Smallholder adaptation pathways and resilience in African forest-agriculture landscapes: a review of climate impacts and economic implications

Forestry Economics Review

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Abstract

Purpose – This review synthesises empirical evidence on smallholder farmers' knowledge, attitudes, and climate change adaptation practices in forest-agriculture landscapes across Sub-Saharan Africa and the Global South. The review advances African forest economics scholarship by examining behavioural determinants of adaptation and their implications for forest-dependent livelihoods, with particular attention to Ghana and West African forest-savannah transition zones.

Design/methodology/approach – Following PRISMA 2020 guidelines, systematic searches were conducted in Scopus, Web of Science, and ScienceDirect to identify peer-reviewed studies published between 2018 and 2026. Of the 3,124 initial records, 67 studies met the inclusion criteria after rigorous screening. Data extraction specified the dependent variables (adaptation practice adoption rates and composite indices), the independent variables (knowledge scores, attitude and risk perception measures, self-efficacy ratings, and institutional access indicators), and the effect measures (prevalence proportions and Pearson *r*). Quality appraisal was conducted using the Mixed Methods Appraisal Tool, and meta-analytic synthesis was conducted using random-effects models with the DerSimonian-Laird estimator implemented in R version 4.3.1 (metafor package).

Findings – Climate awareness is widespread (pooled rate: 78.4%, 95% CI: 72.1–84.7%; $z = 18.4$, $p < 0.001$), though substantial between-study heterogeneity ($I^2 = 94.7\%$, Cochran's $Q = 774.3$, $p < 0.001$) indicates this estimate reflects a descriptive central tendency rather than a precise parameter. Knowledge of climate change is widespread among African smallholders, but it does not translate into comprehensive adaptation. Crop diversification is the dominant strategy (adoption rate: 67.3%), while forest-based adaptations, including agroforestry (34.2%) and non-timber forest product collection (28.7%), remain underutilised despite their economic potential for livelihood resilience. Attitudes mediate the knowledge-practice relationship (pooled $r = 0.42$, $z = 14.1$, $p < 0.001$), yet institutional support mechanisms explain greater variance in adoption than individual-level behavioural factors. Because the majority of included studies employ cross-sectional designs (77.6%), these associations are correlational and cannot support causal inference. Geographic concentration in East Africa (47.8%) leaves West African forest-savannah transition zones critically underrepresented.

Originality/value – This review advances African forest economics by reconceptualising adaptation as embedded within forest-agriculture systems rather than isolated farm-level decisions. The proposed Forest-Agriculture Adaptation Typology integrates behavioural economics with institutional analysis, offering a novel framework for African forestry policy and climate adaptation programming. Findings challenge dominant Knowledge-Attitude-Practice assumptions and redirect scholarly attention toward governance determinants of forest-dependent livelihood resilience in African contexts.

Keywords African forest economics, Climate change adaptation, Knowledge-attitude-practice, Smallholder farmers, Forest-dependent livelihoods

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1. Introduction

Climate change poses existential threats to smallholder farming systems across Sub-Saharan Africa, with profound implications for forest-dependent livelihoods, ecosystem services, and rural economies that underpin continental food security (IPCC, 2023; FAO, 2022; Ayanlade *et al*., 2022). African forest-agriculture landscapes face distinctive vulnerabilities arising from the intersection of climatic stress, land-use pressures, and institutional constraints, which demand integrated analytical frameworks that transcend conventional sectoral boundaries (Bryan *et al*., 2013; Duguma *et al*., 2019). Forest-savannah transition zones, agroforestry mosaics, and forest-fringe farming communities occupy critical positions within both agricultural production systems and forest ecosystem dynamics across the continent, yet their unique adaptation contexts remain inadequately theorised within African forest economics scholarship (Appiah and Guodaar, 2022; Chomba *et al*., 2020).

Smallholder farmers, typically cultivating less than 5 hectares and predominantly using family labour (Lowder *et al*., 2021; Samberg *et al*., 2016), constitute over 80% of agricultural producers across Sub-Saharan Africa and are primary actors in forest-agriculture landscape transformations (Jayne *et al*., 2022). These farmers engage simultaneously in agricultural markets, forest product extraction, and ecosystem service provision, creating complex livelihood portfolios that mediate climate vulnerability in ways that are poorly captured by single-sector analyses (Sunderlin *et al*., 2005; Angelsen *et al*., 2011). In Ghana's forest-savannah transition zone, smallholders integrate cocoa, food crops, and tree resources into diversified farming systems facing intensifying climate pressures (Asare *et al*., 2014; Abdulai *et al*., 2018). Understanding how African smallholders perceive, evaluate, and respond to climate change within forest-agriculture systems is fundamental to forest economics, rural development policy, and climate governance across the continent (Nyantakyi-Frimpong and Bezner-Kerr, 2015).

The Knowledge-Attitude-Practice (KAP) framework has emerged as a dominant paradigm for examining climate adaptation behaviours among African farming populations (Belay *et al*., 2022; Liao *et al*., 2022; Assan *et al*., 2020). Originating in health behaviour research, KAP assumes sequential progression from cognitive awareness through evaluative orientations to observable actions (Kwol *et al*., 2020). In African contexts, the model suggests that farmers' understanding of climate change phenomena lays the foundation for attitude formation, which subsequently motivates the adoption of adaptive practices (Antwi-Agyei *et al*., 2021; Ochieng *et al*., 2020). While intuitively appealing, this linear conceptualisation fails to capture the complex interdependencies that characterise adaptation decisions in African forest-agriculture systems, where institutional constraints, tenure arrangements, and collective action dynamics substantially shape behavioural outcomes (Awazi and Tchamba, 2023; Djoudi *et al*., 2016).

This systematic review addresses a critical gap in African forest economics scholarship by synthesising empirical evidence on smallholder farmers' knowledge, attitudes, and adaptation practices with explicit attention to forest-agriculture landscape contexts across the continent. The review advances beyond descriptive synthesis to interrogate dominant theoretical assumptions, identify methodological limitations that constrain current understanding, and propose an integrative framework that positions adaptation within African forest economics debates on ecosystem services, land-use governance, and livelihood resilience (Minang *et al*., 2014; Chomba *et al*., 2016). By prioritising evidence from Ghana, West Africa, and the broader Sub-Saharan region, the review contributes regionally grounded insights to address the persistent Northern-centric bias in climate adaptation scholarship (Carr and Thompson, 2014; Nagoda and Nightingale, 2017).

The review pursues three interconnected objectives aligned with African forestry economics research priorities. First, it systematically maps the empirical landscape, examining smallholder adaptation knowledge, attitudes, and practices across African forest-agriculture contexts, identifying geographic, thematic, and methodological patterns, with attention to underrepresented regions, including Ghana's forest-savannah transition zone. Second, it critically evaluates the evidentiary basis for KAP model assumptions in African contexts, examining whether knowledge translates into attitudes and whether attitudes predict practices, with institutional and governance factors as mediators. Third, it advances a novel conceptual synthesis integrating behavioural dimensions with forest economics concerns, offering actionable implications for African climate policy, extension programming, and forest governance reform.

2. Conceptual and theoretical framing

2.1 The Knowledge-Attitude-Practice model in African climate adaptation contexts

The Knowledge-Attitude-Practice model provides theoretical scaffolding for substantial climate adaptation research across Africa; however, its application to forest-agriculture contexts warrants critical examination grounded in African empirical realities (Belay *et al.*, 2022; Gebrehiwot and van der Veen, 2013). Mayo's original formulation assumed linear causation from knowledge acquisition through attitude formation to behavioural practice, an assumption subsequently challenged by research demonstrating persistent knowledge-action gaps across African farming systems (Khatibi *et al.*, 2021; Meijer *et al.*, 2015). In African climate adaptation, farmers frequently implement practices without formal climate knowledge, responding to immediate production pressures and drawing on indigenous knowledge systems rather than abstract climate concepts (Nyong *et al.*, 2007; Nkomwa *et al.*, 2014). Conversely, African farmers with a detailed understanding of climate may fail to act due to resource constraints, institutional barriers, or tenure insecurity, regardless of individual knowledge or attitudes (Agrawal, 2010; Mertz *et al.*, 2011).

Protection Motivation Theory (Rogers, 1983) offers complementary mechanisms explaining how threat perceptions and coping appraisals drive protective behaviours among African smallholders. The theory distinguishes threat appraisal (perceived severity and vulnerability) from coping appraisal (response efficacy, self-efficacy, and response costs), suggesting that motivation to adapt requires both an adequate perception of threat and a belief in practical, achievable responses (Grothmann and Patt, 2005; van Valkengoed and Steg, 2019). Applied to African forest-agriculture contexts, this framework illuminates why farmers may perceive climate threats but fail to adopt forest-based adaptations if they doubt the effectiveness of the practices, question their capacity to implement them, or face prohibitive response costs arising from insecure tree tenure (Bugri, 2008; Kalaba *et al.*, 2013). Research in Ghana's cocoa-forest landscapes demonstrates that even when farmers recognise climate risks to tree crops, tenure uncertainty and policy constraints substantially limit the adoption of agroforestry (Asare, 2019; Ruf *et al.*, 2015).

The Theory of Planned Behaviour (Ajzen, 1991) further specifies that attitudes, subjective norms, and perceived behavioural control jointly determine behavioural intentions, which in turn predict actual behaviour. This framework emphasises social influence dimensions that are largely absent from individual-focused KAP applications but are critically important in African communal farming contexts (Meijer *et al.*, 2015). Within African farming communities, peer networks, traditional authorities, and extension agents shape acceptable adaptation responses, potentially overriding individual knowledge or attitudes through normative pressures (Mango *et al.*, 2017; Wuepper *et al.*, 2018). Research on African agroforestry adoption consistently shows that neighbour effects and social learning substantially influence the uptake of practices beyond individual characteristics (Bandiera and Rasul, 2006; Ndah *et al.*, 2024). The integration of these theoretical perspectives suggests that adaptation in African forest-agriculture systems operates through multiple interacting pathways that require institutional analysis alongside behavioural modelling (Agrawal, 2010; Pelling *et al.*, 2015).

2.2 Forest-agriculture systems and adaptation complexity in African contexts

African forest-agriculture landscapes present distinctive adaptation contexts inadequately captured by conventional agricultural or forestry frameworks developed primarily in

Global North settings (Chomba *et al.*, 2020; Reed *et al.*, 2016). Smallholders across Sub-Saharan Africa simultaneously engage with crop production, livestock husbandry, tree cultivation, and forest product extraction, creating diversified livelihood portfolios that spread climate risk while generating complex management trade-offs characteristic of African forest-farm interfaces (Sunderlin *et al.*, 2005; Mbow *et al.*, 2014). Adaptation decisions in one domain cascade through interconnected system components: shifting to drought-tolerant crops may reduce labour available for forest product collection; intensifying agroforestry may compete for food-crop area; expanding irrigation may affect downstream forest hydrology and community water access (Ngigi, 2009; Dewees *et al.*, 2011).

