

Women at the Core of Climate-Smart Agriculture: Advancing Equity and Food Security through Empowerment

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ABSTRACT

Climate volatility threatens global food security, particularly in developing nations where female farmers face severe resource barriers. This narrative review synthesizes empirical research published between 2010 and 2026 to evaluate women's empowerment, climate-smart agricultural adoption, and household food security. Applying structured narrative frameworks, 44 academic studies and policy reports were synthesized across four major academic databases. The selected literature was analyzed using Feminist Political Ecology and the Women's Empowerment in Agriculture Index conceptual frameworks. Findings reveal that conventional technical adaptation programs often fail by ignoring local power dynamics and increasing female unpaid care burdens. In contrast, gender-responsive interventions addressing land tenure, credit constraints, and information gaps generate strong economic benefits. Securing equal access to essential productive assets directly increases agricultural yields for female farmers. This productivity gain expands household dietary diversity, reduces child stunting, and strengthens climate shock absorption. Labor-saving equipment and solar micro-irrigation reduce drudgery while improving seasonal farm earnings. However, national climate policies often ignore gender metrics, lack gender-disaggregated data, and risk male control over profitable practices. Achieving sustainable food security requires moving from gender-neutral programs toward gender-transformative governance models. National frameworks must mandate joint land titling and protect female property rights. Public agencies and financial institutions should offer flexible credit programs, direct mobile digital advisories, and inclusive participatory technology design. Evidence confirms that targeted investment in female agricultural producers is essential for building efficient, fair, and productive agrifood systems across vulnerable communities.

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1. INTRODUCTION

Global agricultural systems face an unprecedented and compounding crisis driven by accelerating climate volatility, extreme weather events, land degradation, and biodiversity loss (FAO, 2024; Gemtou et al., 2024). Severe and prolonged drought cycles, altered rainfall patterns, rising ambient temperatures, extreme heat stress, and the increasing frequency of tropical storms disrupt agrarian livelihoods across the Global South (Afzal et al., 2024; FAO, 2024). These environmental stresses threaten global food security, rural stability, and ecological sustainability, particularly in developing countries where agriculture remains the primary foundation of socioeconomic organization and rural employment (Sirilakshmi et al., 2026). Within low- and middle-income countries (LMICs), smallholder farming systems account for the vast majority of agricultural production, national food supplies, and rural employment (Doss & Raney, 2011; FAO, 2023). However, agricultural production within these developing contexts is characterized by deep-rooted, structural socioeconomic inequalities (Doss et al., 2018; Kabeer, 1994). Chief among these structural distortions is the persistent, multidimensional agricultural gender gap (FAO, 2023; Puskur & Malhotra, 2024).

Women represent a foundational segment of the global agricultural labor force across smallholder systems (Sirilakshmi et al., 2026). Globally, women comprise approximately 43% of the agricultural workforce in developing nations, a figure that exceeds 50% across sub-Saharan Africa and reaches up to 70% in parts of South Asia (Doss & Raney, 2011; FAO, 2023). Beyond their contributions to field labor, rural women play indispensable roles across the entire agrifood value chain (Doss et al., 2018; Sirilakshmi et al., 2026). They serve as primary custodians of crop seed selection and preservation, post-harvest processing, small livestock management, local water fetching, home gardening, and family dietary preparation (Doss & Raney, 2011; Sirilakshmi et al., 2026). Consequently, women operate at the core of the four fundamental pillars of food security: food availability, food access, food utilization, and temporal food stability (Sirilakshmi et al., 2026).

Despite their vital and multifaceted roles in food production and household survival, women in agriculture face severe structural constraints (Doss et al., 2018; Kabeer, 1994). Discriminatory legal structures, deeply entrenched patriarchal social norms, institutional gender biases, and market exclusions systematically restrict female farmers' access to core productive assets, formal land ownership titles, microfinance and agricultural credit, technical extension advice, climate-smart technological innovations, and local decision-making platforms (FAO, 2023; Kabeer, 1994). As anthropogenic climate change intensifies environmental shocks, unempowered female farmers face heightened vulnerability (FAO, 2024). Their heightened exposure stems not from any inherent physical frailty, but from socially constructed inequalities that restrict their financial resources, information access, mobility, and adaptive capacity (Djoudi et al., 2016; Vigil, 2024).

To address the twin challenges of environmental degradation and hunger, the concept of Climate-Smart Agriculture (CSA) has emerged as a central paradigm in international agricultural development (FAO, 2023; Puskur & Malhotra, 2024). Promoted by the Food and Agriculture Organization (FAO), the CGIAR consortium, and international development agencies, CSA seeks to achieve three primary objectives (the “triple pillars”):

1. Sustainably increase agricultural productivity and farm incomes to support food security (FAO, 2023; Puskur & Malhotra, 2024);
2. Adapt and build the resilience of agricultural and food systems to climate change shocks (FAO, 2024); and
3. Reduce and/or remove greenhouse gas (GHG) emissions where possible (FAO, 2023; UN Women, 2023).

While CSA offers a compelling technical framework for climate adaptation, its real-world implementation often treats adaptation as a set of gender-neutral technical solutions (Kristjanson et al., 2017; Puskur & Malhotra, 2024). Emerging research shows that technocratic CSA strategies frequently fail or even worsen existing gender inequalities when implemented without considering local power relations, intra-household resource distribution, and women's time burdens (Kristjanson et al., 2017; Mekasha et al., 2026). When technical packages are designed under the assumption of a unified household utility function, male household heads frequently capture the economic benefits of climate innovations, while female members bear additional manual labor without gaining control over decision-making or farm income (Kabeer, 1994; Theis et al., 2018).

Conversely, fully integrating gender equity and empowering women within CSA initiatives generates a powerful multiplier effect across rural communities (Puskur & Malhotra, 2024; Sirilakshmi et al., 2026). When female farmers gain equal access to secure land tenure, financial capital, climate advisories, labor-saving technologies, and community leadership positions, farm productivity rises, household resilience strengthens, child health and nutrition improve, and community adaptive capacity expands (FAO, 2023; Mkupete, 2024; UN Women, 2025). Fostering gender equity in climate-smart agriculture is therefore not merely a secondary ethical or social goal, but an absolute operational prerequisite for building resilient, sustainable, and inclusive food systems in climate-affected regions (Kristjanson et al., 2017; Sirilakshmi et al., 2026).

