TECHNICAL REPORT

Who Benefits From Mechanization? Evidence for Inclusive and Responsible Scaling of Smallholder Mechanization in Sub-Saharan Africa: A Practice-Oriented Synthesis

A practice-oriented synthesis companion to the scoping review on gender, youth, service-provider models, finance and enabling institutions, with implications for program design, monitoring and reporting in Southern Africa

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Front cover photo: Workshop participants on inclusive mechanization adoption, Asmara Hotel in Lusaka, Zambia on June 30, 2026 (*Photo*: Namukolo-Nali Rachel)
Back cover photo: Workers tend to cucumber seedlings in a greenhouse in Durban, South Africa (*Photo:* Dubes Sonego/ Shutterstock)

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Acronyms

2WT – two-wheel tractor

ACIAR – Australian Centre for International Agricultural Research

CAADP – Comprehensive Africa Agriculture Development Programme

CIMMYT – International Maize and Wheat Improvement Center

FACASI – Farm Mechanization and Conservation Agriculture for Sustainable Intensification

FAO – Food and Agriculture Organization of the United Nations

FGD – focus group discussion

GESI – gender equality and social inclusion

HAFIZ – Harnessing Appropriate-scale Farm Mechanization in Zimbabwe

IWMI – International Water Management Institute

KII – key informant interview

MSP – mechanization service provider

PRISMA-ScR – Preferred Reporting Items for Systematic Reviews and Meta-Analyses – Extension for Scoping Reviews

RCC – risk-contingent credit

S4I – Scaling for Impact

SAMA – Sustainable Agricultural Mechanization: A Framework for Africa

SMS – short message service

SSA – sub-Saharan Africa

TVET – technical and vocational education and training

VSLA – village savings and loan association

WTP – willingness to pay

Executive Summary

Agricultural mechanization is increasingly promoted as a pathway for transforming smallholder farming in sub-Saharan Africa (SSA) by reducing labor drudgery, improving the timeliness of farm operations, raising productivity and creating rural service markets. Yet access, participation and benefit remain uneven, particularly for women and young people as users, operators, service providers and entrepreneurs.

This report, prepared under the CGIAR Scaling for Impact (S4I) Program, is a shorter, practice-oriented synthesis of a scoping review of inclusive and responsible scaling of smallholder mechanization in SSA. The full review, with its complete methods and analytical argument, has been prepared separately as a journal manuscript (Choruma and Enokenwa Baa, under review). This report draws on the same evidence base but focuses on what the findings mean for program design, monitoring and reporting, particularly in Southern Africa. It asks who takes part in, gains from and is left out of mechanization as it is scaled.

652
records identified across Scopus, Web of Science, Google Scholar and supplementary sources

112
full texts assessed for eligibility

41
reports met the initial inclusion criteria

21
unique mechanization evidence records synthesized

The 21 evidence records were organized under five themes: structural drivers of gendered exclusion; digital and platform-based models; youth agripreneurship and service markets; financial innovation for inclusive access; and enabling environment – policy, governance and partnerships.

Key findings

- **Exclusion is systemic.** It comes from interacting constraints in asset ownership, finance, information, skills, social norms and the way service markets are organized, not from technology alone.
- **Service provision widens access, but not automatically.** Service-provider models, group access, digital booking and risk-responsive finance can lower barriers, but none is inclusive without deliberate design, monitoring and institutional support.
- **Digital platforms work as hybrids.** Booking agents and phone calls remain central for smallholders even where tractor-hire apps exist.
- **Risk matters as much as price.** In Zambia, credit that adjusts to shocks and protection against repair costs were strongly valued, and female farmers were more likely to prefer group ownership.
- **Control, income and risk are unevenly shared.** Women and young people appear more often as clients, operators or booking agents than as machine owners; income goes mainly to owners, and borrowers with the least capital carry the heaviest risk.
- **Southern African evidence is narrow.** Nine of the 11 Southern African records come from Zambia or Zimbabwe, so implications for the wider sub-region are design principles to be tested, not proven solutions.
- **Evidence on who benefits is thin.** Few studies follow agency, drudgery, income and retention over time, broken down by sex and age.

What this means for S4I

Inclusive mechanization scaling needs several entry routes into service markets, finance designed around risk, gender-responsive and youth-oriented skills development, accountable partnerships, and monitoring that tracks who control machines, who earns income and who carry risk, not only how many machines or hectares are reached. Three tools in this report support this: the diagnostic questions in Table 2, the control, benefit and risk guide in Table 6, and the suggested indicators in Table 8.

About this Report

This report and the companion journal manuscript (Choruma and Enokenwa Baa, under review) come from the same scoping review and evidence base of 21 mechanization evidence records. They are prepared in parallel but serve different purposes, as summarized in Table 1.

Table 1. How this report relates to the companion manuscript.

Aspect	This S4I technical report	Companion journal manuscript
Purpose	Turn the evidence into practical guidance for designing, monitoring and reporting inclusive mechanization scaling	Make an original scholarly contribution on inclusive and responsible scaling of mechanization
Main audience	S4I solution-track teams, implementation partners, national governments and funders	Researchers, journal reviewers and the wider scientific community
Methods	Summarized in Section 2; readers are referred to the manuscript for the full protocol	Full search strategy, eligibility criteria, screening counts and evidence-audit categories
Emphasis	Key findings, strength of evidence, program implications and indicators for monitoring	Analytical depth, methodological rigor and comparison with earlier reviews
Review status	Not peer reviewed; subject to IWMI research-quality and S4I knowledge-product procedures	Prepared for submission to a peer-reviewed journal

Avoiding duplication

This report does not reproduce the manuscript. It condenses the methods, results and discussion into a practice-oriented synthesis, and it cross-references the manuscript wherever more detail is available, for example on the keyword strategy, the full eligibility criteria and the evidence-audit categories. Figures and tables reused from the review are marked as adapted from the companion manuscript. Section 6 and Table 8 are specific to this report and are not part of the manuscript.

Contribution to S4I reporting

The report is intended as an S4I knowledge product that supplies evidence for inclusive and responsible scaling of mechanization. It informs the CIMMYT-led S4I work on scaling inclusive mechanization through rural entrepreneurship and financial innovation in Zambia and complements the companion workshop report on inclusive scaling for mechanization adoption in Zambia (Enokenwa Baa et al., 2026). The S4I key performance indicator under which this report is counted, and the applicable publication and knowledge-product review steps, will be confirmed with the S4I monitoring, evaluation and learning team before publication.

How to use this report

- **For a quick overview:** the Executive summary and Table 5.
- **For program design:** Table 2 (diagnostic questions for women and youth) and Section 4.4 (implications for Southern Africa).
- **For monitoring and reporting:** Table 6 (control, benefits and risks) and Section 6 (suggested indicators).
- **For the strength of the evidence:** Table 4, the “Strength of evidence” notes at the end of each theme, and Table 7.

1 Introduction

1.1 Why Inclusion Matters in Mechanization

Agricultural mechanization is increasingly promoted as a pathway for transforming smallholder farming in SSA, yet evidence remains fragmented on how it can be scaled in ways that are both inclusive and responsible (Van Loon et al., 2020). Existing studies examine adoption, two-wheel tractors, machinery-hire markets, service-provider models and digital platforms, but fewer ask who gains access, who controls mechanization services, who captures income and labor savings, and who is left out (Mohammed et al., 2023; Ngoma et al., 2023; Daum et al., 2021; Takeshima, 2024; Yahaya et al., 2026). This matters because mechanization is not socially neutral: access and outcomes depend on land and asset ownership, finance, technical knowledge, social norms, labor relations and information (Chigbu et al., 2019; Njuki et al., 2022).

SSA still has a large mechanization gap. Weak rural financial markets, high purchase and maintenance costs, limited after-sales services and machinery poorly matched to small farms all hold it back (Daum and Birner, 2020; Van Loon et al., 2020). These constraints are felt unequally: women and young people often have weaker access to machinery ownership, training, finance and service-provider opportunities (Daum et al., 2022; Fischer et al., 2018). The report focuses on tillage, planting, harvesting and post-harvest operations, although similar dynamics are likely to apply to mechanized irrigation equipment.