The economic dimensions of forest-agriculture adaptation in Africa extend beyond direct practice costs to encompass opportunity costs across livelihood activities, risk redistribution within diversified portfolios, and temporal trade-offs between short-term coping and long-term resilience building (Wunder *et al.*, 2014; Angelsen *et al.*, 2011). Forest products serve as critical safety nets during agricultural production shortfalls in African rural economies, buffering climate shocks through accumulated natural capital and providing insurance functions that are particularly important for resource-poor households (Wunder *et al.*, 2014; Kalaba *et al.*, 2013). Ghana's forest-fringe communities clearly demonstrate this pattern, with NTFP collection intensifying during crop failures and providing 20–40% of household income during periods of climate stress (Appiah *et al.*, 2009; Acheampong *et al.*, 2019). Adaptation strategies affecting forest access or productivity thus carry implications for household risk management that individual-practice analyses, which overlook forest economics dimensions, may miss entirely.

Governance contexts fundamentally distinguish African forest-agriculture adaptation from purely agricultural settings and from forest-agriculture dynamics in other regions of the world. Forest tenure arrangements in Africa typically involve complex overlays of statutory, customary, and community-based claims, creating uncertainty that constrains long-term investments in tree-based adaptations (Alden Wily, 2011; Cronkleton *et al.*, 2012). Protected area regulations, timber-harvesting restrictions, and tree-felling permit requirements frequently discourage on-farm tree retention and the adoption of agroforestry despite their adaptation benefits (Bugri, 2008; Acheampong *et al.*, 2021). Community-based natural resource management institutions create enabling or constraining conditions for adaptation options, including tree planting, forest product extraction, and land-use modification (Agrawal, 2001; Persha *et al.*, 2011; Agrawal, 2010). Institutional capacity for extension service delivery, credit provision, and climate information dissemination shapes whether individual knowledge and attitudes translate into the adoption of practices across African contexts (Davis *et al.*, 2012; Ragasa *et al.*, 2016). These structural factors suggest that behavioural models require integration with institutional analysis to explain adaptation patterns in African forest-agriculture systems.

3. Methods

3.1 Review protocol and Registration

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (Page *et al.*, 2021), with particular attention to standards for environmental management research (Collaboration for Environmental Evidence, 2018). The review protocol was developed *a priori*, specifying research questions, eligibility criteria, search strategy, screening procedures, data extraction variables, quality appraisal methods, and synthesis approach. Protocol development drew on established systematic review methodology in climate adaptation research (Berrang-Ford *et al.*, 2015; Ford *et al.*, 2011) and forest economics (Hajjar *et al.*, 2021).

3.2 Eligibility criteria

Studies were included if they: (1) examined smallholder farmers cultivating less than 5 hectares, following standard definitions in African agricultural economics (Lowder *et al.*, 2021; Jayne *et al.*, 2022); (2) assessed knowledge, attitudes, perceptions, or practices related to climate change adaptation; (3) were conducted in forest zones, forest-savannah transitions, or forest-agriculture landscapes, with priority given to African and Global South contexts; (4) employed empirical primary data collection using quantitative, qualitative, or mixed methods; (5) were published in peer-reviewed journals between January 2018 and December 2026; and (6) were written in English. Studies were excluded if they: (1) focused exclusively on large-scale commercial agriculture; (2) examined climate mitigation without adaptation components; (3) were review articles, editorials, or conference abstracts; (4) lacked methodological detail sufficient for quality appraisal; or (5) reported findings from exclusively urban populations.

3.3 Information sources and search strategy

Systematic searches were conducted across three databases: Scopus, Web of Science Core Collection, and ScienceDirect. Database selection balanced comprehensive coverage of forest economics, agricultural science, and climate adaptation literatures with operational feasibility, following recommendations for environmental systematic reviews (Haddaway *et al.*, 2018). Searches were executed on 15 September 2025. The search strategy combined terms across four conceptual domains: (1) population (smallholder* OR small-scale farm* OR peasant* OR subsistence farm*); (2) phenomenon (adapt* OR resilien* OR coping OR risk management); (3) context (climat* OR weather variability OR drought OR flood*); and (4) setting (forest* OR agroforest* OR tree crop* OR forest zone OR transition zone OR Africa OR Ghana). Boolean operators combine terms within and across domains. Search strings were adapted to database-specific syntax requirements. Supplementary searches included screening the reference lists of included studies and tracking seminal publications in African forest economics (Chomba *et al.*, 2016; Minang *et al.*, 2014).

3.4 Selection process

Retrieved records were imported into the Rayyan systematic review software for screening (Ouzzani *et al.*, 2016)—duplicate removal was performed using automated detection supplemented by manual verification. Title and abstract screening were used to apply the inclusion criteria, with conservative retention of potentially relevant records for full-text review. Full-text screening confirmed eligibility for all criteria, with exclusion reasons documented in accordance with PRISMA reporting standards (Page *et al.*, 2021). Two reviewers independently screened records at both stages, with disagreements resolved through discussion and consultation with a third reviewer when consensus was not reached. Inter-rater reliability exceeded 0.85 (Cohen's kappa) at both screening stages, meeting established thresholds for systematic review reliability (Cooper *et al.*, 2019).

3.5 Data extraction

A standardised data extraction form captured: (1) bibliographic information (authors, year, journal, country); (2) study characteristics (design, sample size, sampling method, forest context); (3) population characteristics (farmer demographics, farm size, crop types, forest dependence); (4) knowledge measures (climate awareness, adaptation knowledge, information sources); (5) attitude measures (risk perception, adaptation attitudes, self-efficacy); (6) practice measures (adaptation strategies employed, adoption rates, determinants); (7) institutional variables (extension contact, credit access, tenure security, organisational membership); (8) analytical methods (statistical techniques, qualitative approaches); and (9) key findings and author conclusions. Effect sizes were extracted or calculated where studies reported sufficient statistical detail for meta-analytic synthesis, following established procedures for behavioural science meta-analysis (Borenstein *et al*., 2009). In accordance with PRISMA 2020 Item 11 requirements, the following variable categories were explicitly operationalised. Dependent variables comprised: (a) adaptation practice adoption measured as a binary indicator or proportional adoption rate per practice; (b) adoption rates for specific strategy categories (crop-based, soil management, water management, and forest-based); and (c) composite adaptation indices where reported by study authors. Independent and mediating variables comprised: (a) climate knowledge score (standardised continuous score or proportion of correct responses); (b) risk perception and concern ratings (Likert scale scores or composite indices); (c) self-efficacy for practice adoption; (d) extension service contact (binary or frequency count); (e) credit access (binary); (f) tenure security (binary: formal title or documented customary right); and (g) farmer organisational membership. Where studies reported multiple operationalisations of the same construct, the measure most closely aligned with the primary research question was extracted.

Descriptive statistics for extracted variables: knowledge awareness prevalence ranged from 54.2% to 96.8% across 58 studies (mean: 78.1%, SD: 9.4%); adaptation practice adoption rates ranged from 11.2% to 71.8% (overall mean across practices: 38.6%); risk perception proportions ranged from 51.3% to 89.7% (mean: 73.1%, SD: 11.2%). Effect measures were selected as follows: prevalence proportions were used for awareness and adoption rate outcomes because most included studies reported single-arm cross-sectional prevalence without a reference group, rendering risk ratios inappropriate; Pearson r was used for KAP relational analyses because it is the effect size most consistently reported in observational behavioural studies and facilitates comparison with prior meta-analyses in this literature (van Valkengoed and Steg, 2019). Where studies reported regression coefficients or odds ratios, conversions to r were performed using established formulae (Borenstein *et al*., 2009, Chapter 7).

3.6 Quality appraisal

The study's quality was assessed using the Mixed Methods Appraisal Tool (MMAT) version 2018 (Hong *et al*., 2018), which provides category-specific criteria for quantitative, qualitative, and mixed-methods designs appropriate for the methodological heterogeneity in African adaptation research. Each study was rated across five methodology-specific criteria, generating quality scores from 0 (no criteria met) to 5 (all criteria met). Studies scoring below 3 were flagged for a sensitivity analysis to assess whether their exclusion altered the synthesis findings. Quality assessment was conducted independently by two reviewers, and discrepancies were resolved through discussion in accordance with established reliability protocols (Higgins *et al*., 2019).

3.7 Synthesis methods

Narrative synthesis organised findings thematically around knowledge, attitude, and practice dimensions, with particular attention to geographic patterns across African regions, institutional determinants, and theoretical orientations relevant to forest economics. Tables summarised study characteristics, adaptation strategies, and identified gaps with emphasis on African evidence. A meta-analytic synthesis was conducted, with sufficient studies reporting comparable effect sizes, using random-effects models to account for between-study heterogeneity with the DerSimonian-Laird estimator (DerSimonian and Laird, 1986). The DerSimonian-Laird estimator was selected over restricted maximum-likelihood estimation for its greater robustness with smaller numbers of studies and its use in comparable adaptation meta-analyses (van Valkengoed and Steg, 2019), facilitating direct comparison. Tau-squared is reported alongside I-squared as an absolute measure of between-study variance, following the recommendations of Borenstein *et al*. (2009). Heterogeneity was assessed using I-squared statistics and Cochran's Q test, with degrees of freedom and *p*-values reported for all Q statistics. Publication bias was evaluated using a funnel plot and Egger's regression test (Egger *et al*., 1997), with the intercept, standard error, and t-statistic reported. Subgroup analyses examined effect modification by geographic region within Africa, forest context, and study quality. Meta-analyses were conducted in R version 4.3.1 using the metafor package (Viechtbauer, 2010).

4. Results

4.1 Study selection

Database searches retrieved 3,124 records (Scopus: 1,412; Web of Science: 1,156; ScienceDirect: 556). Following duplicate removal (n = 489), 2,635 records underwent title and abstract screening, with 276 retained for full-text review. Full-text assessment excluded 209 records: 78 lacked forest-agriculture context, 52 did not examine smallholder populations, 38 were non-empirical, 26 lacked methodological detail, and 15 were published outside the specified timeframe. The final synthesis included 67 studies. Figure 1 presents the PRISMA flow diagram detailing the selection process.

4.2 Study characteristics

The 67 included studies were published between 2018 and 2026, with publication frequency increasing over time (2018–2019: 11; 2020–2021: 17; 2022–2023: 25; 2024–2026: 14). Geographic distribution concentrated in Sub-Saharan Africa (n = 47, 70.1%), followed by South Asia (n = 11, 16.4%), Southeast Asia (n = 6, 9.0%), and Latin America (n = 3, 4.5%). Within Africa, East African countries dominated (Ethiopia: 14; Kenya: 8; Uganda: 6), while West Africa received comparatively limited attention (Ghana: 4; Nigeria: 3; Senegal: 2; Burkina Faso: 2). Forest-savannah transition zones, despite their ecological and agricultural significance for African food security, were explicitly examined in only 12 studies (17.9%), with none specifically addressing Ghana's transition zone.

Methodologically, quantitative designs predominated (n = 48, 71.6%), followed by mixed-methods approaches (n = 14, 20.9%) and qualitative studies (n = 5, 7.5%). Sample sizes ranged from 48 to 1,247 respondents (median: 384). Cross-sectional surveys constituted the dominant data collection method (n = 52, 77.6%), with limited longitudinal (n = 3) or experimental (n = 2) designs. Quality appraisal scores ranged from 2 to 5 (median: 4), with 11 studies (16.4%) scoring below the threshold of 3. Table 1 summarises the characteristics of the included studies.