This narrative review synthesizes empirical literature published between 2010 and 2026 to answer one central research question: How does empowering rural women through gender-responsive climate-smart agriculture impact household food security and climate resilience across developing nations? While existing literature predominantly focuses on the biophysical and agronomic outcomes of CSA practices, this review makes a distinct contribution by systematically integrating social power dynamics, intra-household resource control, and nutritional outcomes into the climate adaptation discourse. To achieve this, the synthesis is structured around two complementary analytical frameworks: Feminist Political Ecology (FPE) and the Women's Empowerment in Agriculture Index (WEAI). FPE provides the conceptual lens to examine how gendered power relations, institutional structures, and property regimes shape access to environmental resources and dictate the distribution of climate vulnerabilities. Concurrently, the five domains of empowerment from the WEAI framework—decisions over agricultural production; access to and decision-making power over productive resources; control over use of income; leadership in the community; and allocation of time—are used to organize and evaluate empirical findings on how targeted empowerment interventions influence CSA adoption rates and household food security outcomes (Alkire et al., 2013; Doss et al., 2018; Kristjanson et al., 2017; Rocheleau et al., 1996; Sirilakshmi et al., 2026).

2. OBJECTIVES

The primary objective of this review article is to evaluate and synthesize current peer-reviewed literature on women's empowerment within climate-smart agriculture, identifying how gender-responsive strategies contribute to sustainable rural livelihoods, improved household resilience, and enhanced food security in developing countries (Sirilakshmi et al., 2026).

To accomplish this overall objective, the review pursues four specific sub-objectives:

1. Identify and analyze the structural, legal, socio-cultural, and institutional barriers that restrict rural women's access to agricultural assets, financial credit, extension services, digital technologies, and community decision-making authority (FAO, 2023; Kabeer, 1994).
2. Evaluate gender-differentiated preferences, adoption rates, and sustained utilization patterns of key CSA practices, including conservation agriculture, drought-tolerant crop varieties, micro-irrigation, agroforestry, and clean energy technologies, across diverse geographical regions (Aryal et al., 2014; Gemtou et al., 2024).
3. Analyze empirical evidence linking women's empowerment, measured through standardized diagnostic tools such as the WEAI, to agricultural productivity gains, household climate resilience, and child nutritional outcomes (Alkire et al., 2013; Mkupete, 2024; UN Women, 2025).
4. Formulate evidence-based, actionable policy recommendations for international development agencies, national governments, research institutions, and civil society organizations to foster gender-transformative climate-smart food systems (Kristjanson et al., 2017; UN Women, 2023).

3. SOURCE SEARCH STRATEGY

This structured narrative review used a mapping search procedure to identify, critically evaluate, and interpret multidisciplinary global scholarship on gender dynamics, climate adaptation, and household food security (Gemtou et al., 2024; Sirilakshmi et al., 2026).

3.1 Search Strategy and Information Sources

Literature searches were conducted on 15 March 2026 across four academic databases: Scopus, Web of Science, PubMed, and Google Scholar (Gemtou et al., 2024; Sirilakshmi et al., 2026). Institutional reports were collected from international bodies, including the FAO, CGIAR GENDER Impact Platform, the International Food Policy Research Institute (IFPRI), UN Women, World Bank, and CARE International. Policy reports were included alongside peer-reviewed studies to bridge academic theory with field implementation, capture governance frameworks, and incorporate practitioner evaluations.

The search used the following Boolean query strings (e.g., Scopus TITLE-ABS-KEY and Web of Science TS syntax):

("women empowerment" OR "gender equality" OR "gender equity" OR "female agency" OR "women's autonomy") AND ("climate-smart agriculture" OR "CSA" OR "climate adaptation" OR "conservation agriculture" OR "resilient farming" OR "sustainable agriculture") AND ("food security" OR "nutrition" OR "dietary diversity" OR "yield productivity" OR "livelihood resilience" OR "stunting").

3.2 Inclusion and Exclusion Criteria

Studies were selected based on specific eligibility criteria. For temporal scope, articles and institutional reports published between 2010 and 2026 were eligible (Sirilakshmi et al., 2026). Geographical focus included developing regions across sub-Saharan Africa, South Asia, Southeast Asia, and Latin America. Thematic relevance required studies to evaluate women's empowerment, gender dynamics, CSA adoption, agricultural yields, household food security, or climate shock resilience (Mkupete, 2024; UN Women, 2025). Methodological rigor necessitated qualitative, quantitative, or mixed-methods studies published in peer-reviewed journals or policy reports. Articles were excluded if they focused exclusively on high-income industrialized nations, lacked a gender-specific analytical lens, or consisted of non-peer-reviewed opinion pieces.

3.3 Data Extraction and Thematic Synthesis

The final review includes 44 sources that met all criteria. This total contains 28 scholarly papers and 16 policy reports. We grouped the extracted data into three main themes. The first theme covers female involvement and resource access. It reviews land rights, credit, training, digital tools, and time use (FAO, 2023; Kabeer, 1994). The second theme tracks how farmers adopt climate tools. It focuses on soil care, seed choices, water systems, tree planting, and clean energy (Aryal et al., 2014; Gemtou et al., 2024). The third theme checks food security and child diets. It also reviews asset growth and climate shock survival (Alkire et al., 2013).

4. THEORETICAL AND CONCEPTUAL FRAMEWORKS

Evaluating how women's empowerment drives CSA adoption and food security requires frameworks analyzing power dynamics, resource control, and agency in agrarian environments (Harcourt, 2023; Kabeer, 1994).

4.1 Feminist Political Ecology (FPE)

We use FPE to sort review sources (Harcourt, 2023; Vigil, 2024). We filtered literature demonstrating environmental relations and climate vulnerabilities are deeply gendered (Harcourt, 2023; Kabeer, 1994). We omitted broad theory, prioritizing studies proving climate vulnerability is socially constructed (Djouidi et al., 2016; Vigil, 2024). We categorized data on structural hierarchies, like patriarchal property rights, which marginalize female farmers and deny them legal entitlement to productive resources (Doss et al., 2018; Kabeer, 1994; Vigil, 2024). FPE guided our extraction of papers framing climate adaptation as a political arena dictating who gains adaptive technologies and bears labor burdens (Harcourt, 2023; Kristjanson et al., 2017).

