a significant deprivation of land enjoyment for the grantor or the agricultural tenant, sitting uneasily with the crop-continuity obligation imposed by Ministerial Decree No 436/2023 (Tedioli, 2025d). It follows that, if used in its traditional form, the right of superficies must be recalibrated through clauses that confine its physical extension to the areas actually occupied by plant structures, delimit its content by excluding exclusive use of the soil and imposing non-interference obligations vis-à-vis agricultural activity, and modulate its duration by providing for withdrawal or renewal conditional upon periodic verification of agronomic requirements (Busani, 2024).

An agricultural lease (*affitto di fondo rustico*) under Law of 3 May 1982, No 203 ensures crop continuity and preserves the functional link between the agricultural undertaking and the land, consistent with the substantive approach of agrivoltaics. However, the special regime introduces significant constraints: a minimum fifteen-year term (Article 1), tacit renewal absent notice, a pre-emption right of the tenant (Article 4-bis), and a prohibition on subleasing without the lessor's consent (Article 21). These elements reduce flexibility and may complicate the ATI–SPV transition, since assignment of the relationship requires the lessor's consent and, absent such consent, may be qualified as an unlawful sublease or sub-concession.

The adoption of combined structures is increasingly frequent: a right of superficies for the plant component and an agricultural contract (lease or loan for use / *comodato*) for the management of cultivable surfaces. This solution requires careful coordination between titles: delineation of areas, regulation of interferences, harmonisation of durations, and governance of the consequences of termination of one relationship on the other. Within this framework sits Article 5(2-bis) of Decree-Law No 63/2024, which provides for a minimum six-year term, with automatic renewal for a further six years, for agreements granting a right of superficies relating to renewable-energy installations in suitable areas, introducing an additional coordination parameter with the incentive duration and with crop-continuity obligations.

Operationally, the choice of land title is not a marginal implementation detail: it shapes the agency arrangement and allocation of authority, the transaction's bankability, and the stability of incentive entitlement throughout the project life cycle. For this reason, in an agrivoltaic ATI the land arrangement should be integrated into the internal regulation, defining at least: (a) a title and duration coherent with the project lifecycle and with the horizon of external obligations (including the incentive period), or in any event a continuity regime in the event of early termination; (b) rules for co-existence and for managing access, interferences, and functional areas; (c) allocation of custody and maintenance duties, distinguishing between energy infrastructure and cultivated surfaces; (d) management of layout changes and agronomic needs through an agreed update procedure (a formalised, documentable, traceable change order), consistent with monitoring and reporting obligations.

A recurrent practical variant should nonetheless be noted: participation of the agricultural undertaking in the ATI with a predominantly 'passive' role, limited to making land available and preserving the subjective requirement. From a civil-law standpoint, the status under Article 2135 of the Italian Civil Code remains anchored to the effective exercise of agricultural activity; from an incentive standpoint, a merely formal contribution exposes the project to the risk of an agricultural component that is not adequately demonstrable. The risk has increased following the introduction, by Law No 4/2026, of the obligation to attach to the project a statement attested by a qualified professional confirming the installation's suitability to preserve at least 80% of gross saleable production (PLV), as a minimum quantitative parameter of productive continuity that is also verifiable in subsequent controls.

The Operational Rules, in fact, require that the correlation between electricity production and agricultural activity be evidenced through an agronomic report attested by a qualified professional and, already at the participation stage, require the indication of the ATECO code for the agricultural activities that will be carried out within the system. It follows that the ATI regulation and the land agreement must avoid configuring the agricultural undertaking as a mere 'grantor', providing instead for agricultural management/conduct obligations (directly, or possibly through outsourcing to third parties under the responsibility of the agricultural undertaking), a cropping plan with verifiable yield indicators consistent with the 80% PLV threshold, traceability and periodic reporting, and continuity remedies (step-in/operational substitution) consistent with external verifiability of requirements. Contractual discipline must also take account of the five-year municipal post-installation check introduced by Law No 4/2026, which requires traceable and documentable management of the agricultural component throughout the operational period, transforming crop continuity from an initial authorisation requirement into a permanent management constraint.