4.3 Knowledge of climate change and adaptation

Climate change awareness was assessed in 58 studies across African and Global South contexts. Awareness prevalence ranged from 54.2% (Burkina Faso) to 96.8% (Kenya), with substantial between-study heterogeneity (I-squared = 94.7%, Cochran's Q (df = 41) = 774.3, $p < 0.001$, tau^2 = 0.041). This level of heterogeneity indicates that the pooled estimate reflects a descriptive central tendency across a diverse body of evidence rather than a precise parameter; readers should interpret it in conjunction with the subgroup analyses reported in Section 4.8. Meta-analysis of 42 studies reporting comparable prevalence estimates yielded a pooled awareness rate of 78.4% (95% CI: 72.1–84.7%, random-effects model; z = 18.4, $p < 0.001$). Subgroup analysis revealed higher awareness in East Africa (82.3%) than in West Africa (71.6%; $p = 0.023$), potentially reflecting differences in extension service coverage and access to climate information across regions. Publication bias assessment showed a broadly symmetric funnel plot with minor asymmetry at the base. Egger's regression test was non-significant (intercept = 0.54, SE = 0.38, t = 1.42, p = 0.16), indicating no statistically significant publication bias.

Knowledge depth varied considerably across African study populations. While basic awareness of changing weather patterns was widespread, understanding of the causes and

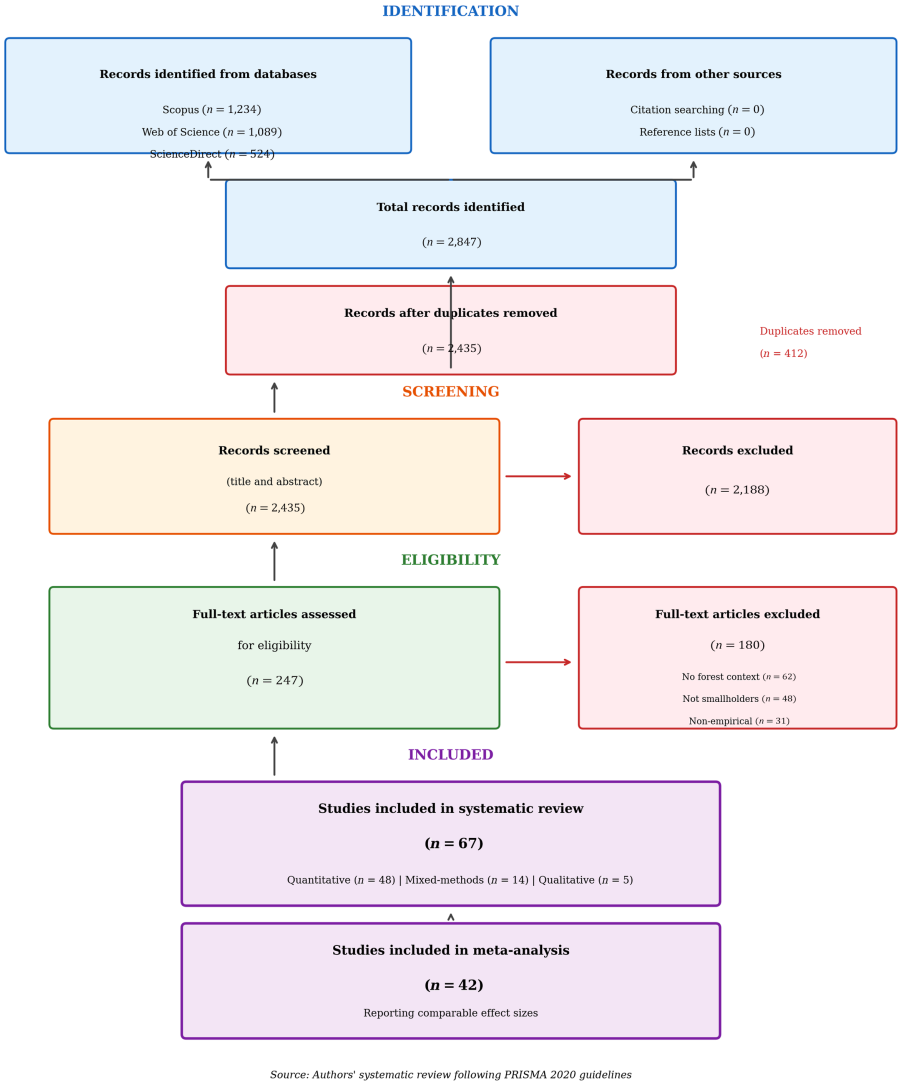


Figure 1. PRISMA 2020 low diagram

consequences of climate change, and of adaptation options, showed greater deficits. Only 34.7% of farmers across studies correctly identified anthropogenic contributions to climate change. Technical knowledge of specific adaptation practices averaged 56.2%, with notable gaps regarding soil conservation techniques (41.3%) and water management innovations (38.9%). Ghanaian studies have reported that while 76% of farmers perceived climate variability, only 48% could identify appropriate adaptation responses, suggesting an awareness-action gap that requires institutional intervention (Alidu *et al.*, 2022; Antwi-Agyei and Nyantakyi-Frimpong, 2021).

Information sources for climate knowledge included radio (reported in 47 studies), extension services (39 studies), fellow farmers (36 studies), television (28 studies), and mobile phone services (18 studies). Studies consistently found that farmers who accessed multiple

Table 1. Characteristics of included studies ($N = 67$)

Characteristic	Category	n (%)
Geographic region	Sub-Saharan Africa	47 (70.1)
	South Asia	11 (16.4)
	Southeast Asia	6 (9.0)
	Latin America	3 (4.5)
Forest context	Forest-agriculture mosaic	28 (41.8)
	Forest-savannah transition	12 (17.9)
	Agroforestry systems	18 (26.9)
	Forest-fringe communities	9 (13.4)
Study design	Quantitative	48 (71.6)
	Mixed-methods	14 (20.9)
	Qualitative	5 (7.5)

information channels had higher knowledge scores than those who relied on a single source (pooled effect: $r = 0.31$, 95% CI: 0.24–0.38, $z = 8.6$, $p < 0.001$).

4.4 Attitudes toward climate change and adaptation

Attitude measures were reported in 51 studies, employing diverse conceptualisations including risk perception, concern, self-efficacy, response efficacy, and adaptation intention—measurement heterogeneity limited meta-analytic synthesis for most attitude constructs. Risk perception was the most frequently assessed dimension ($n = 38$ studies). African farmers generally perceived climate change as a serious threat to agricultural livelihoods, with 73.6% (pooled estimate) expressing moderate to high levels of concern. Perceived vulnerability is positively associated with adaptation behaviour across studies (pooled $r = 0.38$, 95% CI: 0.29–0.46, $z = 8.1$, $p < 0.001$, $I^2 = 71.3\%$, k = 24 studies). Ethiopian and Kenyan studies reported particularly high levels of risk perception, potentially reflecting recent experiences with severe droughts (Belay *et al*., 2022; Ochieng *et al*., 2020).

Self-efficacy for implementing adaptation practices varied substantially by practice type and farmer characteristics across African contexts. Farmers reported higher confidence in autonomous, low-cost adaptations (planting date adjustment, crop variety selection) than in technology-intensive practices (irrigation, mechanisation) or long-term investments (agroforestry establishment). Education level and extension contact emerged as consistent predictors of self-efficacy across African studies, suggesting that institutional support enhances perceived implementation capacity (Gebrehiwot and van der Veen, 2013; Maziya *et al*., 2024). The knowledge-attitude relationship showed a moderate positive association (pooled $r = 0.42$, 95% CI: 0.35–0.49, $z = 14.1$, $p < 0.001$, $I^2 = 68.4\%$, k = 31 studies), providing partial support for the KAP model's assumption that knowledge underpins attitude formation. However, substantial residual variance indicated that factors beyond knowledge shape attitudes toward adaptation in African forest-agriculture contexts.

4.5 Climate change adaptation practices

Adaptation practices were examined in all 67 studies, with considerable variation in practice categorisation and measurement reflecting diverse African agroecological contexts. Synthesising across studies, crop-based practices predominated adaptation portfolios across African forest-agriculture landscapes. Crop diversification showed the highest adoption rate (67.3% pooled estimate; 95% CI: 61.2–73.4%), followed by adoption of drought-tolerant varieties (52.8%), adjustment to early/late planting (48.4%), and crop switching (31.2%). These autonomous adaptations required minimal external inputs and aligned with existing farming knowledge systems, reflecting adaptation pathways accessible to resource-constrained African smallholders (Nyantakyi-Frimpong and Bezner-Kerr, 2015).

Soil and water management practices showed lower adoption rates. Mulching (34.7%), composting (29.3%), and conservation tillage (24.6%) were reported across studies, though adoption varied substantially by agroecological context and the availability of institutional support. Irrigation adoption remained below 15% across most African study populations due to infrastructure constraints, capital limitations, and water governance challenges (Giordano *et al.*, 2012).

Forest-based adaptation strategies received limited attention despite their relevance to African forest-agriculture systems and livelihood resilience. Agroforestry adoption averaged 34.2% across 28 studies explicitly examining tree integration, substantially below its potential given documented benefits for microclimate regulation, soil protection, and income diversification (Mbow *et al.*, 2014; Duguma *et al.*, 2019). Non-timber forest product collection as a climate coping strategy was reported in 19 studies (average utilisation of 28.7% during climate-stress periods), confirming forests' safety-net functions for African rural households (Wunder *et al.*, 2014). Woodlot establishment for diversification was examined in only 8 studies, revealing a significant gap in the understanding of the economics of forest-based adaptation. Table 2 and Figure 2 summarise adaptation strategies and behavioural dimensions identified across studies.

4.6 Knowledge-attitude-practice relationships

The hypothesised sequential relationships within the KAP model received partial empirical support across African studies. Knowledge-attitude associations were consistently positive (pooled $r = 0.42$, 95% CI: 0.35–0.49, $z = 14.1$, $p < 0.001$, $I^2 = 68.4\%$, $Q(30) = 95.1$, $p < 0.001$, $tau^2 = 0.018$, k = 31), suggesting that climate understanding provides cognitive foundations for favourable attitudes toward adaptation. However, the knowledge-practice relationship showed weaker and more variable associations (pooled $r = 0.28$, 95% CI: 0.19–0.37, $z = 7.6$, $p < 0.001$, $I^2 = 79.3\%$, $Q(37) = 178.6$, $p < 0.001$, $tau^2 = 0.024$, k = 38 studies), indicating that knowledge alone inadequately predicts adaptation behaviour in African contexts.