We applied FPE's intersectionality concept to sort sources showing how gender interacts with class, caste, ethnicity, and marital status to shape adaptive capacities (Carr & Thompson, 2014; Harcourt, 2023). We grouped studies on young, unmarried women facing compound structural exclusions separately from those evaluating older, married women in landed households (Carr & Thompson, 2014). By interrogating gendered knowledge, we isolated literature proving female farmers possess specialized agro-ecological wisdom about local seed varieties and microclimates that formal institutions frequently ignore (Carr & Thompson, 2014; Harcourt, 2023).

4.2 The Women's Empowerment in Agriculture Index (WEAI)

We used the WEAI and variants like the Abbreviated WEAI (A-WEAI) and Project-level WEAI (pro-WEAI) to sort empirical sources (Alkire et al., 2013; Malapit et al., 2019). We organized extraction around the five core domains of empowerment (5DE) (Alkire et al., 2013):

1. **Production:** Decision-making authority regarding agricultural production, crop selection, and livestock husbandry (Alkire et al., 2013; Malapit et al., 2019).
2. **Resources:** Ownership, access to, and decision-making power over productive assets, land, farm machinery, and credit (Alkire et al., 2013; Doss et al., 2018).
3. **Income:** Control over household expenditures and agricultural earnings (Alkire et al., 2013; Kabeer, 1994). We linked income to farm choices; empowered women actively fund diverse, nutrient-dense crops instead of monocultures.
4. **Leadership:** Active influence in community groups, agricultural cooperatives, and water management bodies (Alkire et al., 2013; Malapit et al., 2019).
5. **Time Use:** Time allocation across agricultural work, unpaid care, and leisure (Alkire et al., 2013; Mekasha et al., 2026). We linked time to food safety; heavy labor restricts post-harvest hygiene time, directly degrading food safety.

The WEAI operationalizes these five domains into ten indicators defining an "empowered" farmer (Alkire et al., 2013; Malapit et al., 2019). We sorted studies using the Gender Parity Index (GPI) to reflect women's empowerment relative to the primary adult male in their household (Alkire et al., 2013). The pro-WEAI framework extends this by incorporating modules assessing health, physical mobility, domestic violence, and institutional leadership (Malapit et al., 2019). We extracted research proving higher WEAI scores correlate directly with higher CSA adoption, improved yields, and better child dietary diversity (Mkupete, 2024; UN Women, 2025).

4.3 The Gender-Awareness Continuum in Agricultural Interventions

We sorted agricultural adaptation initiatives based on how they address gender inequalities (Kristjanson et al., 2017; Puskur & Malhotra, 2024). We categorized interventions into four distinct levels (Kristjanson et al., 2017; Puskur & Malhotra, 2024):

1. **Gender-Blind:** Interventions ignoring gender dynamics, assuming technologies affect men and women equally. We filtered approaches that widen existing resource gaps by benefiting men disproportionately (Kristjanson et al., 2017).
2. **Gender-Sensitive:** Interventions recognizing gender differences and addressing practical operational needs of female farmers (e.g., providing female-only training sessions) without challenging underlying power structures (Kristjanson et al., 2017).
3. **Gender-Responsive:** Strategies designed to deliberately remove barriers to women's participation by facilitating equal access to resources, extension, credit, and technologies (CARE International, 2025; UN Women, 2023).

4. **Gender-Transformative:** Projects that actively transform structural barriers, discriminatory social norms, patriarchal land tenure systems, and power relations, positioning women as equal leaders and decision-makers in environmental governance (Hillenbrand et al., 2024; Kristjanson et al., 2017).

We prioritized research showing gender-transformative approaches intentionally engage both men and women in critical reflections on intra-household power distribution, time use burdens, and asset control (Hillenbrand et al., 2024; Kristjanson et al., 2017). Rather than treating female farmers as passive recipients of “women-friendly” agricultural inputs, transformative interventions work with traditional leaders, male family members, and local government institutions to reshape socio-cultural expectations around property ownership and civic leadership (Hillenbrand et al., 2024). This institutional shift ensures that when women adopt new CSA practices, their economic gains are protected against male re-appropriation and their societal status is permanently elevated (Hillenbrand et al., 2024; Kristjanson et al., 2017).

Figure 1 illustrates the conceptual pathway through which enabling institutional contexts, structural resource access, and multidimensional empowerment enable women to adopt appropriate CSA technologies, ultimately leading to higher farm yields, improved household nutrition, and resilient rural livelihoods.