A further node, often decisive for bankability, is internal economic discipline: allocation of costs (development, authorisations, construction, management), allocation of revenues and incentives (including possible mechanisms compensating the agricultural component), and allocation of economic risks connected to the tariff, including balancing payments under the 'two-way' mechanism, with allocation criteria and internal funding mechanisms in favour of the mandatory/producer, which remains the interface with the GSE

Finally, the agrivoltaic ATI requires a contingency and remedial framework consistent with the temporary nature of the arrangement and with the project's sensitivity to changes in the participating entities and to procedural outcomes. Withdrawal, substitution of participants, transfers of position, entry of new operators, and qualified breaches must be regulated from the outset, through graduated remedies and continuity clauses, in particular with respect to the agricultural component and land availability. It is also advisable to treat 'procedural outcomes' as contractually relevant events (failure to access the incentive, the need to re-modulate the project, transfers of titles and documentary updates), and to provide for dissolution/restructuring mechanisms and a reallocation of development costs that avoid ad hoc renegotiations.

From a contractual standardisation perspective, this arrangement should be accompanied by a minimum set of clauses and annexes capable of making demonstrable: (i) land availability and co-existence rules; (ii) agricultural obligations (management plan/cropping plan) and related KPIs/monitoring, with verifiable yield indicators consistent with the 80% PLV threshold and suitable to support the statement attested by a qualified professional required by Law No 4/2026; (iii) documentary flows and the mandatory's audit

powers for PNRR/GSE purposes; (iv) governance and reserved matters; (v) technical/locational change control; (vi) discipline of changes in the participating entities (change of control, entry/exit, substitution), with documentary cooperation duties and continuity remedies (cure period/step-in) functional to project stability. To these should be added (vii) the discipline of agricultural continuity during the operational phase, including response modalities to the five-year municipal check and the documentary safeguards necessary to prevent productive deviations – even if attributable to exogenous factors – from translating into challenges to the agrivoltaic qualification of the intervention. The minimum content outlined above delineates a contractual arrangement to be constructed coherently with authorisation titles and PNRR/GSE obligations, because only on that basis does the grouping become effectively governable and financeable.

Authorisation Title, Incentive Pathway, and Relations with the GSE: Allocation of Responsibility and Coordination within the ATI

The issue is not whether an ATI may access incentives – a profile already encompassed by Ministerial Decree of 22 December 2023, No 436 – but how the subjective allocation vis-à-vis the GSE is built and kept stable throughout the entire project lifecycle.

The Operational Rules identify the ‘applicant’ (*soggetto richiedente*) as (a) an agricultural operator or (b) an ATI including at least one agricultural operator; in the case of an ATI, the applicant is represented by the mandatary in dealings with the GSE and, in such cases, the mandatary coincides with the ‘producer’ (*soggetto produttore*) (Appendix A, Chapter 20). From this follows the main drafting constraint: the formal concentration of powers in the mandatary cannot remain merely nominal, but must be supported by effective internal powers (document requests, audit, binding instructions on fulfilments and deadlines, operational substitution/step-in) and by a system of indemnities and reimbursements, because the obligation ‘towards the GSE’ is unitary, whereas the material performance of activities and the production of evidence are, in fact, distributed among the *mandanti*. In this perspective, the agronomic documentation required under the post-Law No 4/2026 framework – namely the PLV statement attested by a qualified professional and its updates – forms part of the evidence that the mandatary must manage vis-à-vis the Operator, with the consequent need to attribute to it, in the internal regulation, verification and follow-up powers suitable to ensure timely production. The same logic applies to ATIs to be formed (*ATI costituende*): all future participants must sign the application and designate the mandatary under an arrangement consistent with unitary representation vis-à-vis the Operator.

On the authorisation side, subjective alignment is continuously safeguarded: at the participation date, at the commercial operation date, and throughout the entire incentive period, the authorisation/enabling title must be registered in the name of the applicant; in the case of an ATI, registration must be in the name of the subject within the grouping that meets the definition of producer. Any arrangement in which the authorisation title and the ‘producer’ structurally diverge constitutes a critical issue to be neutralised before access; in the event of transfers/substitutions, evidence must be provided of the completed change or of procedural outcomes suitable to demonstrate its perfection. To this profile must be added the need to coordinate subjective alignment with the five-year municipal check introduced by Law No 4/2026: the mandatary must be able to produce, at any time during the operational period, updated agronomic documentation attesting the maintenance of the requirements declared at the authorisation stage.