Policy has shifted accordingly. The 2014 Malabo Declaration recommitted African Union member states to the Comprehensive Africa Agriculture Development Programme (CAADP) and placed agricultural transformation at the center of Africa's food-security agenda. The Sustainable Agricultural Mechanization: A Framework for Africa (SAMA) makes sustainable mechanization a core part of that transformation and stresses private-sector participation, gender equality, youth employment and environmental sustainability (FAO and African Union, 2022). At country level, Zambia's National Agricultural Mechanisation Strategy 2024–2028 explicitly includes smallholder farmers, women and youth in its financing and service-delivery objectives (Ministry of Agriculture, 2024). The question is therefore no longer whether mechanization should expand, but how can investments avoid reproducing existing inequalities as they scale.

1.2 From Adoption to Scaling

Scaling means extending an innovation to many more people and places and embedding it in the markets, institutions and policies that sustain it (Wigboldus et al., 2016; Woltering et al., 2019; Kihoro et al., 2025). A *scaling pathway* is the combination of business model, delivery channel and institutional arrangement through which machinery or mechanized services reach farmers (Van Loon et al., 2020). Common pathways include two-wheel tractor systems, fee-for-service hiring, mechanization service providers (MSPs), group ownership, state-supported service centers and digital booking platforms such as Hello Tractor (Daum et al., 2021; Yahaya et al., 2026). Experience from agricultural innovation platforms in Southern Africa shows that scaling depends on sustained coordination, joint learning and institutional anchoring, not on spreading technology alone (Ncube et al., 2025).

Three tools from scaling science shape this report. The *Scaling Scan* is a practical diagnostic that helps teams find the strengths and weaknesses of their scaling ambition across ten ingredients, such as finance, business case, value chains, skills and public-sector governance (Jacobs et al., 2021). *Responsible scaling* means expanding an innovation in ways that anticipate and manage its social, economic and environmental consequences, so that benefits are shared and harm to vulnerable groups is avoided (Stilgoe et al., 2013; Kihoro et al., 2025). The *GESI-Responsive Scaling Framework* puts these principles into practice through six domains that treat scaling as a social process (McGuire et al., 2026).

1.3 The Southern African Context

The evidence base is regionally uneven. Eastern and Southern Africa have substantial work on two-wheel tractors, conservation-agriculture equipment, willingness to pay and service provision; West Africa has evidence on tractor-hire markets and digital or state-supported services; and Central Africa is weakly represented in English-language sources (Baudron et al., 2015, 2019; Diao et al., 2014; Ngoma et al., 2023). Southern Africa is particularly relevant because recent studies there offer some of the clearest evidence on demand for mechanized services, ownership preferences and gender differences. In Zambia and Zimbabwe, demand for services exists even where few farmers own two-wheel tractors (Ngoma et al., 2023), and in Zambia female farmers are more likely to favor group ownership and risk-contingent finance (Mulungu et al., 2025). Initiatives supported by the International Maize and Wheat Improvement Center (CIMMYT) in both countries have tested starter packs, local manufacturing, service-provider training and vocational pathways, showing that the service-provider approach can work but that its spread depends on finance,

training and repair capacity rather than machinery alone (Matin et al., 2022; CIMMYT, 2022b). Service provision is therefore, a practical route to wider access, but it is not automatically inclusive.

1.4 Objectives and Questions

The review maps and synthesizes evidence on inclusive and responsible scaling of smallholder mechanization across SSA, using gender and youth as central lenses. It addresses five questions:

1. How do gender and age shape access to and benefit from mechanization?
2. Which service and scaling models show potential for inclusion?
3. Which financial mechanisms address capital and risk barriers?
4. Which enabling institutional conditions support inclusive scaling?
5. Which evidence gaps remain, particularly for program design in Southern Africa?

Compared with earlier reviews, which have examined the supply, demand and governance of mechanization (Daum and Birner, 2020), the limits to scaling service models (Van Loon et al., 2020) and the drivers that make mechanization gendered (Kansanga and Dinko, 2024), the review adds three things. It examines each scaling ingredient in terms of whom it works for and whom it leaves out; it uses a political-economy lens to ask who controls machines, service markets and data, who captures income and who carries risk; and it uses a responsible-scaling lens to anticipate harms and trade-offs as mechanization spreads. The full argument is set out in the companion manuscript.

2 How the Evidence was Assembled

This section summarizes the methods. The full protocol, keyword strategy, eligibility criteria and audit categories are reported in the companion manuscript (Choruma and Enokenwa Baa, under review).

2.1 Search, Screening and Evidence Audit

The scoping review followed Arksey and O'Malley (2005) and Levac et al. (2010), with reporting guided by the PRISMA Extension for Scoping Reviews (PRISMA-ScR) (Tricco et al., 2018). English-language publications from January 2004 to August 2026 were searched in Scopus, Web of Science and Google Scholar, supplemented by CGSpace, the open-access repository of CGIAR research outputs, and by citation tracking. The 2004 start date follows the 2003 Maputo Declaration, through which African Union member states endorsed CAADP, and covers two decades of renewed interest in smallholder mechanization (Daum and Birner, 2020). Studies were eligible if they provided substantive evidence on mechanization in smallholder systems in SSA and addressed at least one of gender, youth, inclusion, service provision, entrepreneurship, finance or scaling. Studies of large-scale commercial farming only, studies outside SSA, non-English sources and studies of irrigation or land preparation without a substantive mechanization component were excluded.

From 652 records to 41 reports. The searches identified 652 records: 618 from the three databases and 34 from gray literature and hand-searching. After 165 duplicates were removed, two reviewers independently screened the titles and abstracts of the remaining 487 records and resolved disagreements through discussion. They excluded 375 records, mainly because the geography or topic was wrong, mechanization was not the focus, or there was no gender, youth or scaling dimension. The remaining 112 reports were read in full, and 71 were excluded, most often because methods were poorly reported or there were no primary data. This left 41 reports that met the initial criteria (Figure 1).

From 41 reports to 21 evidence records. Closer reading showed that not all of these 41 reports contained mechanization evidence of their own, so a final evidence audit applied two rules. Reports without substantive mechanization-specific evidence from SSA, such as conceptual frameworks, broad policy documents and contextual literature on gender, digital agriculture, finance or land tenure, were reclassified as supporting sources: they are cited to interpret findings but not counted as evidence. Publications reporting the same dataset or program were consolidated into one evidence unit. Together, these rules removed 20 reports from the count and left 21 unique evidence records. Reviews were kept as evidence records only where they synthesized mechanization-specific evidence from SSA. Two records on non-motorized technologies (treadle pumps and manual planting basins) were kept as indirect evidence on farm power and labor burden, and a recent economic analysis of the Zimbabwean service-provider model (Matin et al., 2026) was merged with the earlier record on the same model (Matin et al., 2022).