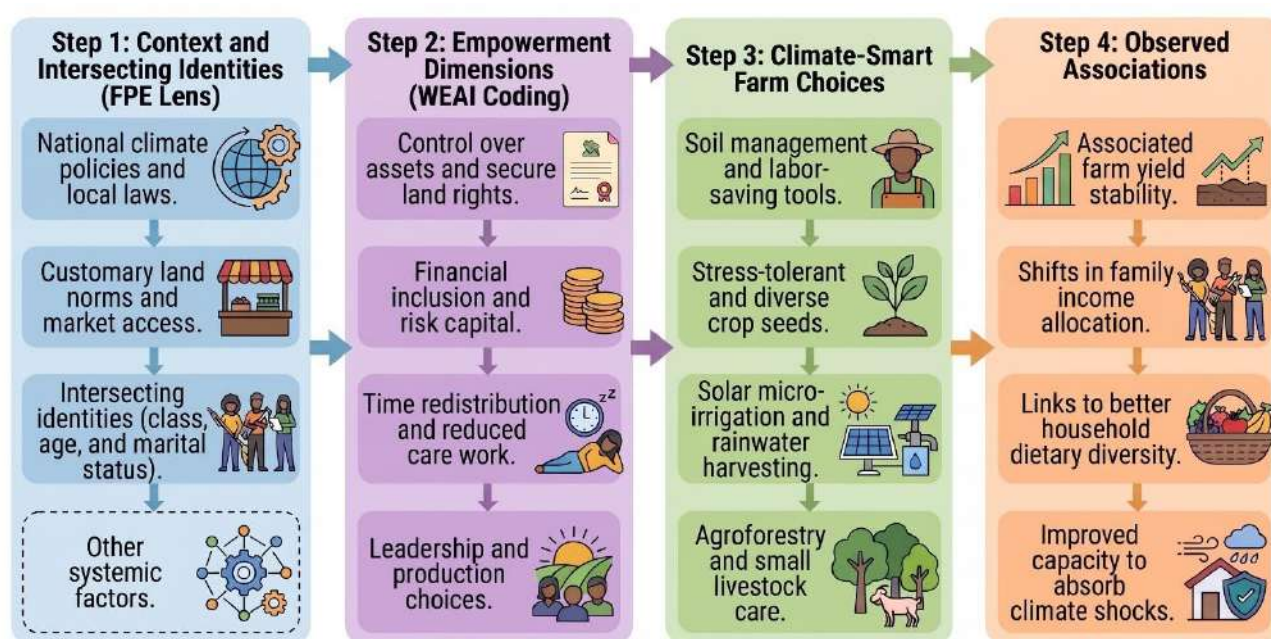


Figure 1. Conceptual Framework Mapping Observed Associations Between Intersectional Empowerment, CSA Adoption, and Household Resilience

5. RESULTS AND DISCUSSION: WOMEN'S PARTICIPATION AND STRUCTURAL RESOURCE ACCESS

Agrarian empowerment is structured by differentiated access to productive assets and institutional arenas (FAO, 2023; Kabeer, 1994). Crucially, treating women as a uniform group is analytically flawed; FPE demonstrates how environmental realities and ecological shocks are socio-political events shaped by intersecting axes of power, marginalization, class, and marital status (Kabeer, 1994; Rocheleau et al., 1996). In parallel, the WEAI conceptualizes disparities across five domains (5DE): Production, Resources, Income, Leadership, and Time Use (Alkire et al., 2013). These institutionalized gender gaps correlate strongly with constrained adaptation (Doss et al., 2018; FAO, 2023).

Intersectional FPE explains how resource access diverges fundamentally by socioeconomic class, age, and marital status (Kabeer, 1994). Wealthier female smallholders with registered land leverage liquidity to hire wage laborers and purchase inputs, whereas asset-poor smallholders, marginalized caste members, and landless laborers face compounding economic vulnerability (Kabeer, 1994). Generational hierarchies create sharp divides: senior matriarchs exercise allocative control over family labor, while younger married women and junior daughters-in-law face restrictive mobility norms and decisional exclusion (Kabeer, 1994). Marital status radically alters access: *de jure* female heads (widows, divorced) maintain autonomous plot control but risk land dispossession, whereas *de facto* female heads (husbands migrated for off-farm employment) manage daily operations but lack legal autonomy to contract credit without distant spousal approval (Doss et al., 2018).

5.1 Land Tenure Security and Customary Property Entitlements

Land secures credit, input subsidies, and long-term CSA investments (Doss et al., 2018; FAO, 2023; Kabeer, 1994). Across 46 countries, women's share among agricultural landowners or holders of secure rights ranged from 6.6% in Pakistan (based on 2018 data) to 57.8% in Malawi (based on 2020 data) (FAO, 2023). This empirical deficit directly suppresses the WEAI Resources domain, denying women independent asset ownership (Alkire et al., 2013).

FPE explains this gap through patrilineal inheritance regimes in sub-Saharan Africa and South Asia, restricting women to secondary usufructuary rights mediated by male kin (Doss et al., 2018; Kabeer, 1994). Consequently, women are disincentivized from CSA investments like hillside terraces, as male lineage heads can easily appropriate returns (Doss et al., 2018; Kristjanson et al., 2017). Class and marriage dictate this tenure insecurity (Kabeer, 1994). Wealthier women purchase statutory freehold land, whereas low-income tenants cultivate degraded parcels (Doss et al., 2018). Older widows with adult resident sons maintain stable usufruct claims, whereas young divorced mothers and junior co-wives in West Africa risk acute eviction upon household dissolution (Doss et al., 2018; Kabeer, 1994). Customary tribunals routinely override national laws, concentrating lower-income women on nutrient-depleted parcels (Doss et al., 2018; FAO, 2023; Kristjanson et al., 2017).

5.2 Financial Inclusion, Risk Capital, and Credit Infrastructure

CSA requires financial liquidity for certified seeds and micro-irrigation (CGAP, 2024; FAO, 2023). Systemic exclusion from formal finance suppresses the WEAI Resources and Income domains, restricting decision-making over credit (Afzal et al., 2024; Alkire et al., 2013; CGAP, 2024). Banks require registered land titles as collateral, barring women governed by patriarchal inheritance (Afzal et al., 2024; Doss et al., 2018). In Pakistan, empirical surveys indicate over 70% of female farmers face severe economic and credit constraints because they lack titled collateral for formal loans (Nadeem et al., 2023). Village Savings and Loan Associations (VSLAs) provide short-term liquidity but lack long-term capital (Mkupete, 2024; UN Women, 2025).

FPE highlights how class and marital status alter financial marginalization (CGAP, 2024; Kabeer, 1994). Wealthier females obtain commercial loans via savings or guarantors, whereas resource-poor females and *de jure* heads rely on predatory informal moneylenders (Afzal et al., 2024; CGAP, 2024). In remittance-dependent South Asia and sub-Saharan Africa, *de facto* female heads face regulations requiring spousal signatures, delaying seasonal inputs (Afzal et al., 2024; Kabeer, 1994). Algorithmic banking biases and weather insurance overwhelmingly target registered male operators (CGAP, 2024; Fisher & Kandiwa, 2014). Uninsured, asset-poor females resort to distress coping—liquidating assets or withdrawing children from schooling—which diminishes resilience (Fisher & Kandiwa, 2014; Mkupete, 2024).

5.3 Agricultural Extension, Information Asymmetry, and Digital Advisory Services

Unrestricted access to agrometeorological forecasts directly supports the WEAI Production domain (technical knowledge) and Leadership domain (organizational efficacy) (Alkire et al., 2013; Mittal et al., 2025; UN Women, 2023). However, public extension networks direct training primarily toward male household heads (Doss et al., 2018; Mittal et al., 2025). FPE frames these environmental knowledge asymmetries through male institutional biases and scarce female extension officers in LMICs (Mittal et al., 2025; UN Women, 2023). In environments with strict *purdah* or socio-religious segregation such as rural Punjab (Pakistan), northern Nigeria, and conservative areas of South Asia, females are culturally restricted from interacting with male personnel (Afzal et al., 2024; Mittal et al., 2025).