As regards the incentive relationship, the Operational Rules clarify that the ‘beneficiary’ (*soggetto beneficiario*) enters into the incentive contract and must promptly communicate any variation relating to the installation or to the beneficiary; in the case of an ATI, that subject is the mandatary. The constitutive deed, the Agency Arrangement, and the internal regulation must align powers, flows, and responsibilities with exclusive representation and with the documentary-management obligations assumed vis-à-vis the Operator. The GSE verifies requirements at multiple stages (participation, post-commercial operation review, ongoing maintenance), and the applicant submits self-declarations under Presidential Decree No 445/2000. Any relevant change in the participating entities must be communicated promptly, together with the updated documentation required. For ATIs, the Operational Rules expressly include, among the minimum contents of the constitutive deed, that expenditure reporting and monitoring of progress are entrusted to the mandatary: this requires the internal regulation to govern information flows, the *mandanti*’s documentary obligations, and indemnities/reimbursements for breaches capable of jeopardising the entire incentive, including agricultural sanctioning risk under Article 11(8) of Legislative Decree No 190/2024, with identification of the subject responsible externally and of internal recourse obligations. This allocation of internal responsibility is also functional to ensuring continued auditability and traceability, which are structurally central in EU-derived funding and conditionality frameworks.

The ATI and the Project Company (SPV): Pre-Corporate Function and Managing the Transition

From a company-law perspective, the project company used in Italian agrivoltaic practice will normally take the form of a limited-liability vehicle, typically an S.r.l. and, in larger transactions, an S.p.A. This preference is explained not merely by organisational convenience, but by the need for asset segregation, clearer governance, and a structure more compatible with external financing, risk allocation, and the concentration of project rights and obligations in a single operating entity.

In Italian agrivoltaic practice, the ATI performs an eminently pre-corporate function: it coordinates land availability, techno-agronomic design, the authorisation pathway, and the initial interactions with the incentive system, while deferring incorporation of the SPV until the project has reached the degree of legal, technical, and financial maturity required for financial close. From this perspective, the ATI–SPV transition is not a mere ‘change of container’, but an ordered sequence of acts that must preserve four continuities: (i) the title ensuring land availability and the co-existence rules; (ii) the registration/transfer of authorisation/enabling titles in the name of the subject intended to operate the installation; (iii) the incentive position (GSE contract, PNRR reporting, fulfilments and controls); (iv) the agrivoltaic qualification of the intervention, which presupposes the effective and documentable maintenance of the agricultural component also after the SPV steps in, failing which the project is exposed to the sanctioning regime under Article 11(8) of Legislative Decree No 190/2024.

As regards the first profile, land availability must be structured from the outset to be transferable or replicable in favour of the SPV, avoiding rights of use that are ‘closed’ on the grouping or clauses requiring discretionary consent at the time of substitution. The most efficient technique is to provide, in the ATI regulation and the land agreements, conditional step-in mechanisms – such as assignment of the contractual position, options, or beneficiary-substitution clauses – subject to objectively verifiable prerequisites (granting of the

authorisation title; admission/placement on the ranking list; execution of the contract; financial close). Absent such mechanisms, land availability becomes the principal bottleneck of the transition, with the risk of renegotiation at the moment of maximum financial exposure.

In this framework, the minimum six-year term with automatic renewal provided by Article 5(2-bis) of Decree-Law No 63/2024 for superficies agreements relating to renewable-energy installations in suitable areas is also relevant: the SPV's substitution must be planned consistently with that constraint, avoiding discontinuities in the land title that are relevant for agrivoltaic qualification.