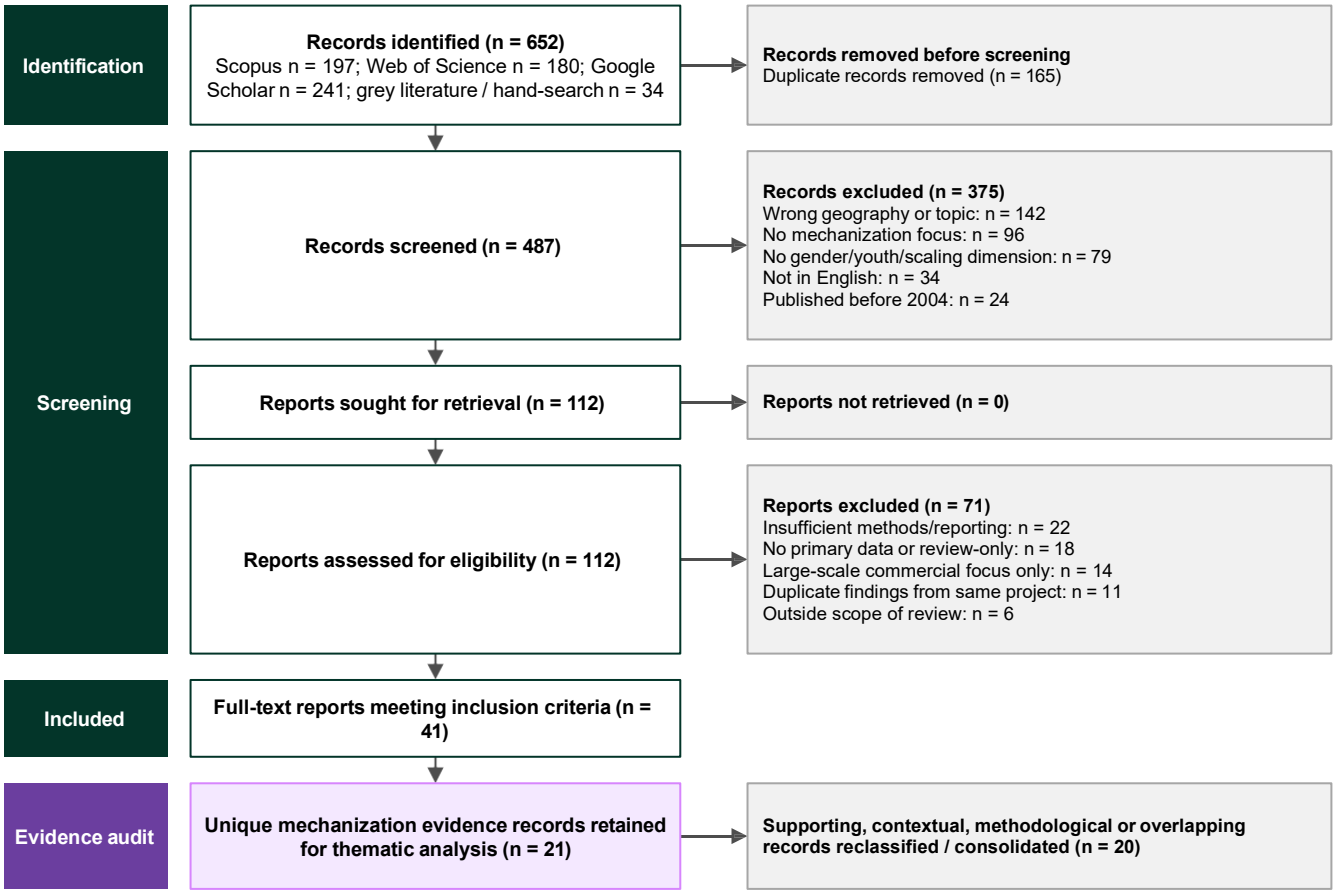


Figure 1. Study selection and final evidence audit (PRISMA-style flow diagram).
Source: Adapted from the companion manuscript.

2.2 Analysis

Data on study design, country, mechanization type, target group, inclusion findings, barriers, enablers, scaling model and financing were extracted with a standard form. Thematic analysis followed Braun and Clarke (2006), combining categories from the conceptual framework with themes that emerged from the evidence. Two reviewers coded a subset of ten records independently, reaching 84% agreement before resolving differences. To keep findings separate from interpretation, each theme in Section 3 first reports what the records found and ends with a short “Strength of evidence” note and a brief “For practice” pointer; fuller program implications are drawn in Sections 3.7, 4 and 5.

2.3 Conceptual Framework

The review combines four perspectives (Figure 2): the Scaling Scan, used with an inclusion lens (Jacobs et al., 2021); responsible-scaling principles of anticipation, inclusion, reflexivity and responsiveness (Stilgoe et al., 2013; Kihoro et al., 2025); the six domains of the GESI-Responsive Scaling Framework (McGuire et al., 2026); and a gendered political-economy lens that treats access as shaped by power, institutions and social norms (Chigbu et al., 2019; Kansanga and Dinko, 2024). Together they ask who benefits from mechanization scaling, who is excluded, why, and which conditions enable fairer outcomes. Table 2 turns the framework into practical diagnostic questions that program teams can use when designing or reviewing a mechanization scaling pathway.

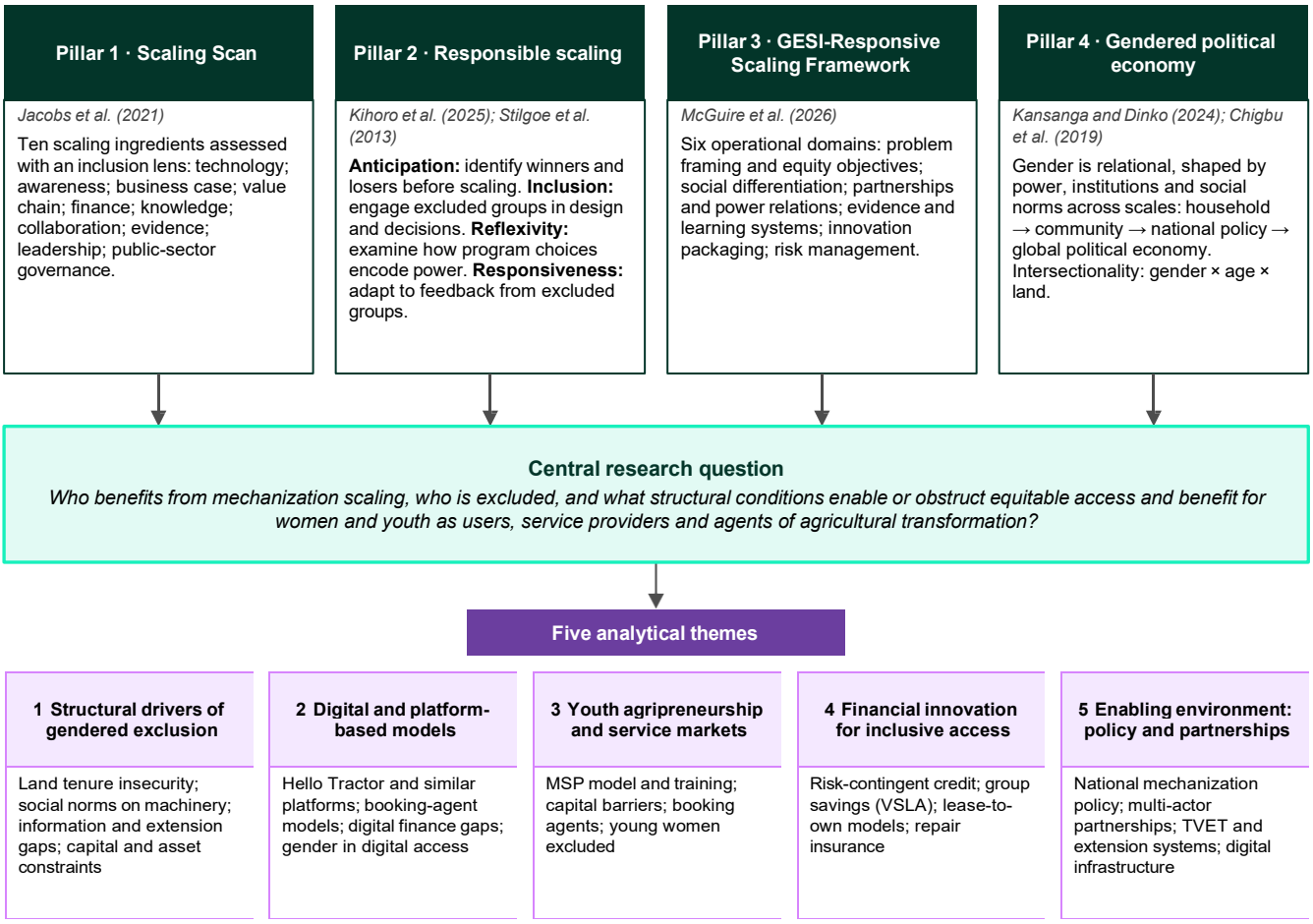


Figure 2. Integrated analytical framework linking the Scaling Scan, responsible scaling, GESI-responsive scaling and a gendered political-economy lens to the five analytical themes.
Source: Adapted from the companion manuscript.

Table 2. Diagnostic questions linking Scaling Scan ingredients to inclusion of women and youth.