Information access fractures by class and age (Mittal et al., 2025). Senior matriarchs possess the freedom to attend public meetings, while young daughters-in-law face strict domestic seclusion (Kabeer, 1994; Mittal et al., 2025). Wealthy landowning households afford private advisory visits, whereas resource-poor females rely on delayed informal networks (Mittal et al., 2025). A digital gender divide limits Information and Communication Technology (ICT) uptake in LMICs (Mittal et al., 2025; UN Women, 2023). Male farmers use apps for real-time prices, while female farmers depend on delayed channels, limiting negotiation capacity (Mittal et al., 2025).

5.4 Time Poverty, Unpaid Care Work, and Labor Constraints

Rural women experience severe structural time poverty, directly evaluated under the WEAI Time Use domain (Alkire et al., 2013; Kabeer, 1994; Mekasha et al., 2026). Environmental degradation forces women to walk greater distances for water and fuel (FAO, 2024; Mekasha et al., 2026). Econometric time-use evaluations across sub-Saharan Africa (Ethiopia, Ghana) and South Asia (India, Bangladesh) demonstrate female farmers spend 4 to 7 hours per day on unpaid domestic care, compared to less than 1 hour per day for adult men (Kabeer, 1994; Mekasha et al., 2026). Water and fuelwood collection routinely consumes an additional 2 to 4 hours daily in semi-arid East Africa and South Asia (Mekasha et al., 2026). This workload restricts CSA adoption and extension attendance (Kristjanson et al., 2017; Mekasha et al., 2026).

FPE reveals how time poverty is shaped by intersectional class variables: wealthier females in electrified villages with piped water, or those hiring domestic laborers, experience lower workloads, allocating surplus time to CSA (Kabeer, 1994; Mekasha et al., 2026). Marital status and class uniquely alter empowerment, highlighted by empirical data from the agropastoral Hamer district of Ethiopia (Nurye et al., 2026). While female labor is critical—women perform 98% of domestic cooking, 96% of water collection, and 91% of dairy processing—men monopolize 95% of livestock decisions and 93% of asset sales (Nurye et al., 2026). In over 95% of inheritance cases, sons inherit major assets (cattle and land) (Nurye et al., 2026). Furthermore, during divorce proceedings, merely 12% of divorced women receive marital assets, paralyzing de jure female-headed households' climate adaptation capacity (Nurye et al., 2026). Table 1 summarizes these structural barriers, the corresponding gender disparities, and the institutional enablers.

Table 1. Structural Resource Barriers, Gender Disparities, and Institutional Enablers

Structural Dimension	Male Status / Access	Female Status / Access	Structural Impact on CSA	Gender-Transformative Enablers
Land Tenure	Statutory ownership; direct patrilineal inheritance (Doss et al., 2018).	Landownership <30% in one-third of 46 countries (6.6% in Pakistan (based on 2018 data)); secondary usufruct rights (FAO, 2023).	Lowers long-term soil/agroforestry investments (Kristjanson et al., 2017).	Joint statutory titling, widow protection (UN Women, 2023).
Financial Credit	Direct commercial loans via titled collateral (Doss et al., 2018).	Over 70% of female farmers in Pakistan face severe financial and credit constraints (Nadeem et al., 2023).	Limits upfront capital for stress-tolerant seeds (CGAP, 2024).	Non-land collateral, mobile micro-credit, VSLAs (UN Women, 2025).
Extension Info	Direct contact with public extension officers (Mittal et al., 2025).	Cultural seclusion norms and digital divide in LMICs limit access (Mittal et al., 2025).	Knowledge gaps regarding weather forecasts and practices (Mittal et al., 2025).	Female extension officers, interactive voice response (IVR) advisories (Mittal et al., 2025).
Time Use	Field crop labor; domestic care <1 hour/day (Kabeer, 1994).	4–7 hours/day domestic care; 2–4 hours fetching water in semi-arid East Africa (Mekasha et al., 2026).	Severe time poverty restricts training attendance (Mekasha et al., 2026).	Labor-saving tools, solar water, clean cookstoves (Hillenbrand et al., 2024; Kristjanson et al., 2017).

6. ADOPTION DYNAMICS OF CLIMATE-SMART AGRICULTURE (CSA) PRACTICES

Gendered preferences, intra-household resource allocation, and culturally prescribed agrarian roles structure climate-smart farming adoption (Aryal et al., 2014; Gemtou et al., 2024). Rural obligations drive smallholders to prioritize distinct adaptive interventions (Aryal et al., 2014; Doss et al., 2018). FPE demonstrates localized gender power relations dictate control over productive and reproductive spheres, shaping environmental decisions (Aryal et al., 2014; Kabeer, 1994).

6.1 Conservation Agriculture, Minimum Tillage, and the Manual Weeding Reality

Conservation Agriculture (CA) requires minimal soil disturbance, organic cover, and diversified rotations (Gemtou et al., 2024; Onyeneke et al., 2018). Zero-tillage conserves moisture but heavily shifts labor (Onyeneke et al., 2018; Theis et al., 2018). Unplowed plots face aggressive early weed emergence (Onyeneke et al., 2018; Theis et al., 2018). Across sub-Saharan Africa (Zambia, Zimbabwe, Malawi) and South Asia (eastern India, Bangladesh), cultural norms strictly assign manual hand-weeding to women (Glazebrook et al., 2020; Theis et al., 2018). Minimum-tillage without chemical herbicides doubles female weeding labor, exacerbating time poverty and depressing WEAI Time Use scores (Mekasha et al., 2026; Theis et al., 2018). Bundling soil conservation with gender-responsive machinery reduces this drudgery (Onyeneke et al., 2018; Theis et al., 2018).