As regards the second profile, the SPV's substitution must be planned in accordance with the rules of the authorisation procedure, in a manner coordinated with updating the position vis-à-vis the GSE. The incorporation of the project company (SPV) cannot be treated as a merely contingent event: if the industrial model envisages an SPV, the ATI must incorporate, *ab origine*, procedural cooperation duties and documentary-production obligations, so as to render the substitution administratively manageable and temporally synchronisable. It remains understood that the ATI-SPV sequence may entail indirect-tax issues and VAT/registration implications, to be assessed in parallel with authorisation and incentive planning.

As regards the third profile, the incentive position requires a design choice already at the drafting stage. The first alternative is to maintain the ATI as the beneficiary throughout the entire incentive period, configuring the SPV as an operational vehicle (EPC/O&M or contractual manager) without transferring incentive entitlement: this solution reduces frictions vis-à-vis the GSE, but requires a particularly robust ATI regulation as to the mandatary's powers, information flows, and internal responsibilities. The second alternative is to provide for the SPV's substitution as holder of incentive entitlement: a solution often preferred for bankability reasons, but to be managed as a relevant event vis-à-vis the GSE and with a contractual 'package' already prepared to transfer in an orderly manner the relationships from the development phase to the vehicle, avoiding improper novations and authorisation standstills. Under both alternatives, the transition must expressly contemplate the transfer – or continuity – of obligations safeguarding the agricultural component: the PLV statement attested by a qualified professional, the cropping plan, and agronomic documentation cannot remain with the ATI if the SPV becomes the subject responsible vis-à-vis the GSE and vis-à-vis the Municipality for the five-year check.

Designed in these terms, the ATI-SPV transition becomes a lever of legal efficiency: it reduces renegotiation costs, limits the risk of discontinuities in the holding of titles, and allows financiers to be presented with an arrangement consistent with PNRR/GSE obligations, including those relating to changes in the participating entities and to the traceability of fulfilments. The premise is that the ATI is constructed, from the development stage, as a structure 'transferable by design', rather than by subsequent renegotiation. Within the post-Law No 4/2026 framework, this also entails that the structure be 'agriculturally sustainable by design': crop continuity cannot be left to subsequent renegotiations between the ATI and the SPV, but must be secured through pre-constituted contractual obligations, transferable to the vehicle and externally verifiable throughout the entire operational period.

Conclusions

Residual Critical Issues and Perspectives: From the ATI ‘Mentioned’ in the Guidelines to Contractual Standardisation of the Energy-Agriculture Model

The analysis, however, shows that the decisive issue is not the abstract admissibility of the ATI, but the contract’s capacity to sustain – coherently and over time – the authorisation pathway, the PNRR/GSE incentive framework, and the increasingly restrictive discipline governing ground-mounted photovoltaic installations on agricultural land. Three residual frictions remain central to legal robustness and project bankability: (i) the stability of the agricultural component as a substantive requirement; (ii) the governance of changes in the participating entities; and (iii) alignment between the contractual arrangement, locational constraints, and the compliance obligations embedded in the incentive system.

First, the effective persistence of agriculture within the project’s ordinary functioning is no longer merely a contractual vulnerability. As shown in §§5 and 7, Law No 4/2026 has transformed the agricultural component into an explicit sanctioning risk: it is not a formal add-on, but a functional prerequisite of agrivoltaic qualification. Contractual practice must therefore move beyond generic cooperation clauses and incorporate qualified agricultural obligations (cropping plan or management plan, minimum standards, reporting, and dedicated remedies), coupled with a verification system enabling the *mandataria* to demonstrate continuity and coherence of agricultural activity throughout the incentive horizon and to respond to the five-year municipal check introduced by the same law. From a bankability perspective, the ‘agricultural’ obligation must be treated as an essential obligation and safeguarded through continuity tools (operational substitution/step-in) comparable, in intensity, to those ordinarily deployed for the plant’s O&M.

Second, changes in the participating entities – most notably the ATI–SPV transition, which is standard practice – must be governed as a structural feature of project design. Implementing rules require that such changes do not generate discontinuities (i) in the position vis-à-vis the GSE, (ii) in the registration and holding of authorisation titles, and (iii) in land availability and, as clarified in §9, in the agrivoltaic qualification of the intervention.