Scaling ingredient	Standard question (adapted from Jacobs et al., 2021)	Inclusion lens – women	Inclusion lens – youth
Technology and practice	Is the technology relevant, functional and better than existing alternatives?	Is machinery physically and practically accessible? Does design address women's workloads, safety and tasks? Were women involved in design and testing?	Are pay-per-use or lower-capital entry options available? Are machine packages suited to young people with few assets?
Awareness and demand	Do target users know about the innovation and want to use it?	Do demonstrations reach women at accessible times and places? Do households and community leaders accept women operating machines or running machinery businesses?	Are young women and men told about both service use and enterprise opportunities? Do communities see young people, particularly young women, as credible operators?
Business case	Is there a viable proposition for users, service providers and investors?	Can women MSPs run viable businesses despite smaller networks, mobility limits or less start-up capital?	Can young people enter without collateral or credit histories? Are apprenticeship or staged-entry models viable?
Value chain	Are equipment, spare parts, services and markets functional and accessible?	Are women included as operators, mechanics, traders and service providers as well as clients?	Are young people included as operators, booking agents, mechanics, dealers and entrepreneurs?
Finance	Are financing options available, affordable and well structured?	Do products allow for lower collateral, seasonal risk and repair costs? Are group finance and risk protection accessible?	Do lease, pay-per-use or group finance options reduce collateral and credit-history barriers?

(continued)

Scaling ingredient	Standard question (adapted from Jacobs et al., 2021)	Inclusion lens – women	Inclusion lens – youth
Knowledge and skills	Do users and service providers have technical and business skills?	Are training formats, timing and trainers accessible to women and suited to literacy and workload constraints?	Does training cover operation, maintenance, business and financial skills, including technical and vocational education and training (TVET)?
Collaboration	Are partnerships in place to sustain and grow the innovation?	Are women's organizations formal partners with decision-making influence?	Are youth organizations, agripreneur networks and vocational institutions part of scaling governance?
Evidence and learning	Is evidence generated to guide adaptation and investment?	Are access, use, agency, drudgery, income and retention tracked by sex, including non-users?	Are outcomes broken down by age and sex, including for young women?
Leadership and management	Are effective champions and managers in place?	Are women in substantive leadership and program-design roles, not only role models?	Are young people in leadership and supported with mentoring and networks?
Public-sector governance	Do policies and institutions enable rather than obstruct scaling?	Do mechanization policies include measurable gender objectives, implementation mechanisms and monitoring?	Do policies link mechanization to youth employment, enterprise development and funded skills pathways?

Source: Adapted from the companion manuscript.
Note: MSP = mechanization service provider.

3 Key Findings

3.1 Overview of the Evidence

The 21 evidence records span 2012–2026 and include 16 peer-reviewed articles or reviews and five program, institutional or industry sources. They combine household surveys, econometric analyses, mixed-methods studies, case studies, program evaluations, market analyses and reviews (Annex). Evidence is concentrated in Eastern and Southern Africa, with fewer records from West Africa and none from Central Africa (Table 3). Table 4 shows which records support each theme and how consistent and complete that evidence is.

Table 3. Included evidence records by sub-region (non-exclusive counts).

Sub-region	n	Main evidence types	Mechanization focus
Eastern Africa (Ethiopia, Kenya, Tanzania, Uganda)	10	Farm surveys, mixed-methods studies, program and platform evidence	Two-wheel tractors, combine harvesters, forage choppers, service provision, digital platforms
Southern Africa (Zambia, Zimbabwe, Malawi)	11	Mixed methods, willingness-to-pay studies, farm assessments, program evaluations	Two-wheel tractors, rippers, basin diggers, threshers, tractor ownership, MSP models
West Africa (Ghana, Nigeria, Benin, Mali, Burkina Faso)	7	Market analysis, adoption surveys, digital and service-market case studies	Tractor hire, two-wheel tractor service markets, digital platforms
Multi-country / SSA-wide	2	Mechanization reviews and multi-country evidence	Service markets, enabling conditions and mechanization systems

Source: Adapted from the companion manuscript.
Note: Several records cover more than one sub-region, so counts exceed 21.
Record 17 (Daum et al., 2022) covers Benin, Kenya, Mali and Nigeria, so it is counted under Eastern and West Africa only.

Table 4. Strength of evidence behind each theme.

Theme	Records (Annex no.)	Coverage	Consistency of findings	Main gaps
1. Structural drivers of gendered exclusion	1, 2, 5, 9, 10, 15, 17, 18, 20, 21 (n = 10)	Southern, Eastern and West Africa	High in direction: records that break results down by gender show greater constraints for women. Mostly cross-sectional; records 10 and 15 are indirect.	Control of machines and income within households; change over time; young women; Central Africa
2. Digital and platform-based models	6, 14, 18, 19 (n = 4)	Nigeria, Kenya, multi-country	Moderate: one independent empirical study and company or program reporting agree that agents and phone calls remain central. Gender effects not measured directly.	Independent, sex- and age-disaggregated platform evaluations; no Southern African platform study
3. Youth agripreneurship and service markets	3, 4, 7, 8, 11, 13, 17, 18 (n = 8)	Eastern, Southern and West Africa	Moderate: viability of two-wheel tractor services is consistent; evidence that youth benefit rests mainly on a perception survey and program reporting.	Survival, income and retention of youth-led enterprises; young women as providers
4. Financial innovation for inclusive access	1, 2, 8, 12, 14, 20 (n = 6)	Zambia, Zimbabwe, Ethiopia, Ghana; Nigeria, Kenya and Uganda (record 14)	Consistent that finance and risk constrain access; gender-differentiated preferences rest largely on one Zambian study.	Tested finance products; gendered effects of leasing, pay-per-use and digital finance
5. Enabling environment – policy, governance and partnerships	3, 4, 6, 8, 16 (n = 5)	Zimbabwe, Zambia, SSA-wide	Consistent that technology readiness alone does not secure scaling; mainly multi-case and program evidence.	Whether gender and youth policy commitments are implemented; Central Africa

Source: Adapted from the companion manuscript.
Note: Record numbers refer to the Annex. Consistency describes agreement in the direction of findings, not the size of effects.

3.2 Theme 1: Structural Drivers of Gendered Exclusion

Why women, and young women in particular, are less likely than men to access, operate or benefit from mechanization.

Land, assets and control over investment

Women's access to mechanization depends more on control over assets and finance than on technical ability. Services and equipment often require cash, collateral or decision-making authority over land, and these requirements meet unequal land and asset rights across SSA (Chigbu et al., 2019). In Zambia and Zimbabwe, female-headed households were willing to pay less than male-headed households for two-wheel tractor services, and wealth strongly shaped demand (Ngoma et al., 2023). In Malawi, women's uptake of treadle-pump irrigation fell short of expectations because of time burdens, mobility limits and weak control over assets (Kamwamba-Mtethiwa et al., 2012). In Zambia, female farmers were more likely than men to prefer group ownership, which shares costs and risks (Mulungu et al., 2025). Finance built around individual ownership therefore tends to favor better-off farmers.

Social norms, tasks and machine design

Gender norms shape who is seen as a legitimate operator, service provider or technical decision-maker, and continue to limit young women's involvement in machinery work (Daum et al., 2022). In Kenya, female tractor operators performed well but faced social resistance, and some dropped out of male-dominated training and work settings (FSD Kenya, 2024). In Tanzania, women adopted mechanized forage chopping where it addressed tasks they already did (Fischer et al., 2018), and there is substantial demand for post-harvest operations such as threshing and shelling, often done by women (Baudron et al., 2019; Yahaya et al., 2026). These are useful entry points, but if a sheller is introduced only for women's work, men may still own it and control its income. In Murehwa, Zimbabwe, manual planting basins increased labor without raising yields (Rusinamhodzi, 2015), showing that drudgery reduction should be an explicit program outcome, not an assumed side benefit.

Information and digital access

Information gaps go beyond knowing that tractors exist: farmers may not know who offers services, what they cost, how to book and pay, or where to get repairs. In Ghana, access to information was linked to adoption alongside credit, remittances and farm size (Mohammed et al., 2023). Digital channels can widen reach but may exclude those

with less access to phones, connectivity and digital skills, a gap that is often wider for women (Choruma et al., 2024, 2026).

Strength of evidence. Ten records from three sub-regions agree in direction, but most are cross-sectional, two concern non-motorized technologies, and few observe who controls machines and income inside the household.