Age and wealth determine equipment adoption and dictate sustainability (Onyeneke et al., 2018; Theis et al., 2018). Younger, wealthy farmers leverage liquidity to buy motorized weeders. Conversely, asset-poor female farmers and junior wives endure a severe two- to three-year manual labor surge during initial CA transitions in Zambia and Zimbabwe (Onyeneke et al., 2018; Theis et al., 2018). Lacking capital, these resource-constrained women abandon CA despite acknowledging its soil benefits (Onyeneke et al., 2018; Theis et al., 2018).

6.2 Crop Diversification, Indigenous Seed Systems, and Stress-Tolerant Varieties

Women drive crop diversification, traditional intercropping, and stress-tolerant seed adoption (Aryal et al., 2014; Gemtou et al., 2024). In Pakistan, a multistage random sampling survey of 384 women-operated farms using a multivariate probit model found only 17.4% adopted CSA practices like zero tillage. Furthermore, over 70% of respondents cited severe infrastructural and economic limits restricting machinery access (Nadeem et al., 2023). Lacking mechanization, female farmers intercrop staple grains with indigenous legumes, boosting WEAI Production scores and nutrition (Aryal et al., 2014; Sirilakshmi et al., 2026). Legume intercropping (maize with cowpeas or groundnuts) fixes nitrogen, supplies protein, generates female market revenue, and suppresses weeds (Gemtou et al., 2024; Puskur & Malhotra, 2024).

Female farmers select short-duration, drought- and flood-tolerant cultivars for harvest security (Aryal et al., 2014; Gemtou et al., 2024). Men prioritize commercial yield, whereas women demand storability, weevil resistance, easy threshing, fast cooking, and culinary palatability (Aryal et al., 2014; Fisher & Kandiwa, 2014). In drought-tolerant maize trials across Zimbabwe and Malawi, women rejected high-yielding commercial hybrids requiring excessive pounding labor (Fisher & Kandiwa, 2014). Participatory plant breeding integrating female knowledge yields higher sustained adoption (Aryal et al., 2014; Fisher & Kandiwa, 2014).

Age and wealth stratify seed choices (Puskur & Malhotra, 2024). Wealthier, younger female producers managing irrigated plots adopt commercial hybrid vegetables. Asset-poor older matriarchs rely on informal, zero-input farmer-saved seed networks for heirloom varieties, guaranteeing survival but limiting commercial expansion (Fisher & Kandiwa, 2014; Puskur & Malhotra, 2024).

6.3 Micro-Irrigation, Renewable Energy, and Clean Agricultural Technologies

Increasing rainfall variability threatens rainfed smallholders (FAO, 2024; UN Women, 2023). Solar drip irrigation kits and rainwater cisterns provide critical climate adaptations (Theis et al., 2018; UN Women, 2023).

Clean energy technologies alleviate manual water fetching drudgery (Theis et al., 2018; UN Women, 2023). Applying precise water to crop roots, drip networks cut evaporation and slash manual labor (Theis et al., 2018; UN Women, 2023). Secure access to solar drip kits enables women to turn domestic gardens into commercial dry-season plots, generating cash flow, providing micronutrients, and boosting WEAI Income scores (Sirilakshmi et al., 2026; Theis et al., 2018; UN Women, 2023). Pairing micro-irrigation with biodigesters and clean cookstoves reduces indoor smoke, lowers respiratory illness, and cuts firewood collection hours (Glazebrook et al., 2020; UN Women, 2023).

Wealth and age dictate solar pump adoption (Theis et al., 2018; UN Women, 2023). High capital costs restrict hardware exclusively to older, wealthy landed households without subsidies (Theis et al., 2018). In male-headed households, men frequently commandeered communal solar units for cash crops, diverting female labor to irrigate male fields and eroding empowerment gains (Theis et al., 2018; UN Women, 2023).

6.4 Small Livestock Management, Agroforestry, and Coastal Aquaculture

Gender strictly governs livestock: men control large livestock; women manage small ruminants (goats, sheep) and poultry (Doss et al., 2018; Sirilakshmi et al., 2026). Supplying veterinary vaccines and fodder banks builds female assets and improves WEAI Resources scores, particularly benefiting widows and asset-poor women unable to purchase cattle (Alkire et al., 2013; Sirilakshmi et al., 2026).

Agroforestry trees moderate microclimates, control erosion, and yield firewood (Gemtou et al., 2024; Kristjanson et al., 2017). Customary tenure deeply restricts female tree planting (Kristjanson et al., 2017). In patrilineal sub-Saharan societies, tree planting signifies permanent land ownership; male authorities thus forbid young wives and female tenants from planting long-lived species to prevent them solidifying land claims (Doss et al., 2018; Kristjanson et al., 2017).

In coastal zones facing sea-level rise and soil salinization, women organize adaptive collectives (Roy et al., 2024). In southwest Bangladesh's coastal deltas, empirical surveys document how women's self-help groups pioneer floating agriculture—hydroponic beds constructed from water hyacinths, bamboo, and compost to cultivate vegetables during extended monsoon floods (Bernier et al., 2016; Roy et al., 2024). These floating beds empower landless women and marginalized widows to produce nutrient-rich food during inundation shocks without requiring formal land rights (Bernier et al., 2016; Roy et al., 2024). Table 2 summarizes regional variations in CSA adoption rates, preferences, enablers, obstacles, and data collection methodologies.

Table 2. Regional Variations in CSA Adoption Rates, Preferences, Enablers, Barriers, and Data Collection Methodologies