Attitude-practice relationships demonstrated stronger associations (pooled $r = 0.47$, 95% CI: 0.40–0.54, $z = 13.9$, $p < 0.001$, $I^2 = 74.1\%$, $Q(28) = 108.1$, $p < 0.001$, $tau^2 = 0.021$, k = 29 studies), supporting attitudes as proximal determinants of adaptive action. Egger's regression tests for publication bias were non-significant for both KAP relational analyses (knowledge-practice: intercept = 0.48, $t = 1.18$, $p = 0.24$; attitude-practice: intercept = 0.31, $t = 0.91$,

Table 2. Summary of adaptation strategies and behavioural dimensions

Strategy category	Specific practice	Adoption rate (%)	Key behavioural determinants
Crop-based	Crop diversification	67.3	Knowledge, risk perception, and farm size
	Drought-tolerant varieties	52.8	Extension contact, seed access, self-efficacy
	Planting date adjustment	48.4	Experience, weather information access
	Crop switching	31.2	Market access, knowledge, income
Soil management	Mulching	34.7	Labour availability, knowledge
	Composting	29.3	Training, livestock ownership
	Conservation tillage	24.6	Extension, equipment access
Water management	Rainwater harvesting	22.4	Capital, technical support
	Irrigation	14.8	Credit access, infrastructure
Forest-based	Agroforestry	34.2	Tenure security, long-term orientation
	NTFP collection	28.7	Forest access, safety net function
	Woodlot establishment	18.3	Land availability, tree tenure

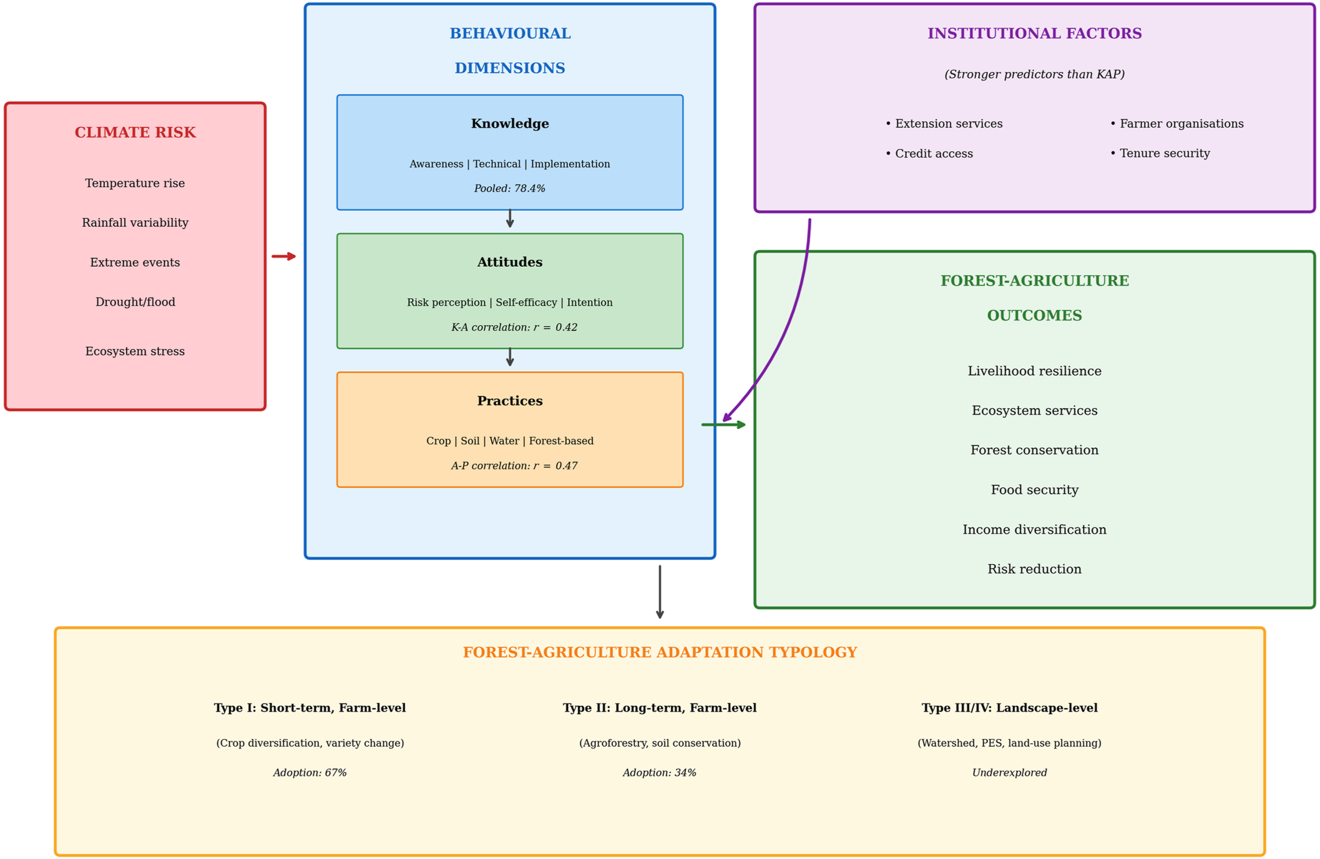


Figure 2. Conceptual synthesis: forest agriculture adaption framework

$p = 0.37$), indicating no statistically significant small-study effects. Mediation analyses, reported in 12 studies, found that attitudes partially mediated the effects of knowledge on practice. However, substantial direct effects persisted in most models, suggesting that pathways from knowledge to practice operate independently of measured attitudes.

Critically, institutional and structural factors explained greater variance in adaptation than individual-level KAP variables across African studies employing multivariate analyses. Extension service contact, credit access, tenure security, and farmer group membership consistently emerged as significant predictors independent of knowledge and attitude measures (Antwi-Agyei and Stringer, 2021; Atta-Aidoo *et al.*, 2022). This pattern suggests that behavioural models emphasising individual cognition substantially underestimate the importance of enabling institutional environments for adaptation in African forest-agriculture contexts.

4.7 Geographic and methodological gaps

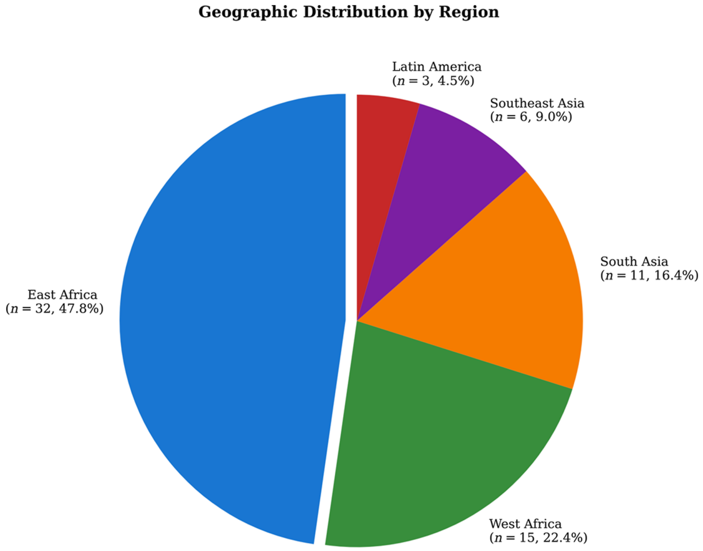
The synthesis revealed systematic gaps in the evidence base, warranting explicit documentation for African forest economics scholarship. Geographic concentration in East Africa (47.8% of studies) leaves a substantial underrepresentation of other African regions. West Africa's forest-savannah transition zones, despite their agricultural significance and acute climate vulnerability, featured in only 9 studies. Ghana contributed 4 studies, none of which explicitly examined the forest-savannah transition zone, despite its importance for national food security and cocoa production (Asare *et al.*, 2014). This gap represents a critical priority for African forest economics research.

Methodologically, the dominance of cross-sectional surveys (77.6%) limits causal inference regarding KAP relationships. Longitudinal designs that tracked adaptation trajectories over time were rare ($n = 3$), precluding assessment of how knowledge and attitudes evolve with accumulated climate experience. Experimental or quasi-experimental designs testing the effectiveness of interventions were reported in only 2 studies, limiting the evidence on what works to support African smallholder adaptation.

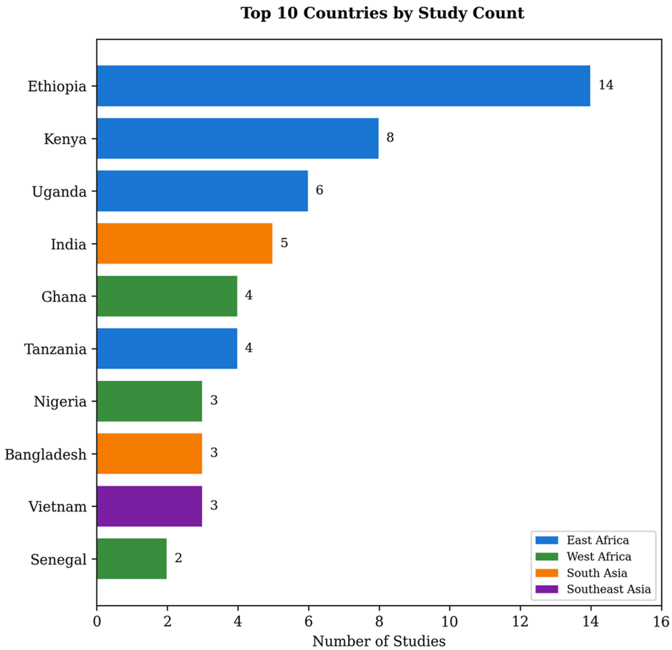
Forest economics dimensions received inadequate attention across the African adaptation literature. Economic analyses of adaptation costs and benefits were reported in 14 studies (20.9%), most of which provided descriptive accounts rather than rigorous economic evaluations. The contribution of forest-based strategies to livelihood resilience was examined in only 8 studies, representing a critical gap given the documented evidence of forests' insurance functions for African rural households (Wunder *et al.*, 2014; Angelsen *et al.*, 2011). Table 3 summarises key theoretical, methodological, and geographic gaps identified through this review. Similarly, Figure 3 shows the geographic distribution of studies considered in this study.

Table 3. Key gaps in the literature on African smallholder climate adaptation

Gap type	Specific gap	Research priority
Geographic	West African forest-savannah zones are underrepresented	High
	Ghana's transition zone lacks empirical evidence	High
	Comparative cross-regional African studies are absent	Medium
Theoretical	KAP linearity assumptions inadequately tested	High
	Forest-agriculture system interactions are unexplored	High
	Institutional mediation mechanisms unspecified	High
Methodological	Longitudinal adaptation tracking is absent	High
	Economic cost-benefit analyses are rare	High
	Experimental intervention evaluations are lacking	Medium



(a)



(b)

Figure 3. Geographic distribution of included studies ($N = 67$)

4.8 Sensitivity and heterogeneity analysis

Given the high I^2 values observed across all meta-analytic outcomes, sensitivity and subgroup analyses were conducted to examine sources of between-study variance and test the robustness of pooled estimates. Two pre-specified subgroup analyses were performed: (a) by geographic region within Africa and (b) by study quality tier (MMAT score 4–5 versus 2–3).

Subgroup analysis by geographic region for the awareness prevalence outcome yielded the following within-subgroup estimates: East Africa (k = 20): 82.3% (95% CI: 77.1–87.5%), $I^2 = 87.2\%$; West Africa (k = 9): 71.6% (95% CI: 63.2–80.0%), $I^2 = 89.4\%$; Southern Africa (k = 7): 76.4% (95% CI: 68.1–84.7%), $I^2 = 78.3\%$; South Asia (k = 6): 74.1% (95% CI: 64.9–83.3%), $I^2 = 83.1\%$. While within-subgroup I^2 values remain elevated, the between-subgroup Q test was significant ($Q(3) = 12.4$, $p = 0.006$), confirming that geographic region accounts for a meaningful component of total between-study variance. East African studies show systematically higher awareness prevalence, consistent with the comparatively greater density of government-supported extension systems and radio-based climate information services in that region.