For practice. Offer access routes that do not depend on individual collateral, track drudgery and control of income as outcomes, and use several communication channels.

3.3 Theme 2: Digital and Platform-Based Models

Whether digital tools that connect farmers with tractor owners, sometimes called "Uber for tractors", widen or narrow access.

In Nigeria, digital monitoring and coordination on the Hello Tractor platform reduced transaction costs for service providers, especially larger ones, but smallholders mostly reached services through booking agents and phone calls rather than apps (Daum et al., 2021). Platforms therefore build on existing intermediaries rather than replacing them. Hello Tractor reports serving more than two million farmers in 18 African countries (Hello Tractor, 2026), but these figures are self-reported and not broken down by gender or age. Digital mechanization adds a second layer of potential exclusion, because women with less access to phones, airtime, data, digital skills or mobile money may be disadvantaged as clients, agents or providers (Choruma et al., 2024).

Strength of evidence. Four records, only one independent empirical study; no included record evaluates a platform in Southern Africa, and gendered effects are inferred rather than observed.

For practice. Combine apps with booking agents, SMS, voice and extension channels, and require platform partners to report results by sex and age.

3.4 Theme 3: Youth Agripreneurship and Service Markets

Mechanization as a source of jobs and enterprises for young people, and the barriers to entering and staying in business.

Stakeholders surveyed in Benin, Kenya, Mali and Nigeria report that young people generally view mechanization positively but name capital and skills as major barriers (Daum et al., 2022). The CIMMYT-led Farm Mechanization and Conservation Agriculture for Sustainable Intensification (FACASI) project (2013–2019) trained more than 100 young people as service providers in Ethiopia, Kenya, Tanzania and Zimbabwe (CIMMYT, 2022a). A peer-reviewed analysis of a comparable service-provider model in Masvingo, Zimbabwe, illustrates the potential (Matin et al., 2026):

42
months of monitoring of one service provider in Masvingo, Zimbabwe

136
farmers and two farmer groups served

167%
return on investment without subsidy (US$9,318 gross revenue)

50%
of clients were women

These figures are illustrative, not independently evaluated impact estimates. Across Ethiopia, Burkina Faso and Zimbabwe, two-wheel tractor services were economically viable, with multifunctional machines and post-harvest services extending the revenue base (Yahaya et al., 2026). Operator, apprentice, booking-agent, mechanic and post-harvest roles offer lower-capital entry points than ownership. Barriers remain: young entrants often lack savings, collateral and credit histories, while high maintenance costs and weak spare-parts supply undermine ownership (Mulungu et al., 2025; Yahaya et al., 2026). Young women face compounded barriers where age and gender norms interact, and need mentoring, safe training environments and accessible finance as well as technical skills (Fischer et al., 2018; FSD Kenya, 2024).

Strength of evidence. Viability of service provision is consistent across three countries, but evidence that young people specifically benefit rests mainly on a perception survey and program reporting; no record follows youth enterprises over time.

For practice. Build staged entry routes into service markets and track whether young women and men stay in business across seasons.

3.5 Theme 4: Financial Innovation for Inclusive Access

How the structure of finance, and who carries the risk, shapes who can own, operate or use machinery.

Finance is one of the most consistent constraints in the evidence. Collateral-based lending excludes farmers with few assets, and even where credit is available the borrower carries the risk of breakdowns, seasonal swings in demand and repayment schedules that do not adjust to shocks. A Zambian study combining a survey of 208 farmers, 18 focus group discussions and 28 key informant interviews found risk-contingent credit to be a highly preferred incentive for tractor ownership, with added demand for repair-risk protection, especially among female farmers (Mulungu et al., 2025). Reducing risk may therefore matter as much as lowering interest rates. Risks differ by model: a farmer group sharing a two-wheel tractor must coordinate use and repayment, while a provider with a four-wheel tractor must keep it busy enough to cover costs.

Group ownership can lower individual capital needs and spread risk, and in Ethiopia cooperative membership was associated with higher adoption of tractor plowing and combine harvesting (Mengesha Abebe et al., 2025). Groups need clear rules for use, maintenance, conflict resolution and asset replacement. Pay-per-use and lease-to-own arrangements further separate access from ownership, and machine-use records from platforms could help lenders judge whether a business can repay (Daum et al., 2021; Hello Tractor, 2024). Mobile financial services have improved farmers' market participation in Kenya where supporting infrastructure and regulation are in place (Parlasca et al., 2022), but evidence on the gendered effects of mechanization-specific digital finance remains limited.

Strength of evidence. Six records agree that finance and risk constrain access, but gender-differentiated preferences rest largely on one Zambian study, and no record tests a risk-contingent or repair-risk product in practice. These findings show demand, not effectiveness.

For practice. Pilot bundled products (credit, group finance, leasing, repair cover) and compare uptake and repayment by sex, age and provider type.

3.6 Theme 5: Enabling Environment – Policy, Governance and Partnerships

The wider conditions that allow inclusive mechanization to spread and last.

SAMA and Zambia's 2024–2028 strategy recognize gender, youth and affordable financing for smallholders, women and youth organizations (FAO and African Union, 2022; Ministry of Agriculture, 2024); the open question is whether these commitments produce measurable results. In Zimbabwe, the CIMMYT-led Harnessing Appropriate-scale Farm Mechanization in Zimbabwe (HAFIZ) project, funded by the Australian Centre for International Agricultural Research (ACIAR), trains local artisans to build and repair two-wheel tractor attachments and embeds machinery skills in vocational courses, so that capacity remains after the project ends (CIMMYT, 2022b). Across mechanization cases, collaboration and finance were among the weakest scaling ingredients even where technology was mature, and coaching and brokering often stayed dependent on project staff (Van Loon et al., 2020). Scaling needs active brokerage and institutional anchoring (Ncube et al., 2025), and women's organizations, youth networks and vocational institutions need real roles in shaping service models, finance and indicators (McGuire et al., 2026).

Strength of evidence. Five records, mainly multi-case and program evidence; none evaluates whether gender and youth commitments in mechanization policies have been implemented.

Main evidence gaps

- Control of machines and income within households (Njuki et al., 2022; Takeshima, 2024).
- Long-term evidence on whether mechanization reduces or reproduces gender inequality.
- The specific experience of young women (Daum et al., 2022; FSD Kenya, 2024).
- Central Africa and French- and Portuguese-speaking contexts (Table 3).
- Independent, gender-disaggregated evaluations of digital platforms (Daum et al., 2021).
- How women and young people enter, stay and grow in service-provider roles (Yahaya et al., 2026).
- Mechanized irrigation equipment such as motorized pumps (Kamwamba-Mtethiwa et al., 2012).

3.7 Synthesis Across the Five Themes

Figure 3 brings the themes together. Women's participation is held back by interacting asset, finance, information and social-norm barriers; young people by capital, skills, weak repair networks and weak entry routes into service markets. Service-provider models, group access, hybrid digital channels and risk-responsive finance can lower these barriers, but only with deliberate targeting, institutional support and monitoring, many of which depend on the enabling conditions described under Theme 5.