Geographic al Region	Female Agricultural Workforce Share	Preferred CSA Technologies & Practices	Major Adoption Enablers	Primary Structural Obstacles	Data Collection Methodology & Context
Sub-Saharan Africa	50–60% of regional agricultural labor (FAO, 2023)	Drought-tolerant maize, legume intercropping, rainwater ponds, small ruminants (Gemtou et al., 2024; Nyasimi et al., 2014)	VSLAs, Women's Farmer Field Schools, joint titling laws (UN Women, 2023)	Patrilineal customary land inheritance, time poverty, lacking titled collateral (Doss et al., 2018)	Sex-disaggregated cross-sectional surveys ($N > 1,200$), Living Standards Measurement Study–Integrated Surveys on Agriculture (LSMS-ISA) data, smartphone time-tracking, focus group discussions (FGDs) across East/Southern Africa (Doss et al., 2018; Theis et al., 2018)
South Asia	60–70% of rural female agricultural labor (Doss & Raney, 2011)	Kitchen gardens, salt-tolerant rice, solar drip irrigation, laser land leveling (Aryal et al., 2014)	Women's Self-Help Groups (SHGs), IVR audio advisory (Mittal et al., 2025)	Socio-religious purdah seclusion, low handset ownership, mobility limits (FAO, 2023)	Multistage random surveys ($N = 384$ in Pakistan; $N = 1,661$ in Indo-Gangetic Plains), Multivariate Probit modeling, participatory appraisals (Nadeem et al., 2023; Aryal et al., 2014)
Latin America	30–45% of agrarian labor across diverse contexts (FAO, 2023)	Shade coffee, hillside terracing, biodigesters, rainwater cisterns (Bryan et al., 2018; Carr & Thompson, 2014)	Fairtrade/organic specialty cooperatives, carbon offset premiums (CGAP, 2024)	Cultural machismo norms, heavy domestic care burdens, credit exclusion (Doss et al., 2018)	Mixed-methods producer association surveys ($N = 130$), key informant interviews, intra-household resource mapping in Central/South America (Bryan et al., 2018; Carr & Thompson, 2014)
Southeast Asia	40–50% of the rice-producing agrarian workforce (FAO, 2023)	Mechanized direct-seeded rice, alternate wetting and drying, integrated rice-fish farming (Aryal et al., 2014; Bernier et al., 2016)	Participatory breeding programs, community-managed seed banks (Puskur & Malhotra, 2024)	Small operational parcel sizes, gender wage disparities, formal bank loan deficits (FAO, 2023)	Char-area multistage sample surveys ($N = 480$), gendered task-allocation tracking, econometric propensity score matching across deltaic rice zones (Bernier et al., 2016; Puskur & Malhotra, 2024)

7. FOOD SECURITY, HOUSEHOLD NUTRITION, AND CLIMATE RESILIENCE OUTCOMES

Agrarian literature links female empowerment across WEAI domains to higher agricultural productivity, food security, and climate resilience (Alkire et al., 2013; Mkupete, 2024; UN Women, 2025). Evaluating this requires context-specific analysis of agroecological and socioeconomic heterogeneity.

7.1 Yield Productivity Impacts and Agricultural Output Expansion

Policy narratives assume closing resource gaps universally boosts yields (FAO, 2023; Sirilakshmi et al., 2026). Counterfactual models project equalizing input access correlates with 20% to 30% yield increases on female-managed plots globally, associating with 2.5% to 4% output expansion and 12% to 17% undernourishment reduction (FAO, 2023). Micro-econometric evaluations urge caution (Doss et al., 2018; FAO, 2023). In Ethiopia, decompositions link a 23.4 percentage point yield gap to land quality, extension, and male labor deficits, not inefficiency (Aguilar et al., 2015). Malawian female smallholders face similar deficits; yield disparities associate with men's greater market, fertilizer, and labor access (Kilic et al., 2015). With equal inputs, female smallholders achieve comparable efficiency, linking to the WEAI Production domain (Doss et al., 2018). Wealthier female farmers with titled parcels (WEAI Resources) rapidly boost productivity. Conversely, resource-poor females, de jure female heads lacking labor, and young wives on marginal plots show modest yield links (FAO, 2023; Kristjanson et al., 2017).

7.2 Intra-Household Resource Allocation, Expenditure Behavior, and Dietary Diversity

Female-controlled income correlates stronger with family health and dietary diversity investments than male-controlled income (Kabeer, 1994; Sirilakshmi et al., 2026), reflecting the WEAI Income domain (Alkire et al., 2013). When females control assets and sales, expenditures associate with basic welfare (Bryan et al., 2018). Higher empowerment scores link to an 18% Household Dietary Diversity Score (HDDS) increase in rural Kenya and Ethiopia, plus higher nutrient-dense food consumption (Bryan et al., 2018; Sirilakshmi et al., 2026). Across sub-

Saharan Africa and South Asia, this correlates with reduced child stunting, wasting, and maternal anemia (Bryan et al., 2018; Sirilakshmi et al., 2026). Males link discretionary cash to personal consumption; females prioritize food, child preventive care, schooling, and sanitation (Kabeer, 1994). Age, marital status, and headship mediate this. De jure female heads have discretion, but poverty constrains spending. In extended patriarchal households, young married women and junior daughters-in-law lack crop revenue control, which husbands or senior fathers-in-law appropriate, lowering dietary yield translation (Kabeer, 1994; Sirilakshmi et al., 2026).

7.3 Household Shock-Absorptive Capacity and Climate Resilience

Empowerment associates with the capacity to absorb climate-induced shocks, evaluated via Resilience Index Measurement and Analysis (RIMA) and WEAI (Mkupete, 2024; UN Women, 2025). In eastern Kenya's dryland farming systems, higher empowerment scores correlate with elevated Resilience Capacity Index (RCI) scores, associating with a 25% farm yield stability increase and asset retention during drought (UN Women, 2025). In flood- and drought-prone rural Bangladesh, higher WEAI scores link to smaller food consumption declines following extreme rainfall (Mkupete, 2024). Micro-credit for solar drip irrigation pumps correlates with a 35% rise in off-season vegetable cash income and dietary diversity in southwest coastal Bangladesh and rural Kenya (CGAP, 2024; Roy et al., 2024; Theis et al., 2018). Empowerment reinforces collective resilience. Under the WEAI Leadership domain, female self-help groups, seed banks, and savings associations provide informal safety nets (Agarwal, 2020; Alkire et al., 2013). Groups in rural India and East Africa pool savings, distribute emergency grain, and exchange agricultural labor (WEAI Time Use domain) to rehabilitate plots post-cyclone, helping vulnerable households avoid distress asset sales (Agarwal, 2020; Mkupete, 2024). Table 3 summarizes empirical outcomes reported in selected studies of gender empowerment and climate-smart agriculture.