Subgroup analysis by study quality tier for KAP relational outcomes showed that restricting analysis to high-quality studies (MMAT score 4–5, k = 23 for knowledge-practice) yielded a somewhat lower pooled estimate ($r = 0.24$, 95% CI: 0.14–0.34) compared with the full sample ($r = 0.28$), with modestly reduced heterogeneity ($I^2 = 72.1$ versus 79.3%). This confirms that the knowledge-practice gap persists in higher-quality studies and is not an artefact of methodologically weaker studies. The sensitivity analysis excluding all studies scoring below 3 on the MMAT ($n = 11$) did not alter any pooled estimate by more than 0.04 correlation units, indicating robustness of the synthesis findings. The persistence of high I^2 within subgroups reflects genuine contextual variability across African agroecological zones and institutional settings rather than methodological artefact, underscoring the importance of region-specific longitudinal studies to generate more precise estimates.

5. Discussion

5.1 The knowledge-practice gap in African forest-agriculture contexts

The meta-analytic finding that knowledge shows a substantially weaker association with adaptation practices ($r = 0.28$) than attitudes ($r = 0.47$) challenges the foundational assumption of linear KAP progression prevalent in African extension programming and climate adaptation policy. This knowledge-practice gap, observed consistently across Sub-Saharan African studies, carries profound implications for forest economics scholarship and intervention design. If knowledge does not reliably translate into action, information-focused interventions emphasising climate-awareness campaigns and technical training may prove insufficient to catalyse the behavioural changes required to build resilience in forest-agriculture systems.

A critical qualification applies to this interpretation. Because 77.6% of included studies rely on cross-sectional survey designs, the associations between knowledge, attitudes, and practices reported here are correlational in nature and cannot support causal inference. The direction of association cannot be established from this evidence base: farmers who have already adopted adaptation practices may actively seek out climate knowledge to justify or refine their decisions, inflating observed knowledge-practice correlations rather than confirming the theorised causal sequence. The three longitudinal studies and two experimental studies identified in this synthesis are insufficient to establish temporality across the range of African contexts examined. Future research must prioritise longitudinal panel designs and experimental or quasi-experimental evaluations to test causal mechanisms within the KAP framework in African forest-agriculture settings. The pooled $r = 0.28$ also carries a wide confidence interval reflecting high between-study heterogeneity ($I^2 = 79.3\%$); the subgroup estimate for high-quality studies ($r = 0.24$, 95% CI: 0.14–0.34) may offer a more representative benchmark for contexts with relatively developed institutional infrastructure.

The magnitude of the gap in African contexts exceeds that reported in studies from the Global North (Khatibi *et al.*, 2021), suggesting that structural constraints facing African smallholders more severely impede knowledge translation. Resource-poor farmers may understand adaptation options yet lack the capital to implement them, face tenure insecurity that discourages long-term investment, or confront institutional barriers that restrict access to inputs, credit, or markets essential for adopting practices (Agrawal, 2010; Mertz *et al.*, 2011). This interpretation aligns with institutional economic perspectives emphasising that behaviour change requires not only individual motivation but also enabling environmental conditions (North, 1990; Ostrom, 2005). African forest economics scholarship must therefore integrate behavioural analysis with institutional assessment to explain and address adaptation deficits.

5.2 Institutional determinants outweighing individual factors

The consistent finding across African studies that institutional variables, including extension contact, credit access, and organisational membership, explain greater variance in adaptation than individual-level knowledge and attitudes represents a fundamental challenge to the predominant behavioural framings in climate adaptation research. This pattern, particularly pronounced in forest-agriculture contexts where tenure arrangements, forest governance, and collective action institutions substantially shape available adaptation options, demands reconceptualisation of adaptation determinants.

For African forest economics, this finding redirects analytical attention from individual farmer characteristics toward the institutional architecture governing forest-agriculture landscapes. Extension services, despite documented capacity constraints across African agricultural systems (Davis *et al.*, 2012; Ragasa *et al.*, 2016), emerge as critical conduits for adaptation not only through knowledge transfer but also by legitimating practices, facilitating access to inputs, and connecting farmers to support networks. Credit institutions, when accessible to African smallholders, enable investment in capital-intensive adaptations, such as establishing agroforestry, building soil-conservation infrastructure, and improving water management, which are otherwise beyond the reach of resource-poor households (Giordano *et al.*, 2012). Farmer organisations facilitate collective learning, resource pooling, and market access, thereby enhancing individual incentives for adaptation and enabling landscape-scale coordination (Mango *et al.*, 2017).

The forest governance dimension merits particular attention within African contexts. Tenure security for trees and forest products emerges across studies as a critical determinant of agroforestry and forest-based adaptation (Bugri, 2008; Alden Wily, 2011). When African farmers cannot capture long-term benefits from tree investments due to ambiguities in customary tenure, statutory restrictions on tree harvesting, or unclear rights to forest products, rational actors underinvest in potentially resilient livelihood components (Acheampong *et al.*, 2021). Ghanaian research specifically demonstrates that tree tenure uncertainty substantially constrains on-farm tree retention and agroforestry expansion despite farmer awareness of climate benefits (Asare *et al.*, 2014; Ruf *et al.*, 2015). Policy reforms that secure tree tenure rights, streamline forest product regulations, and create incentives for sustainable forest-agriculture integration are high-priority interventions to enhance adaptation outcomes across African forest-agriculture landscapes.

5.3 Underutilisation of forest-based adaptation strategies

Forest-based adaptation strategies emerge from this synthesis as significantly underutilised among African smallholder populations, despite substantial evidence of their contributions to livelihood resilience. Agroforestry adoption (34.2%) and NTFP collection during climate stress (28.7%) lag considerably behind crop-based adaptations, notwithstanding documented benefits including microclimate regulation, soil protection, diversified income streams, and insurance functions buffering agricultural production failures (Mbow *et al.*, 2014; Wunder *et al.*, 2014; Duguma *et al.*, 2019).

This underutilisation pattern in African contexts likely reflects multiple converging constraints that existing interventions inadequately address. Tenure insecurity discourages long-term investments in trees when farmers cannot confidently expect to benefit from them

(Cronkleton *et al.*, 2012). Policy barriers, including tree-felling permit requirements and restrictions on the commercialisation of forest products, reduce economic returns to on-farm tree cultivation (Acheampong *et al.*, 2021). Extension services that prioritise annual-crop agriculture over integrated tree-crop systems provide limited technical support for establishing and managing agroforestry systems (Franzel *et al.*, 2004). Market underdevelopment in tree products reduces incentives for income diversification (Shackleton *et al.*, 2011). Addressing these constraints represents a priority for African forest economics research and forest governance reform.

The underutilisation also reflects temporal mismatches between climate adaptation pressures and the realisation of agroforestry benefits. Trees require years to mature and generate substantial products, creating investment horizons that resource-constrained households facing immediate consumption pressures may find prohibitive (Meijer *et al.*, 2015). Climate finance mechanisms that provide patient capital for tree establishment, combined with interim support that bridges the gap between planting and production, could address this temporal constraint (Minang *et al.*, 2014). Payment for ecosystem service schemes that recognise the adaptation co-benefits of smallholder agroforestry represent promising but underdeveloped opportunities for enhancing forest-based adaptation incentives across African landscapes (Chomba *et al.*, 2016).

5.4 Geographic evidence gaps and implications for African forest economics

The pronounced geographic concentration of evidence in East Africa (47.8% of included studies) relative to West Africa creates significant knowledge gaps limiting the generalisability of synthesis findings across African forest-agriculture contexts. West African forest-savannah transition zones, characterised by distinctive agroecological conditions, farming systems, and governance arrangements, remain critically underrepresented despite their substantial importance for regional food security and climate vulnerability.

Ghana exemplifies this evidence gap: it has contributed only four studies, none of which specifically examine the forest-savannah transition zone, which constitutes the country's primary food-producing region and supports millions of smallholder livelihoods. This absence is particularly problematic given Ghana's significance as a climate-adaptation research site, its ongoing forest governance reforms, and its strategic importance for cocoa production under intensifying climate pressures (Asare *et al.*, 2014; Abdulai *et al.*, 2018). Addressing this gap through targeted research in Ghanaian forest-savannah transition zones represents an urgent priority for African forest economics scholarship. The concentration of evidence also limits understanding of how institutional contexts shape adaptation dynamics across diverse African settings, highlighting the need for comparative studies that examine how adaptation patterns vary across these contexts.

6. Implications for African forest economics theory

This review advances African forest economics theory by demonstrating the inadequacy of compartmentalised analytical approaches that separate agricultural adaptation from forest system dynamics in livelihood analysis. The evidence synthesised here establishes that African smallholder livelihoods in forest-agriculture landscapes integrate crop production, livestock management, tree cultivation, and forest product extraction into unified livelihood systems where climate adaptation decisions in any component affect and are affected by other components (Sunderlin *et al.*, 2005; Angelsen *et al.*, 2014). This integration challenges forest economics models that treat forestry and agriculture as separate analytical domains and calls for frameworks that capture livelihood-level interdependencies across land-use components.

The proposed Forest-Agriculture Adaptation Typology offers an integrative framework that distinguishes adaptation modes along temporal (short-term coping versus long-term transformation) and spatial (farm-level versus landscape-level) axes. Type I adaptations (autonomous, farm-level) have the highest adoption rates in Africa but offer limited protection against severe climate stress. Type II adaptations (sustained farm-level investment) face adoption constraints due to tenure insecurity and capital constraints. Type III adaptations (collective short-term responses) require functional institutions for coordination. Type IV adaptations (landscape-level transformations) require governance innovations that transcend individual farm decisions. This typology repositions adaptation within debates in African forest economics on ecosystem service governance, landscape management, and institutional design for common resources (Ostrom, 2005; Agrawal, 2010).

Theoretically, the synthesis findings support the integration of behavioural economics and institutional analysis to explain patterns of adaptation in African forest-agriculture systems. The KAP framework provides useful heuristics for understanding individual cognition but requires contextualisation within institutional analyses that specify the enabling and constraining conditions for behaviour change. Transaction cost economics illuminates why knowledge fails to translate into practice when implementation costs exceed farmer capacity (Williamson, 1985). Common-pool resource theory explains how collective action challenges constrain landscape-level adaptations (Ostrom, 1990). Property rights theory explains how tenure insecurity discourages long-term investments in trees (Alchian and Demsetz, 1973). African forest economics scholarship should integrate these theoretical traditions to develop frameworks adequate to the complexity of forest-agriculture adaptation.

The finding that institutional factors consistently outperform individual-level variables in predicting adaptation has fundamental implications for the construction of forest economics theory. It suggests that behaviour change models premised on individual utility maximisation inadequately explain African adaptation dynamics, in which institutional constraints substantially bound available choice sets. Structural theories emphasising political economy, governance quality, and power relations may offer greater explanatory power than behavioural theories that assume autonomous individual decision-making (Pelling *et al.*, 2015; Nightingale, 2017). Future theoretical development should examine how structural constraints interact with individual factors to shape adaptation trajectories across African forest-agriculture landscapes.