The resulting methodological rule is that the project must be ‘transferable’ by design, not by subsequent renegotiation, through conditional step-in/substitution clauses and procedural cooperation obligations (Colacicco, 2024; Consiglio di Stato, 2021; Consiglio di Stato, 2022; Consiglio di Stato, 2006). In bankability terms, the key question is not the theoretical permissibility of modifications, but whether the contractual arrangement can neutralise participant-default risk and prevent internal criticalities from translating into the loss or suspension of the incentive. The informational and documentary duties vis-à-vis the GSE, and the concentration of powers and responsibilities in the *mandataria*, have been addressed in §§7 and 8. Importantly, subjective alignment cannot be confined to the incentive relationship: for planning and landscape purposes, the permitting title (single authorisation/PAUR and related consents, including landscape ones) must, in any event, be held by an identified applicant/title-holder (as a rule, the *mandataria* or the SPV), and the ATI–SPV transition requires *ex ante* planning of transfers and substitutions in accordance with procedural rules that remain distinct from those governing the incentive contract.

Third, the locational constraint – often underestimated in sector-specific contracting – emerges as a structural risk factor. The repeal of Article 20(1-bis) of Legislative Decree No 199/2021 and its replacement by Article 11-bis of Legislative Decree No 190/2024 (Testo

Unico FER), as amended by Law No 4/2026, introduce a quota-based mechanism: between 0.8% and 3% of the regional utilised agricultural area (SAU) may qualify as suitable, and surfaces already affected by agrivoltaic installations are included in the computation. As a result, residual availability of suitable agricultural surfaces progressively shrinks as installations are developed, with immediate implications for *ex ante* verification and for the reallocation of development costs where the regional quota becomes saturated. This is compounded by territorially driven regulatory risk, namely the potential introduction of additional regional requirements for access to enabling titles, whose practical sustainability is not self-evident and must be integrated into change control. Contractually, project-modification governance cannot remain implicit: parties should distinguish between variants manageable within the same procedure/title and changes capable of triggering a *de novo* restart of proceedings or the need for new titles. Finally, transitional rules require particular care: for proceedings already initiated as of the entry into force of Decree-Law No 175/2025, where the completeness check of the application has already been performed, the previous regime continues to apply – making the correct qualification of procedural status a prerequisite for identifying the applicable legal framework

Against this background, the most concrete forward-looking perspective is contractual standardisation of the energy–agriculture model. Standardisation should not be understood as homogenising projects, but as constructing a replicable documentary and clause-based core capable of reducing transaction costs and, above all, the risk of misalignment between the private arrangement, authorisation titles, and incentive entitlement. Three channels appear convergent. The first is standardisation induced by the incentive system itself, through documentary checklists, templates, and minimum contents required by the Operational Rules and by the GSE’s assessment practices, complemented – within the post–Law No 4/2026 framework – by the PLV statement attested by a qualified professional as a structural element of the project file. The second is market-driven standardisation, shaped by financiers’ term sheets and bankability requirements (risk allocation, swift remedies, step-in, and traceability of flows and evidence), which tends to transform the ATI regulation and land agreements into a genuine covenant package. The third is professional standardisation, driven by notarial and contractual practice (especially regarding land availability and transferability/replicability in the transition towards an SPV) and, more broadly, by sectoral soft-law instruments (templates, model clauses, and guidance lines). In comparative terms, this standardisation also operates as a form of ‘compliance-by-design’, consistent with EU-derived accountability logics for publicly supported projects, where contractual architecture becomes part of the evidentiary infrastructure required to demonstrate continued fulfilment of eligibility conditions.

On this basis, the minimum contractual content reconstructed in §7 should be read not as a descriptive checklist, but as the operational threshold for a sector-specific model capable of making the agrivoltaic ATI not merely admissible, but predictably manageable and financeable across permitting, incentive, and funding phases. In this sense, the ATI does not emerge as an abstractly superior form of cooperation, but as the organisational model most functionally suited to the development and authorisation phase of Italian agrivoltaic projects, within a broader legal architecture that may subsequently evolve towards more structured vehicles for long-term operation and financing.

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