Table 3. Empirical Outcomes of Gender Empowerment in Climate-Smart Agriculture

Reference	Country	Study Design and Sample	Empowerment Dimension	Intervention	Observed Outcome
Diirro et al. (2018)	Kenya	Cross-sectional regression ($N = 707$)	Decisional Authority	Empowerment in agriculture	Significant maize productivity increase
Sraboni et al. (2014)	Bangladesh	Household survey	Asset Ownership and Leadership	Group membership and credit access	Positive association with calorie availability and dietary diversity
Tesafa et al. (2025)	Ethiopia	Cross-sectional survey ($N = 250$ households)	Production Decisions and Workload	Crop farming	35% potential crop production increase and improved dietary diversity
Theis et al. (2018)	Ethiopia, Ghana, Tanzania	Qualitative study	Time Redistribution	Small-scale irrigation technologies	Shifts in labor burdens and intrahousehold control

8. SYSTEMIC GAPS AND THE MITIGATION OF TECHNOLOGY BACKLASH

8.1 Global Failures on the Gender-Awareness Continuum

Analyzed through the gender-awareness continuum, international climate frameworks including Nationally Determined Contributions (NDCs), remain structurally “gender-blind,” failing to translate text into funded initiatives, thereby impeding the scaling of agricultural adaptation (CARE International, 2025; Kristjanson et al., 2017; UN Women, 2023). Policy discourse consistently reduces female farmers to passive vulnerabilities rather than recognizing them as institutional leaders (CARE International, 2025; Djoudi et al., 2016). Multilateral funds and carbon markets heavily favor statutory land titles, systemically excluding female smallholders who cultivate customary plots (CGAP, 2024; Doss et al., 2018). Rectifying this requires decolonizing neoliberal metrics to validate indigenous ecological knowledge and create genuinely inclusive paradigms (Djoudi et al., 2016; Vigil, 2024).

8.2 Technology Design and the Drudgery Paradox

Technology deployment frequently ignores female physical ergonomics (Puskur & Malhotra, 2024; Theis et al., 2018). Introducing capital-intensive practices correlates with the “drudgery paradox” increasing plot yields but shifting uncompensated manual labor onto women without transferring revenue control (Mekasha et al., 2026; Theis et al., 2018). Within the WEAI framework, this exacerbates Time Use deficits without improving Income metrics (Alkire et al., 2013). Furthermore, when subsistence activities become lucrative through commercial linkages, male re-appropriation frequently displaces women from their established livelihood niches (Doss et al., 2018; Kabeer, 1994; Theis et al., 2018).

8.3 Localized Failures in Punjab, Pakistan

These structural failures manifest acutely in agricultural hubs like Faisalabad and Okara in Punjab, Pakistan. Despite constituting 67.2% of the national agricultural workforce (Pakistan Bureau of Statistics, 2021), rural women encounter rigid, gender-blind socio-cultural norms that bar them from decision-making (Doss & Raney, 2011). Innovations like direct seeders are adopted exclusively by male landowners, exacerbating unpaid female weeding labor while preserving caste and gender divides (Aryal et al., 2014; Nadeem et al., 2023; FAO, 2023). State agricultural extension services remain male-dominated, systemically bypassing female laborers and denying them critical resilience information (FAO, 2023).

8.4 Mitigation of Technology Backlash

Advancing from gender-blind to gender-transformative programming requires targeted structural safeguards, separated below into global mandates and localized interventions.

Global Advice: Mandate rigorous gender impact assessments prior to introducing capital-intensive innovations to prevent the drudgery paradox (Hillenbrand et al., 2024; Theis et al., 2018). Finance female-led cooperatives, ensure mobile-money access, and support female-tailored machinery design (UN Women, 2025). Engage male spouses in dialogue to redistribute care responsibilities and prevent benefit capture (Hillenbrand et al., 2024; Theis et al., 2018).

Local Advice (Punjab): Establish gender-segregated, localized learning spaces to accommodate strict female mobility constraints in rural districts. Enforce strict gender quotas within district-level Water User Associations (WUAs) and aggressively recruit female agricultural extension staff to bypass exclusionary male advisory networks.

9. CONCLUSION AND RECOMMENDATIONS

Empowering rural women supports climate-smart agriculture and global food security (FAO, 2023; Sirilakshmi et al., 2026). Women play central roles in agricultural production, natural resource management, and family nutrition across the Global South (Doss & Raney, 2011; FAO, 2023). However, persistent structural barriers including discriminatory land tenure systems, unequal credit access, male-biased extension networks, digital divides, and heavy domestic care burdens restrict their adaptive capacity (FAO, 2023; Kabeer, 1994).

Observational evidence links reduced gender gaps with positive development outcomes (FAO, 2023; Mkupete, 2024; UN Women, 2025). Studies associate equal resource access with 20% to 30% higher farm yields, stronger household climate resilience, and better child nutrition outcomes (FAO, 2023; Mkupete, 2024; UN Women, 2025).

Several limitations affect this review. Methodological heterogeneity across studies limits direct cross-country comparisons. The review relies heavily on grey literature. Potential publication bias may favor positive findings. Finally, the authors did not perform a formal quality assessment of the included literature.

To reflect actual evidence strength, policy recommendations require clear division between globally supported measures and context-specific interventions.

9.1 Globally Supported Recommendations

Governments and institutions should institutionalize gender integration in climate governance by embedding explicit targets into NDCs, National Adaptation Plans (NAPs), and budgets (CARE International, 2025). Public agencies must systematically collect and analyze sex-disaggregated data to evaluate climate program impacts and enable evidence-based decisions (CARE International, 2025; Noor & Alam, 2026; UN Women, 2023). Research centers and equipment manufacturers should co-design adaptation tools alongside female farmers (Hillenbrand et al., 2024; Theis et al., 2018). Priority should focus on labor-saving tools like direct-seeded rice machinery, solar micro-irrigation, and processing equipment that reduce drudgery and free time for civic and educational activities (Glazebrook et al., 2020; Theis et al., 2018).

9.2 Context-Specific Recommendations

Interventions involving land and financial systems depend heavily on local legal, cultural, and agrarian structures, such as customary land tenure in Punjab, Pakistan. Governments should reform land registries to support joint titling for married couples and protect independent ownership for unmarried or widowed women where local laws permit (UN Women, 2023). Secure tenure correlates with long-term CSA investments (Doss et al., 2018; Kristjanson et al., 2017). Financial institutions should tailor loans using group guarantees, mobile transaction histories, and crop insurance (CGAP, 2024; UN Women, 2025). Public investments should address digital divides so rural women access advisories and market services (Mittal et al., 2025; UN Women, 2023).

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