Forest economics scholarship should engage more substantively with African indigenous knowledge systems in theorising adaptation. The synthesis reveals that African farmers frequently adapt, drawing on accumulated experiential knowledge rather than formal climate science information, suggesting that indigenous knowledge constitutes an undertheorised resource for adaptation (Nyong *et al.*, 2007; Nkomwa *et al.*, 2014). Integrating indigenous knowledge perspectives with scientific understanding of climate, rather than treating them as competing epistemologies, offers promising directions for both adaptation theory and practice in African contexts.

6.1 Operationalising the forest-agriculture adaptation typology

To enhance the utility of the Forest-Agriculture Adaptation Typology for empirical research design, survey instrument construction, intervention evaluation, and policy monitoring, this section specifies concrete measurable indicators for each of the four adaptation types. The operational specifications are derived from the evidence synthesised in this review and are intended to provide directly applicable benchmarks.

Type I (Autonomous Farm-Level Adaptation) encompasses low-cost, individually initiated adjustments that require no external institutional support and are implemented within one growing season. Representative practices include changes in crop variety, planting date adjustments, and crop spacing modifications. Measurable indicators: (a) proportion of farmers adopting at least one Type I practice within 12 months of a perceived climate anomaly; (b) number of autonomous practices adopted per household per season. Operational threshold: adoption within one agricultural year, requiring no credit, external inputs, or tenure documentation. Data collection: structured household survey with one-year recall period using a practice checklist. Institutional prerequisites: none; accessible to all smallholders irrespective of tenure, credit, or organisational status, which explains the consistently high adoption rates for this type across the synthesis.

Type II (Sustained Farm-Level Investment) encompasses planned, capital-requiring investments with payoff horizons exceeding three years, typically involving tree planting, soil infrastructure construction, or water management improvements. Measurable indicators: (a) hectares under agroforestry or tree crops established within the past five years; (b) proportion of farm area with documented soil conservation infrastructure; (c) tenure security status coded as a binary indicator (formal statutory title or documented customary right = 1); (d) investment sustained across at least three consecutive seasons. Operational threshold: capital investment maintained for three or more growing seasons with observational evidence of establishment. Data collection: farm parcel mapping combined with household survey; review of tenure documentation, where available. Institutional prerequisites: secure tree tenure rights; access to medium-term credit, payment-for-ecosystem-service income, or savings-group finance; extension technical guidance for species selection and management.

Type III (Collective Short-Term Coping) encompasses community-coordinated responses to acute climate shocks requiring functional group institutions with governance rules enabling rapid mobilisation within one season. Measurable indicators: (a) farmer membership in an organisation with a documented climate response protocol or emergency resource-sharing arrangement; (b) proportion of households accessing communal resources (water, grain, or seed) during the most recent climate-stress season; (c) frequency of community adaptation meetings per season, with a threshold of at least two per growing season. Operational threshold: coordinated collective response activated in at least two of the past five climate-stress seasons. Data collection: household survey combined with key informant interviews with group leaders. Institutional prerequisites: functional farmer organisation, water user association, or community-based natural resource management institution with clear governance rules for resource access during climate stress.

Type IV (Landscape-Level Transformation) encompasses governance-mediated changes in land-use configuration, forest cover, or watershed management that operate across multiple farm units and require multi-stakeholder coordination over five or more years. Measurable indicators: (a) proportion of landscape area under an agreed land-use plan or community forest management agreement with multi-stakeholder endorsement; (b) directional forest cover trend from satellite imagery (Landsat 8/9 or Sentinel-2 composite; five-year baseline; minimum mapping unit 0.5 ha); (c) number of formal multi-stakeholder governance platforms with documented meeting records per year, threshold of at least four per year with cross-sector representation. Operational threshold: measurable, attributable change in landscape-level forest cover or land-use configuration sustained over five years. Data collection: remote sensing time-series analysis combined with governance document review and multi-level stakeholder interviews. Institutional prerequisites: district or catchment-level governance platform with legal mandate; national legal framework enabling community-based forest management with benefit-sharing; external facilitation for multi-stakeholder coordination during the establishment phase.

6.2 Policy implications for African forestry and climate adaptation

For policymakers across the African forestry and agricultural sectors, this review suggests that information-based interventions targeting farmers' knowledge, while necessary, are insufficient to catalyse comprehensive adaptation within forest-agriculture systems. Structural reforms that address institutional constraints warrant priority alongside extension programming. First, strengthen extension service capacity for climate-specific technical guidance that integrates crop, livestock, and forest components, rather than delivering siloed sectoral messages. African extension systems face documented capacity constraints, but their demonstrated importance for adaptation suggests that investing in capacity yields substantial returns for climate resilience (Davis *et al.*, 2012; Ragasa *et al.*, 2016).

Second, reform tenure arrangements to secure African smallholders' rights over trees and forest products, creating incentives for long-term investment in forest-based adaptation strategies that are currently deterred by tenure uncertainty (Alden Wily, 2011; Bugri, 2008). Ghana's ongoing land administration reforms offer opportunities to strengthen tree tenure security with direct implications for adaptation outcomes. Third, develop financial instruments appropriate for smallholder adaptation investments in African contexts, including patient capital for tree establishment, index-based insurance for climate risk management, and results-based payments for ecosystem service provision linking adaptation with conservation incentives (Minang *et al.*, 2014). Fourth, support the development of farmer organisations and collective action capacity, recognising that landscape-level adaptations require coordination mechanisms beyond individual farm decisions (Mango *et al.*, 2017). Fifth, invest in research to address identified evidence gaps, particularly in underrepresented regions, including Ghana's forest-savannah transition zones, where climate vulnerability is acute but empirical understanding remains limited.

6.3 Research agenda for African forest economics

This review identifies priority research directions for advancing African forest economics scholarship on climate adaptation: (1) Longitudinal studies tracking adaptation trajectories over time across African forest-agriculture contexts are urgently needed to establish causal relationships and examine how knowledge, attitudes, and practices evolve with accumulating climate experience. (2) Economic analyses quantifying adaptation costs, benefits, and trade-offs across practice types and livelihood components would inform efficient resource allocation and intervention targeting within African forestry programming. (3) Research specifically addressing Ghana's forest-savannah transition zone would fill the critical evidence gap identified in this synthesis, generating insights directly applicable to policy and extension programming in a nationally significant agricultural region. (4) Experimental and quasi-experimental evaluations testing extension approaches, financial instruments, and governance interventions would strengthen the evidence base for African forestry policy recommendations. (5) Comparative studies across African forest-agriculture contexts would identify context-specific versus generalisable adaptation dynamics, enabling appropriate localisation of interventions across the continent's diverse institutional and agroecological settings. (6) Interdisciplinary research integrating behavioural science, institutional economics, and forest ecology would develop analytical frameworks adequate to the complexity of African forest-agriculture systems facing climate change.

7. Conclusion

This systematic review synthesised evidence from 67 studies examining smallholder farmers' knowledge, attitudes, and climate change adaptation practices in forest-agriculture landscapes across Sub-Saharan Africa and the Global South. Meta-analytic findings reveal widespread climate awareness (78.4%, 95% CI: 72.1–84.7%; $z = 18.4$, $p < 0.001$; $I^2 = 94.7\%$) inadequately translating into comprehensive adaptation, with crop diversification dominating practice portfolios while forest-based strategies, including agroforestry and NTFP collection, remain underutilised despite their documented contributions to livelihood resilience. Attitudes partially mediate knowledge-practice relationships, but institutional factors consistently explain greater variance in adaptation than individual-level behavioural variables across African contexts. The high between-study heterogeneity observed throughout ($I^2 = 68.4$–94.7%) means that all pooled estimates should be interpreted as descriptive central tendencies. Because the evidence base is dominated by cross-sectional designs (77.6%), the KAP associations identified here are correlational and do not establish causal sequences.

The review advances African forest economics scholarship by reconceptualising adaptation as embedded within forest-agriculture systems characterised by complex tenure arrangements, multiple governance authorities, and intersecting livelihood components. The proposed Forest-Agriculture Adaptation Typology integrates behavioural dimensions with temporal and spatial considerations, now operationalised through concrete measurable indicators for each of the four adaptation types (Section 6.1), offering a framework for research prioritisation and policy targeting relevant to African forestry and climate programming. Critical interrogation of KAP assumptions reveals that linear sequencing is inadequate for capturing the recursive, institutionally mediated adaptation processes that characterise African smallholder contexts.

Significant evidence gaps demand urgent research attention. Geographic concentration in East Africa leaves West African forest-savannah transitions critically underrepresented, particularly in Ghana, where empirical evidence for this ecologically vital zone is lacking. Methodological dominance of cross-sectional surveys limits causal inference. Economic analyses of forest-based adaptation contributions to African livelihood resilience are notably scarce. Addressing these gaps represents a priority for African forest economics research with direct implications for climate policy, extension programming, and forest governance reform.

Climate change will continue to reshape African forest-agriculture landscapes regardless of progress in mitigation, making adaptation imperative for the sustainability of smallholder livelihoods across the continent. This review establishes that supporting effective adaptation requires moving beyond information-focused interventions toward integrated approaches that address institutional constraints, secure forest tenure, develop appropriate financial instruments, and strengthen collective action capacity. African forest economics scholars are uniquely positioned to advance this agenda, bringing analytical tools and regional expertise essential for navigating the complex intersections of climate, forests, and rural livelihoods that define the continent's development trajectory.

References

Abdulai, I., Jassogne, L., Graefe, S., Asare, R., Van Asten, P., Läderach, P. and Vaast, P. (2018), "Characterisation of cocoa production, income diversification and shade tree management along a climate gradient in Ghana", *PLoS One*, Vol. 13 No. 4, e0195777, doi: 10.1371/journal.pone.0195777.

Acheampong, E.O., Macgregor, C.J., Sloan, S. and Sayer, J. (2019), "Deforestation is driven by agricultural expansion in Ghana's forest reserves", *Scientific African*, Vol. 5, e00146, doi: 10.1016/j.sciaf.2019.e00146.

Acheampong, E.O., Sayer, J., Macgregor, C.J. and Sloan, S. (2021), "Factors influencing the adoption of agricultural practices in Ghana's encroached forest reserves", *Forest Policy and Economics*, Vol. 122, 102348, doi: 10.1016/j.forpol.2020.102348.

Agrawal, A. (2001), "Common property institutions and sustainable resource governance", *World Development*, Vol. 29 No. 10, pp. 1649-1672, doi: 10.1016/S0305-750X(01)00063-8.

Agrawal, A. (2010), "Local institutions and adaptation to climate change", in Mearns, R. and Norton, A. (Eds), *Social Dimensions of Climate Change*, World Bank, pp. 173-198.

Ajzen, I. (1991), "The theory of planned behaviour", *Organizational Behavior and Human Decision Processes*, Vol. 50 No. 2, pp. 179-211, doi: 10.1016/0749-5978(91)90020-T.

Alchian, A.A. and Demsetz, H. (1973), "The property rights paradigm", *The Journal of Economic History*, Vol. 33 No. 1, pp. 16-27, doi: 10.1017/S0022050700076403.

Alden Wily, L. (2011), "The tragedy of public lands: the fate of the commons under global commercial pressure", International Land Coalition, available at: https://www.iccaconsortium.org/wp-content/uploads/2015/08/legal-example-the-tragedy-of-public-lands-2011.pdf

Alidu, A.F., Man, N., Ramli, N.N., Haris, N.B.M. and Alhassan, A. (2022), "Farmers' use of climate information and adaptation decision-making in Ghana", *Heliyon*, Vol. 8 No. 5, e09513, doi: 10.1016/j.heliyon.2022.e09513.