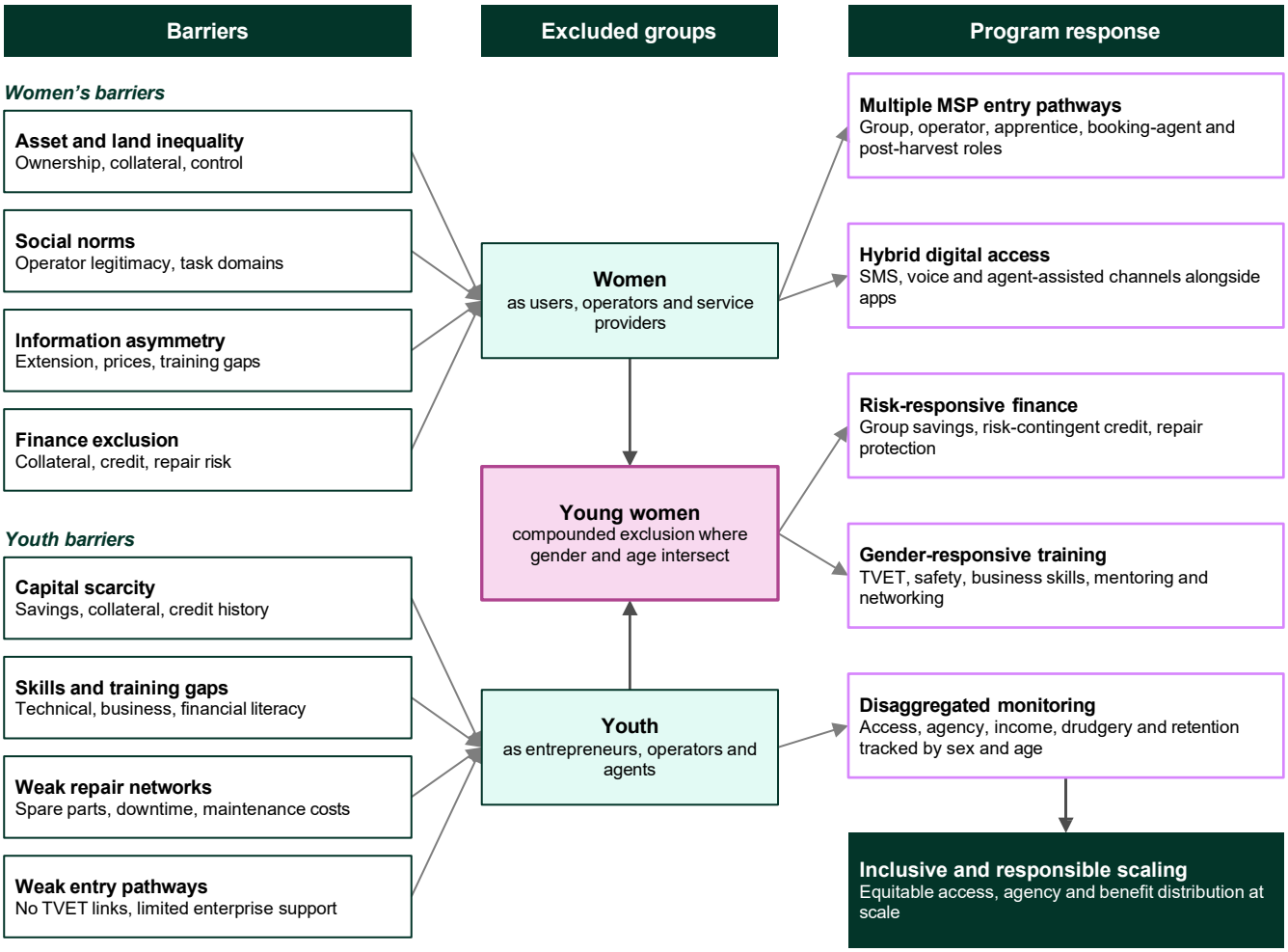


Figure 3. Barriers to inclusive mechanization in SSA, the groups most affected and program responses for equitable scaling. Arrows show the direction of influence. Young women are shown as a distinct group facing compounded exclusion.
Source: Adapted from the companion manuscript.

Table 5. Key evidence and program implications.

Key evidence	Program implications
Women's access is constrained by interacting asset, finance, information and social-norm barriers.	Offer multiple MSP entry pathways: individual, group, apprentice, operator, booking-agent and post-harvest specialist models.
In Zambia, female farmers were more likely to prefer group ownership; risk-contingent credit and repair-risk protection were strongly valued.	Couple training with appropriate finance, repair support and business-development services.
Digital tractor-hire platforms can reduce transaction costs, but many smallholders still depend on booking agents and phone-based intermediation.	Use multi-channel demand aggregation, including booking agents, SMS/voice and in-person extension.
Service-provider models can be commercially viable, especially where machinery is multifunctional and post-harvest services extend the operating season.	Design technology and training around women's workloads, safety and mobility without reinforcing restrictive gender roles.
Youth participation is limited by capital, skills, repair networks and business credibility; young women face compounded barriers.	Integrate TVET, private dealers, finance providers, extension services and farmer organizations into scaling partnerships.
Long-term, sex- and age-disaggregated evidence on who benefits remains limited.	Monitor access, agency, income, labor burden and retention by sex, age and other factors where feasible.

Source: Adapted from the companion manuscript.
Note: The left column summarizes the evidence; the right column gives design principles derived through the framework. These principles to be tested, not evaluated interventions, and rows are not one-to-one pairs.

4 What the Evidence Means for Inclusive and Responsible Scaling

4.1 Patterns Across Sub-Regions

Three patterns cut across sub-regions. First, exclusion is systemic: asset, norm, information, finance and market barriers reinforce each other, so distributing technology alone is unlikely to produce fair outcomes. Second, service-provider and digital models matter because they separate access from ownership, but they can reproduce inequality if provider selection, finance, digital access and business networks remain skewed. Third, youth enterprises have real potential, but it depends on the wider ecosystem of demand, spare parts, repair skills, finance, fuel and legitimacy, not on training alone. Regional differences in farm size, labor markets, gender relations and infrastructure caution against transferring one model across countries without adaptation.

4.2 Who Controls, Who Gains and Who Bears the Risk

A political-economy reading adds three questions to the question of who is excluded. Direct evidence on each is thin, so Table 6 separates what the records show from what is inferred through the framework.

Control. Machine ownership, and with it control over when, where and for whom services are delivered, tends to sit with better-off actors. Demand rose with wealth and was lower among female-headed households in Zambia and Zimbabwe (Ngoma et al., 2023); digital tools reduced costs most for larger providers in Nigeria (Daum et al., 2021); and in Ghana elite capture limited state tractor schemes (Daum and Birner, 2017). Women and young people appear more often as clients, operators or booking agents than as owners (Daum et al., 2022; FSD Kenya, 2024), roles with less say over prices and who is served first at planting time. On platforms, control also extends to booking networks and machine-use data.

Income. Income goes mainly to owners and service providers, who can earn substantial returns (Yahaya et al., 2026; Matin et al., 2026). Client households gain time, timeliness and less drudgery, but not necessarily the person whose labor is saved. Mechanization has been linked to women moving into non-farm activities (Takeshima, 2024), but the records do not show whether this raises women's own income or control over it.

Risk. Financial risk sits with borrowers (Mulungu et al., 2025), and those with the least capital are most likely to be pushed out by a single shock. Labor risk falls on workers whose paid tasks are mechanized and on those whose manual workloads rise; no record measures this. Environmental risk arises from intensive tillage or expansion onto new land; conservation-agriculture equipment offers a lower-impact route (Baudron et al., 2015), but no record assesses environmental and social outcomes together. An intervention can therefore widen access while concentrating control and income.

Table 6. Control, benefits and risks in mechanization scaling: what to monitor.

Dimension	Who tends to hold, gain or bear it	Basis on the evidence	What programs should monitor
Control of machines and service markets	Better-off farmers, larger providers and, in state schemes, politically connected actors	Ngoma et al. (2023); Daum et al. (2021); Daum and Birner (2017, supporting source)	Ownership and control of machines by sex and age; who sets prices and the order of service at peak times
Control of booking networks and data	Platform companies, booking agents and larger fleet owners	Daum et al. (2021); Hello Tractor (2024), self-reported	Who holds booking and machine-use data, and whether it is used to extend or ration finance
Income from services	Machine owners and service providers	Yahaya et al. (2026); Matin et al. (2026); CIMMYT (2022a)	Income by role (owner, operator, agent, client), sex and age
Time and labor savings	Client households, but not always the person whose labor is saved	Fischer et al. (2018); Baudron et al. (2019); Takeshima (2024)	Changes in time use and drudgery by sex and age within households
Financial risk	Borrowers and group members; heaviest for those with least capital	Mulungu et al. (2025); Yahaya et al. (2026)	Repayment stress, machine downtime and business exit by sex and age

(continued)

Dimension	Who tends to hold, gain or bear it	Basis on the evidence	What programs should monitor
Labor risk	Workers whose tasks are mechanized; people whose other workloads rise	Not measured in the included records	Effects on wage work and on workloads in non-mechanized tasks
Environmental risk	Not measured; costs likely to fall on local land users	Baudron et al. (2015); FAO and African Union (2022, supporting source)	Soil disturbance, land expansion and fuel use alongside social outcomes

Source: Adapted from the companion manuscript.
Note: The second column combines findings with interpretation through the political-economy lens; supporting sources are not counted among the 21 evidence records.