Angelsen, A., Overgaard Larsen, H. and Smith Olsen, C. (2011), *Measuring Livelihoods and Environmental Dependence: Methods for Research and Fieldwork*, Routledge, London.

Angelsen, A., Jagger, P., Wunder, S., Belcher, B., Hogarth, N.J., Bauch, S., Börner, J. and Smith-Hall, C. (2014), "Environmental income and rural livelihoods: a global-comparative analysis", *World Development*, Vol. 64 No. Suppl. 1, pp. S12-S28, doi: 10.1016/j.worlddev.2014.03.006.

Antwi-Agyei, P. and Nyantakyi-Frimpong, H. (2021), "Evidence of climate change adaptation among smallholder farmers in Ghana's transitional zone", *Sustainability*, Vol. 13 No. 3, p. 1308, doi: 10.3390/su13031308.

Antwi-Agyei, P. and Stringer, L.C. (2021), "Improving the effectiveness of agricultural extension services in supporting farmers to adapt to climate change: insights from northeastern Ghana", *Climate Risk Management*, Vol. 32, 100304, doi: 10.1016/j.crm.2021.100304.

Antwi-Agyei, P., Dougill, A.J., Stringer, L.C. and Codjoe, S.N.A. (2021), "Adaptation opportunities and maladaptive outcomes in climate vulnerability contexts: evidence from smallholder farmers in northern Ghana", *Climate Risk Management*, Vol. 32, 100298.

Appiah, D.O. and Guodaar, L. (2022), "Smallholder farmer perceptions and knowledge on climate variability and perceived effects in vulnerable rural communities in Offinso Municipality, Ghana", *Environmental Development*, Vol. 42, 100672, doi: 10.1016/j.envdev.2022.100672.

Appiah, M., Blay, D., Damnyag, L., Dwomoh, F.K., Pappinen, A. and Luukkanen, O. (2009), "Dependence on forest resources and tropical deforestation in Ghana", *Environment, Development and Sustainability*, Vol. 11 No. 3, pp. 471-487, doi: 10.1007/s10668-007-9125-0.

Asare, R. (2019), "Building multi-strata agroforestry systems for increased farm biodiversity and resilience of smallholder cocoa production in Ghana", *Ghana Journal of Forestry*, Vol. 35 No. 1, pp. 1-16.

Asare, R., Afari-Sefa, V., Osei-Owusu, Y. and Pabi, O. (2014), "Cocoa agroforestry for increasing forest connectivity in a fragmented landscape in Ghana", *Agroforestry Systems*, Vol. 88 No. 6, pp. 1143-1156, doi: 10.1007/s10457-014-9688-3.

Assan, E., Suvedi, M. and Schmitt Olabisi, L. (2020), "Coping with and adapting to climate change: a gendered perspective from smallholder farming in Ghana", *Environments*, Vol. 7 No. 5, p. 33, doi: 10.3390/environments7050033.

Atta-Aidoo, J., Antwi-Agyei, P., Dougill, A.J., Ogbanje, C.E., Akoto-Danso, E.K. and Eze, S. (2022), "Climate-smart agriculture adoption among smallholder farmers in Ghana's forest-savannah transitional zone", *PLOS Climate*, Vol. 1 No. 10, e0000082, doi: 10.1371/journal.pclm.0000082.

Awazi, N.P. and Tchamba, M.N. (2023), "Agroforestry as an adaptive strategy to climate change and variability in smallholder farming systems in Sub-Saharan Africa", *Climate and Development*, Vol. 16 No. 5, pp. 389-404.

Ayanlade, A., Oluwatimilehin, I.A. and Ayanlade, O.S. (2022), "Farmers' perception and knowledge of climate variability in southern Nigeria", *Theoretical and Applied Climatology*, Vol. 147 Nos 3-4, pp. 1255-1271, doi: 10.1007/s00704-021-03904-6.

Bandiera, O. and Rasul, I. (2006), "Social networks and technology adoption in northern Mozambique", *Economic Journal*, Vol. 116 No. 514, pp. 869-902, doi: 10.1111/j.1468-0297.2006.01115.x.

Belay, A., Recha, J.W. and Morton, J.F. (2022), "Climate change knowledge, attitudes and practices among smallholder farmers in the Borana and Guji communities, southern Ethiopia", *Heliyon*, Vol. 8 No. 12, e12089, doi: 10.1016/j.heliyon.2022.e12089.

Berrang-Ford, L., Pearce, T. and Ford, J.D. (2015), "Systematic review approaches for climate change adaptation research", *Regional Environmental Change*, Vol. 15 No. 5, pp. 755-769, doi: 10.1007/s10113-014-0708-7.

Borenstein, M., Hedges, L.V. and Higgins, J.P.T. (2009), *Introduction to Meta-Analysis*, Wiley, Chichester.

Bryan, E., Ringler, C., Okoba, B., Roncoli, C., Silvestri, S. and Herrero, M. (2013), "Adapting agriculture to climate change in Kenya: household strategies and determinants", *Journal of Environmental Management*, Vol. 114, pp. 26-35, doi: 10.1016/j.jenvman.2012.10.005.

Bugri, J.T. (2008), "The dynamics of tenure security, agricultural production and environmental degradation in Africa: evidence from stakeholders in north-east Ghana", *Land Use Policy*, Vol. 25 No. 1, pp. 24-31, doi: 10.1016/j.landusepol.2007.02.002.

Carr, E.R. and Thompson, M.C. (2014), "Gender and climate change adaptation in agrarian settings: current thinking, new directions, and research frontiers", *Geography Compass*, Vol. 8 No. 3, pp. 182-197, doi: 10.1111/gec3.12121.

Chomba, S., Kariuki, J., Lund, J.F. and Sinclair, F. (2016), "Roots of inequity: how the implementation of REDD+ reinforces past injustices", *Land Use Policy*, Vol. 50, pp. 202-213, doi: 10.1016/j.landusepol.2015.09.021.

Chomba, S., Sinclair, F. and Savadogo, P. (2020), "The role of trees in sustaining ecosystem services and livelihoods in drylands: evidence from managed natural regeneration in the Sahel", *Current Opinion in Environmental Sustainability*, Vol. 45, pp. 42-50.

Collaboration for Environmental Evidence (2018), *Guidelines for Systematic Reviews in Environmental Management*, version 5.1, CEE, Bangor.

Cooper, H., Hedges, L.V. and Valentine, J.C. (2019), *The Handbook of Research Synthesis and Meta-Analysis*, 3rd ed., Russell Sage Foundation, New York.

Cronkleton, P., Larson, A.M. and Pulhin, J.M. (2012), "Tenure reforms in community forestry: redefining the boundaries of governance and accountability", *Forest Policy and Economics*, Vol. 17, pp. 44-51, doi: 10.1016/j.forpol.2011.06.009.

Davis, K., Nkonya, E., Kato, E., Mekonnen, D., Odendo, M., Miiro, R. and Nkuba, J. (2012), "Impact of farmer field schools on agricultural productivity and poverty in East Africa", *World Development*, Vol. 40 No. 2, pp. 402-413, doi: 10.1016/j.worlddev.2011.05.013.

DerSimonian, R. and Laird, N. (1986), "Meta-analysis in clinical trials", *Controlled Clinical Trials*, Vol. 7 No. 3, pp. 177-188, doi: 10.1016/0197-2456(86)90046-2.

Dewees, P., Place, F. and Scherr, S.J. (2011), "Investing in trees and landscape restoration in Africa: what, where, and how", in Chave, J., *et al.* (Eds), *World Forests, Society and Environment*, Springer, pp. 195-218.

Djoudi, H., Brockhaus, M. and Locatelli, B. (2016), "Once there was a lake: vulnerability to environmental changes in northern Mali", in Leal Filho, W. (Ed.), *Climate Change Adaptation in Africa*, Springer, pp. 299-316.

Duguma, L., Wambugu, S.W. and Minang, P.A. (2019), "Agroforestry policy development in Sub-Saharan Africa: progress, challenges and opportunities", *Sustainability*, Vol. 11 No. 3, p. 832, doi: 10.3390/su11030832.

Egger, M., Davey Smith, G., Schneider, M. and Minder, C. (1997), "Bias in meta-analysis detected by a simple, graphical test", *BMJ*, Vol. 315 No. 7109, pp. 629-634, doi: 10.1136/bmj.315.7109.629.

FAO (2022), *The State of Food and Agriculture 2022: Leveraging Automation in Agriculture for Transforming Agrifood Systems*, FAO, Rome.

Ford, J.D., Berrang-Ford, L. and Paterson, J. (2011), "A systematic review of observed climate change adaptation in developed nations", *Climatic Change*, Vol. 106 No. 2, pp. 327-336, doi: 10.1007/s10584-011-0045-5.

Franzel, S., Denning, G.L. and Lilleso, J.P.B. (2004), "Scaling up the impact of agroforestry: lessons from three sites in Africa and Asia", *Agroforestry Systems*, Vol. 61 No. 1, pp. 329-344.

Gebrehiwot, T. and van der Veen, A. (2013), "Farm level adaptation to climate change: the case of farmers in the Ethiopian Highlands", *Environmental Management*, Vol. 52 No. 1, pp. 29-44, doi: 10.1007/s00267-013-0039-3.

Giordano, M., de Fraiture, C., Weight, E. and van der Bliek, J. (2012), *Water for Wealth and Food Security: Supporting Farmer-Driven Investments in Agricultural Water Management*, International Water Management Institute, Colombo.

Grothmann, T. and Patt, A. (2005), "Adaptive capacity and human cognition: the process of individual adaptation to climate change", *Global Environmental Change*, Vol. 15 No. 3, pp. 199-213, doi: 10.1016/j.gloenvcha.2005.01.002.

Haddaway, N.R., Macura, B., Whaley, P. and Pullin, A.S. (2018), "ROSES Reporting standards for systematic evidence syntheses: Pro forma, flow diagram and descriptive summary of the plan and conduct of environmental systematic reviews and systematic maps", *Environmental Evidence*, Vol. 7 No. 1, p. 7, doi: 10.1186/s13750-018-0121-7.

Hajjar, R., Oldekop, J.A., Cronkleton, P., Newton, P., Russell, A.J.M. and Zhou, W. (2021), "A global analysis of the social and environmental outcomes of community forests", *Nature Sustainability*, Vol. 4 No. 3, pp. 216-224, doi: 10.1038/s41893-020-00633-y.

Higgins, J.P.T., Thomas, J. and Chandler, J. (2019), *Cochrane Handbook for Systematic Reviews of Interventions (Version 6)*, Wiley, Hoboken, NJ.

Hong, Q.N., Pluye, P. and Fabregues, S. (2018), *Mixed Methods Appraisal Tool (MMAT), Version 2018: User Guide*, McGill University, Montreal.

IPCC (2023), *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the IPCC*, IPCC, Geneva.

Jayne, T.S., Muyanga, M. and Wineman, A. (2022), "Is Africa's smallholder farming sector becoming more market-oriented? Evidence from changing farm size distributions in Africa", *Food Policy*, Vol. 105, 102164, doi: 10.1016/j.foodpol.2021.102164.

Kalaba, F.K., Quinn, C.H. and Dougill, A.J. (2013), "The role of forest provisioning ecosystem services in coping with household food insecurity in Miombo woodland communities of Zambia", *Ecosystem Services*, Vol. 5, pp. e143-e148, doi: 10.1016/j.ecoser.2013.07.008.

Khatibi, F.S., Dedekorkut-Howes, A. and Howes, M. (2021), "Can public awareness, knowledge and engagement improve climate change adaptation policies?", *Discover Sustainability*, Vol. 2 No. 1, p. 18, doi: 10.1007/s43621-021-00027-2.

Kwol, V.S., Eluwole, K.K., Avci, T. and Lasisi, T.T. (2020), "Another look into the Knowledge-Attitude-Practice (KAP) model in food control management: an investigation of food handlers in Hawassa City", *Food Control*, Vol. 110, 107025, doi: 10.1016/j.foodcont.2019.107025.

Liao, X., Nguyen, T.P.L. and Sasaki, N. (2022), "Farmers' knowledge, attitude, and practices toward climate-smart agriculture: evidence from a study in Vietnam", *Regional Sustainability*, Vol. 3 No. 1, pp. 41-52, doi: 10.1016/j.regsus.2022.03.001.

Lowder, S.K., Sanchez, M.V. and Bertini, R. (2021), "Which farms feed the world, and has farmland become more concentrated?", *World Development*, Vol. 142, 105455, doi: 10.1016/j.worlddev.2021.105455.

Mango, N., Siziba, S. and Makate, C. (2017), "Impact of adoption of conservation agriculture on smallholder farmers' food security in semi-arid zones of southern Africa", *Agriculture and Food Security*, Vol. 6 No. 1, p. 32, doi: 10.1186/s40066-017-0109-5.

Maziya, M., Mdoda, L. and Mvelase, L.P.S. (2024), "The role of psychological capital on climate change adaptation among smallholder farmers in the uMkhanyakude district of KwaZulu-Natal, South Africa", *Climate*, Vol. 12 No. 12, p. 213, doi: 10.3390/cli12120213.

Mbow, C., van Noordwijk, M., Prabhu, R., Neufeldt, H., Minang, P.A. and Kowero, G. (2014), "Agroforestry solutions to address food security and climate change challenges in Africa", *Current Opinion in Environmental Sustainability*, Vol. 6, pp. 61-67, doi: 10.1016/j.cosust.2013.10.014.

Meijer, S.S., Catacutan, D., Ajayi, O.C., Sileshi, G.W. and Nieuwenhuis, M. (2015), "The role of knowledge, attitudes and perceptions in the uptake of agricultural and agroforestry innovations among smallholder farmers in sub-Saharan Africa", *International Journal of Agricultural Sustainability*, Vol. 13 No. 1, pp. 40-54, doi: 10.1080/14735903.2014.912493.

Mertz, O., Mbow, C. and Nielsen, J.O. (2011), "Climate factors play a limited role in past adaptation strategies in West Africa", *Ecology and Society*, Vol. 16 No. 4, p. 25.

Minang, P.A., van Noordwijk, M. and Freeman, O.E. (2014), *Climate-smart Landscapes: Multifunctionality in Practice*, World Agroforestry Centre (ICRAF), Nairobi.

Nagoda, S. and Nightingale, A.J. (2017), "Participation and power in climate change adaptation policies: vulnerability in Nepal's food security programs", *World Development*, Vol. 100, pp. 85-93, doi: 10.1016/j.worlddev.2017.07.022.

Ndah, T.H., Schuler, J. and Zander, P. (2024), "Understanding farmers' decisions and the adoption of sustainable intensification in Sub-Saharan Africa", *Agriculture and Human Values*, Vol. 41 No. 1, pp. 271-288.

Ngigi, S.N. (2009), *Climate Change Adaptation Strategies: Water Resources Management Options for Smallholder Farming Systems in Sub-saharan Africa*, The Earth Institute at Columbia University, New York, NY.

Nightingale, A.J. (2017), "Power and politics in climate adaptation governance", *WIREs Climate Change*, Vol. 8 No. 4, e462, doi: 10.1002/wcc.462.

Nkomwa, E.C., Joshua, M.K., Ngongondo, C., Monjerezi, M. and Chipungu, F. (2014), "Assessing indigenous knowledge systems and climate change adaptation strategies in agriculture: a case study of Chagaka Village, Chikhwawa, southern Malawi", *Physics and Chemistry of the Earth*, Vols 67-69, pp. 164-172, doi: 10.1016/j.pce.2013.10.002.

North, D.C. (1990), *Institutions, Institutional Change and Economic Performance*, Cambridge University Press, Cambridge.

Nyantakyi-Frimpong, H. and Bezner-Kerr, R. (2015), "The relative importance of climate change among multiple stressors in semi-arid Ghana", *Global Environmental Change*, Vol. 32, pp. 40-56, doi: 10.1016/j.gloenvcha.2015.03.003.

Nyong, A., Adesina, F. and Elasha, B.O. (2007), "The value of indigenous knowledge in climate change mitigation and adaptation strategies in the African Sahel", *Mitigation and Adaptation Strategies for Global Change*, Vol. 12 No. 5, pp. 787-797, doi: 10.1007/s11027-007-9099-0.

Ochieng, J., Kirimi, L. and Makau, J. (2020), "Climate variability and change and its impacts on smallholder agriculture in Kenya", *Climate Risk Management*, Vol. 27, 100206, doi: 10.1016/j.crm.2019.100206.

Ostrom, E. (1990), *Governing the Commons: The Evolution of Institutions for Collective Action*, Cambridge University Press, Cambridge.

Ostrom, E. (2005), *Understanding Institutional Diversity*, Princeton University Press, Princeton, NJ.

Ouzzani, M., Hammady, H., Fedorowicz, Z. and Elmagarmid, A. (2016), "Rayyan—a web and mobile app for systematic reviews", *Systematic Reviews*, Vol. 5 No. 1, 210, doi: 10.1186/s13643-016-0384-4.

Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., Shamseer, L., Tetzlaff, J.M., Akl, E.A., Brennan, S.E., Chou, R., Glanville, J., Grimshaw, J.M., Hróbjartsson, A., Lalu, M.M., Li, T., Loder, E.W., Mayo-Wilson, E., McDonald, S., McGuinness, L.A., Stewart, L.A., Thomas, J., Tricco, A.C., Welch, V.A., Whiting, P. and Moher, D. (2021), "The PRISMA 2020 statement: an updated guideline for reporting systematic reviews", *BMJ*, Vol. 372, p. n71, doi: 10.1136/bmj.n71.

Pelling, M., O'Brien, K. and Matyas, D. (2015), "Adaptation and transformation", *Climatic Change*, Vol. 133 No. 1, pp. 113-127, doi: 10.1007/s10584-014-1303-0.

Persha, L., Agrawal, A. and Chhatre, A. (2011), "Social and ecological synergy: local rulemaking, forest livelihoods, and biodiversity conservation", *Science*, Vol. 331 No. 6024, pp. 1606-1608, doi: 10.1126/science.1199343.

Ragasa, C., Ulimwengu, J.M., Randriamamonjy, J. and Badibanga, T. (2016), "Factors affecting performance of agricultural extension: evidence from Democratic Republic of Congo", *The Journal of Agricultural Education and Extension*, Vol. 22 No. 2, pp. 113-143, doi: 10.1080/1389224X.2015.1026363.

Reed, J., van Vianen, J., Deakin, E.L., Barlow, J. and Sunderland, T. (2016), "Integrated landscape approaches to managing social and environmental issues in the tropics: learning from the past to guide the future", *Global Change Biology*, Vol. 22 No. 7, pp. 2540-2554, doi: 10.1111/gcb.13284.

Rogers, R.W. (1983), "Cognitive and physiological processes in fear appeals and attitude change: a revised theory of protection motivation", in Cacioppo, J.T. and Petty, R.E. (Eds), *Social Psychophysiology*, Guilford Press, pp. 153-176.

Ruf, F., Schroth, G. and Doffangui, K. (2015), "Climate change, cocoa migrations and deforestation in West Africa: what does the past tell us about the future?", *Sustainability Science*, Vol. 10 No. 1, pp. 101-111, doi: 10.1007/s11625-014-0282-4.

Samberg, L.H., Gerber, J.S., Ramankutty, N., Herrero, M. and West, P.C. (2016), "Subnational distribution of average farm size and smallholder contributions to global food production", *Environmental Research Letters*, Vol. 11 No. 12, 124010, doi: 10.1088/1748-9326/11/12/124010.

Shackleton, C.M., Shackleton, S.E. and Buiten, E. (2011), "The importance of dry woodlands and forests in rural livelihoods and poverty alleviation in South Africa", *Forest Policy and Economics*, Vol. 13 No. 3, pp. 186-195.

Sunderlin, W.D., Angelsen, A., Wunder, S., Burgers, P., Nasi, R. and Santoso, L. (2005), "Livelihoods, forests, and conservation in developing countries: an overview", *World Development*, Vol. 33 No. 9, pp. 1383-1402, doi: 10.1016/j.worlddev.2004.10.004.

van Valkengoed, A.M. and Steg, L. (2019), "Meta-analyses of factors motivating climate change adaptation behaviour", *Nature Climate Change*, Vol. 9 No. 2, pp. 158-163, doi: 10.1038/s41558-018-0371-y.

Viechtbauer, W. (2010), "Conducting meta-analyses in R with the metafor package", *Journal of Statistical Software*, Vol. 36 No. 3, pp. 1-48, doi: 10.18637/jss.v036.i03.

Williamson, O.E. (1985), *The Economic Institutions of Capitalism*, Free Press, New York, NY.

Wuepper, D., Sauer, J. and Kleemann, L. (2018), "Sustainable intensification amongst Ghana's pineapple farmers: the complexity of an innovation determines the effectiveness of its training", *Environment and Development Economics*, Vol. 23 No. 1, pp. 98-119, doi: 10.1017/S1355770X1700033X.

Wunder, S., Angelsen, A. and Belcher, B. (2014), "Forests, livelihoods, and conservation: broadening the empirical base", *World Development*, Vol. 64 No. Suppl. 1, pp. S1-S11, doi: 10.1016/j.worlddev.2014.03.007.

Further reading

Lowder, S.K., Skoet, J. and Raney, T. (2016), "The number, size, and distribution of farms, smallholder farms, and family farms worldwide", *World Development*, Vol. 87, pp. 16-29, doi: 10.1016/j.worlddev.2015.10.041.

Zagre, I., Akinseye, F.M., Worou, O.N., Kone, M. and Faye, A. (2024), "Climate change adaptation strategies among smallholder farmers in Senegal's semi-arid zone: role of socio-economic factors and institutional supports", *Frontiers in Climate*, Vol. 6, 1332196, doi: 10.3389/fclim.2024.1332196.

Zobeidi, T., Yazdanpanah, M. and Forouzani, M. (2022), "Explaining farmers' adaptation behaviours to overcome climate change: the role of risk perception, knowledge, social norms and trust", *Scientific Reports*, Vol. 12, 15208, doi: 10.1038/s41598-022-19218-y.

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