4.3 What Holds Across SSA and What Applies to Southern Africa

Because the evidence is uneven, Table 7 separates three kinds of conclusion: findings supported in at least two sub-regions; findings grounded in Southern African evidence; and implications transferred to Southern Africa from elsewhere, which need testing. The Southern African evidence is itself narrow: of 11 records, nine concern Zambia or Zimbabwe, one Malawi and one Eastern and Southern Africa together, and none covers Angola, Botswana, Eswatini, Lesotho, Mozambique, Namibia or South Africa. Implications are therefore most applicable to smallholder systems like those in Zambia and Zimbabwe.

Table 7. Findings across SSA, findings grounded in Southern Africa and implications that need testing.

Type of conclusion	Finding	Evidence base (Annex no.)
Holds across SSA	Exclusion comes from interacting assets, finance, information and norm barriers	Southern, Eastern, West (1, 2, 5, 9, 17, 20, 21)
Holds across SSA	Service provision separates access from ownership and can be commercially viable	Eastern, Southern, West (3, 7, 8, 11, 13)
Holds across SSA	Finance and risk are central constraints on access	Southern, Eastern, West (2, 12, 20)
Holds across SSA	Technology readiness alone does not secure scaling	Southern and SSA-wide (3, 4, 6, 8)
Grounded in Southern Africa	Demand for two-wheel tractor services, with lower willingness to pay among female-headed households	Zambia, Zimbabwe (1)
Grounded in Southern Africa	Female farmers prefer group ownership; demand for risk-contingent credit and repair protection	Zambia (2)
Grounded in Southern Africa	Starter packs, local manufacturing and vocational training as institutional pathways	Zimbabwe, Zambia (8, 13, 16)
Grounded in Southern Africa	Labor-intensive practices without appropriate mechanization can raise drudgery	Zimbabwe (15)
Transferred; needs testing	Hybrid digital aggregation with booking agents and phone channels	Nigeria, Kenya (14, 18, 19)
Transferred; needs testing	Women as tractor operators and booking agents	Kenya (18)
Transferred; needs testing	Task-based entry points for women's uptake	Tanzania (9)

Source: Adapted from the companion manuscript.
Note: A finding holds across SSA when records from at least two sub-regions point in the same direction.

4.4 Implications for Inclusive Scaling in Southern Africa

1. **Provide several entry pathways.** Group ownership, operator and apprentice roles, post-harvest services and booking-agent models reduce capital barriers for women and youth (Mulungu et al., 2025; Yahaya et al., 2026). *Basis: mainly Zambian and Zimbabwean evidence.*
2. **Design digital aggregation as a hybrid.** Pilot SMS, voice and agent-assisted channels alongside apps where connectivity and digital skills are uneven (Daum et al., 2021). *Basis: transferred from Nigeria and Kenya; evaluate before scaling.*

3. **Design finance around risk as well as cost.** Test bundled products and compare results by gender, age and provider type (Mulungu et al., 2025). *Basis: one Zambian study of stated preferences; pilots needed.*
4. **Use national strategies and TVET systems as entry points.** Zambia's strategy and Zimbabwe's vocational integration offer routes to embed skills beyond projects (Ministry of Agriculture, 2024; CIMMYT, 2022b). *Basis: Zambian policy and Zimbabwean program documents; outcomes not yet evaluated.*
5. **Monitor beyond hectares and machine numbers.** Track who uses services, who owns machines, who earns income, whose workload changes, and who stays in or leaves service roles. *Basis: responds to an evidence gap across SSA.*

4.5 What the Integrated Perspective Adds

The integrated perspective changes three things. It changes the question, from whether mechanization is adopted to who participates, who controls and who benefits as it spreads. It changes the unit of analysis, from the individual farmer or enterprise to the whole scaling pathway, including finance, value chains, partnerships and governance. And it changes what counts as success, from numbers of machines and hectares to how control, income, labor burden and risk are shared across social groups (Stilgoe et al., 2013; Kihoro et al., 2025; McGuire et al., 2026). Inclusion thus becomes a feature of the scaling pathway rather than a separate workstream.

4.6 Strengths and Limitations

The review brings together mechanization, scaling and GESI literature that is usually analyzed separately, separates direct evidence from supporting sources, and avoids double counting overlapping program outputs. It is limited to English-language sources and so under-represents French- and Portuguese-speaking contexts. Study designs and outcome measures vary, which rules out pooled estimates. Some service-provider and platform findings rely on program or company documents and should be read with more caution than independent peer-reviewed evidence. As a scoping review, it maps the evidence rather than estimating causal effects, and its conclusions for Southern Africa rest mainly on evidence from Zambia and Zimbabwe.

Overall interpretation

Whether mechanization scaling is inclusive depends less on the availability of machines than on how the wider system around them is designed. Because barriers reinforce one another, single fixes such as distributing machines or offering training alone are unlikely to widen participation. Service-provider and digital models create real opportunities, but they can reproduce inequality unless entry pathways, finance, delivery channels and partnerships are built around the constraints different groups face. Given the scarcity of long-term, disaggregated data, these are informed design principles rather than tested interventions.

5 Recommendations

Recommendations are directed to four groups: program teams and implementation partners, national governments, development partners and funders, and researchers. *Program teams and implementation partners* design and deliver mechanization projects, such as research centers, non-governmental organizations, farmer organizations and private companies. *Development partners and funders* are the donors, foundations and investors that finance these programs and set their requirements.

5.1 For Program Teams and Implementation Partners

- **Adopt flexible MSP entry models.** Offer individual, group, apprentice, operator, booking-agent and post-harvest pathways rather than treating ownership as the only successful outcome.
- **Design around women's and young people's realities.** Consider workload, safety, mobility and time when choosing equipment and scheduling services, and involve women and young people in these decisions from the start.
- **Set context-specific inclusion targets** based on baseline participation, local labor markets and feasible enterprise pathways rather than universal percentages.
- **Use several demand-creation channels.** Combine demonstrations with booking agents, farmer organizations, SMS and voice services and accessible extension.
- **Bundle skills with business and finance support,** including business planning, finance referral, mentoring, spare parts and repair networks.

- **Monitor distributional outcomes** (Section 6): access, agency, labor burden, income, service quality and retention by sex, age and other factors.

5.2 For National Governments

- **Require sex- and age-disaggregated reporting** for publicly supported mechanization programs, covering service access, provider ownership, income and retention.
- **Turn SAMA commitments into implementation mechanisms** with clear responsibilities, budgets and monitoring for gender equality, youth employment and environmental sustainability.
- **Strengthen rural connectivity and non-app channels** so that digital platforms do not depend on smartphone ownership.
- **Integrate mechanization into TVET and extension** through accredited short courses in operation, maintenance, safety and business, linked to dealers, lenders and service markets.
- **Pilot risk-responsive finance,** including group finance, risk-contingent repayment and repair cover, and evaluate who can access and sustain these products.

5.3 For Development Partners and Funders

- **Fund inclusion as part of the scaling pathway.** Treat gender- and youth-responsive design, mentoring and disaggregated monitoring as core budget lines, and fund programs long enough for enterprises to become established.
- **Invest in the enabling system,** including spare parts, repair networks, vocational training and connectivity, and share risk with lenders, for example through guarantee funds.
- **Require independent, disaggregated evaluation** of who benefits as a condition of funding, including for digital platform partners.
- **Plan for the end of project support.** Agree early on how coaching, brokering and advocacy will pass to national institutions, farmer organizations or private actors (Van Loon et al., 2020).

5.4 For Researchers

- **Generate long-term evidence** on labor, drudgery, income, agency and enterprise retention over several seasons.
- **Study young women explicitly** rather than assuming that separate gender and youth categories capture compounded exclusion.
- **Evaluate digital platforms independently** with sex- and age-disaggregated indicators.
- **Expand evidence from under-represented regions,** particularly Central Africa and French- and Portuguese-speaking contexts.
- **Evaluate service-provider sustainability,** including business survival, downtime, repair networks and client composition.

6 Using this Evidence in S4I Monitoring and Reporting

The S4I solution track on inclusive mechanization in Zambia aims, by 2030, to work with 10 financial institutions on inclusive financing models so that 1,000 MSPs can access finance and USD 300,000 is leveraged for smallholder mechanization (Enokenwa Baa et al., 2026). The evidence in this report suggests that progress toward such targets should be tracked not only by counts of institutions, providers and funds, but also by who is reached, who controls the machines and who benefits. Table 8 proposes indicators drawn from the review that S4I teams and partners can adapt for planning, adaptive management and reporting.

Table 8. Suggested indicators for inclusive and responsible mechanization scaling.

Dimension	Suggested indicator	Disaggregation	Link to evidence
Access to services	Number and share of farmers using mechanization services, by service type	Sex, age, household headship	Themes 1 and 2
Ownership and control	Machines owned or co-owned, and who decides on use, pricing and order of service	Sex, age, ownership model	Section 4.2; Table 6
Service-provider entry and retention	MSPs, operators, booking agents and mechanics trained, and the share is still active after one and two seasons	Sex, age, role	Theme 3
Access to finance	MSPs accessing finance, by product type (credit, group, lease, risk-contingent) and repayment status	Sex, age, provider type	Theme 4
Income by role	Income from mechanization services by role (owner, operator, agent, client)	Sex, age	Table 6
Time use and drudgery	Change in time spent on mechanized and non-mechanized tasks	Sex and age, within households	Theme 1; Table 6
Downtime and business exit	Machine downtime, repayment stress and exit from service-provider roles	Sex, age, provider type	Themes 3 and 4
Environmental effects	Use of conservation-agriculture equipment, land expansion and fuel use	Location, machine type	Section 4.2
Institutional uptake	Policies, TVET curricula or finance products adopting gender- and youth-responsive provisions	Institution type	Theme 5

7 Conclusions

This report synthesizes 21 mechanization evidence records on inclusive and responsible scaling in smallholder agriculture across SSA, with gender and youth as central lenses and a focus on Southern Africa. Mechanization can reduce drudgery, improve timeliness and create rural enterprises, but these benefits are not shared automatically. Women and young people face interacting constraints in assets, finance, information, skills, norms and markets, so tackling any one alone is unlikely to widen participation. Service-provider models, group access, hybrid digital channels and risk-responsive finance can lower barriers, but only with deliberate design and institutional support.

Because the Southern African evidence comes mostly from Zambia and Zimbabwe, the implications for the wider sub-region are design principles to be tested. The central message for S4I and its partners is that responsible mechanization scaling should be judged by more than machine numbers, hectares or short-term adoption. It should also ask who participates, who controls assets and services, whose labor changes, who earns the income and who stays in enterprise roles over time. Readers seeking the full analytical argument are referred to the companion manuscript (Choruma and Enokenwa Baa, under review).

Appendix A. Evidence Summary

The 21 unique mechanization evidence records are retained after the final evidence audit. Supporting conceptual, policy and contextual sources are cited in the text but not counted here.

Table A.1. Evidence records retained for thematic synthesis (n = 21).

No.	Author and year	Country / region	Study design	Mechanization focus	Key findings
1	Ngoma et al. (2023)	Zambia; Zimbabwe	Mixed methods; experimental auctions (n = 2,800)	WTP for 2WT ripping, seeding and transport	Substantial demand for 2WT services; female-headed households showed lower WTP; wealth strongly shaped demand.
2	Mulungu et al. (2025)	Zambia	Survey (n = 208), 18 FGDs, 28 KIIs	Tractor ownership preferences and finance	Female farmers more likely to prefer group ownership; RCC and repair-risk protection strongly preferred; maintenance and spare parts important.
3	Van Loon et al. (2020)	Zimbabwe; global comparison	Multi-case scaling assessment	Mechanization service scaling	Technology readiness alone insufficient; finance, collaboration, value chains and institutional anchoring constrained scaling.
4	Baudron et al. (2015)	Eastern and Southern Africa	Conceptual / empirical review	2WTs, conservation agriculture, private sector	Scale-appropriate mechanization fits smallholder contexts; service markets and private-sector support central to sustainability.
5	Baudron et al. (2019)	Ethiopia; Kenya; Tanzania; Zimbabwe	Farm surveys and gender-segregated FGDs	Labor and mechanization	Labor constraints varied by context; demand existed across sites; gendered labor patterns affected relevance.
6	Daum and Birner (2020)	SSA	Mechanization review	Tractor hire, digital platforms, service markets	Service markets and digital tools can address access constraints, but institutions and distributional effects need attention.
7	Yahaya et al. (2026)	Ethiopia; Burkina Faso; Zimbabwe	Financial viability analysis and interviews	2WT service-provider economics	Service provision economically viable; multifunctionality and post-harvest services strengthened returns; finance, skills, fuel and spare parts constrained.
8	Matin et al. (2022; 2026)	Zimbabwe; Zambia	Innovation profile; case-study economic analysis	Starter pack and MSP model	Service-provider approach demonstrated across programs; scaling depended on institutional readiness, finance and support systems.
9	Fischer et al. (2018)	Tanzania	Mixed methods	Mechanized forage chopping	Women's uptake higher where mechanization matched their tasks; norm change needed sustained support.
10	Kamwamba-Mtethiwa et al. (2012)	Malawi	Household survey and qualitative analysis	Treadle-pump irrigation (indirect)	Women's uptake lower than expected; time, mobility and asset constraints shaped adoption and benefit.
11	Diao et al. (2014)	Ghana	Survey and market analysis	Tractor-hire services	Demand emerging, but service supply and transaction costs constrained smallholder access.
12	Mengesha Abebe et al. (2025)	Ethiopia	Survey (n = 413); Probit/Tobit	Tractor plowing and combine harvesting	Education, credit and cooperative membership supported adoption; land fragmentation constrained intensity.
13	CIMMYT (2022a) / FACASI	Ethiopia; Kenya; Tanzania; Zimbabwe	Program evaluation / case evidence	2WTs, shellers, seeders; youth MSP training	Youth service-provider training, labor-time savings and enterprise potential, especially for multifunctional and post-harvest services.
14	Hello Tractor (2024)	Nigeria; Kenya; Uganda; multi-country	Company platform reporting	Digital tractor-booking platform	Large-scale reach reported; gender and welfare outcomes largely self-reported.
15	Rusinamhodzi (2015)	Zimbabwe (Murehwa)	Farm-level assessment	Manual planting basins (indirect)	Manual basins increased labor without productivity gains, highlighting the role of appropriate mechanization.
16	CIMMYT (2022b)	Zimbabwe	Program documentation	HAFIZ appropriate-scale mechanization	Local manufacturing, 2WT attachments and vocational training as institutional pathways.

(continued)

No.	Author and year	Country / region	Study design	Mechanization focus	Key findings
17	Daum et al. (2022)	Benin; Kenya; Mali; Nigeria	Multi-country stakeholder survey (n = 195)	Stakeholder perceptions of mechanization, digitalization and rural youth	Youth viewed mechanization positively but cited capital constraints; norms restricted young women. Gender, age and education shaped stakeholder viewpoints.
18	FSD Kenya (2024)	Kenya	Case study / program documentation	Female tractor operators and booking agents	Women showed technical capability but faced social resistance and dropout pressures.
19	Daum et al. (2021)	Nigeria (with India)	Mixed methods; ~400 respondents	Digital tractor-hire platforms	Lower transaction costs for providers; smallholders mainly used agents and phone calls; connectivity and digital literacy mattered.
20	Mohammed et al. (2023)	Ghana	Survey (n = 1,100); logistic regression	Adoption of mechanized technologies	Credit, remittances, farm size, labor and information access shaped adoption.
21	Takeshima (2024)	Ethiopia; Ghana; Nigeria; Tanzania (+ Asia)	Multi-country panel data	Tractors, combines and gendered labor	Mechanization linked to gender-differentiated labor shifts, including women moving into non-farm work.

Source: Adapted from the companion manuscript.
Note: 2WT = two-wheel tractor; FGD = focus group discussion; KII = key informant interview; MSP = mechanization service provider; RCC = risk-contingent credit; WTP = willingness to pay. Record 8 consolidates Matin et al. (2022) and Matin et al. (2026), which report on the same service-provider model.

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