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Agricultural Extension Sustainability in the Face of the COVID-19 Pandemic in Smallholder Markets: A Structured Review

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Abstract: Purpose. The COVID-19 pandemic placed severe strain on agricultural extension and advisory services, particularly for the smallholder farmers who form the backbone of food production in sub-Saharan Africa. Treating the pandemic as one instance of the systemic shocks that extension must increasingly absorb, alongside climate change and market disruption, this structured review synthesises the literature on the sustainability of agricultural extension delivery systems during the pandemic, with the aim of clarifying the theories that explain extension sustainability, the factors that drive or undermine it, and the mitigation strategies adopted by service providers and farmers. Approach. This structured narrative review draws on 90 peer-reviewed articles and 25 institutional reports identified through searches of Scopus, Web of Science, ScienceDirect, CAB Abstracts, AGRIS, and Google Scholar and published between 2019 and November 2021, with the evidence base subsequently updated to early 2026. Records were screened for relevance to extension sustainability, smallholder market systems, and pandemic response, and were synthesised thematically. In all, the revised article draws on 127 cited sources. Findings. The analysis reveals that no single sustainability theory adequately explains how the pandemic disrupted extension delivery; rather, the economic, ecological, systems, and social-capital perspectives each illuminate only part of an irreducibly multi-dimensional problem. Crucially, the disruption was experienced unevenly: whereas comparatively well-resourced providers adapted by migrating to digital channels, under-resourced public systems and the poorest farmers were largely left behind. Across the literature, extension delivery emerges as having shifted progressively from linear technology transfer toward systemic, demand-led, and increasingly digital models; yet this transition remains constrained by weak information and communication infrastructure, low worker-to-farmer ratios, and persistent rural poverty. Consequently, effective sustainability appears to depend far less on any single actor than on the coordinated participation of multiple stakeholders. Conclusion. Sustainable extension delivery is best understood not as the product of one model or theory but as the integration of several complementary perspectives, support functions, and formal and informal rules that bind extension stakeholders together. By contrast with reductionist, supply-driven approaches, a holistic, systems-based reorientation, coupled with targeted investment in digital and increasingly AI-enabled delivery, offers the more credible route to reducing future disruption and broadening inclusion.
Keywords: sustainability; COVID-19; smallholder farmers; agricultural market systems; extension services; digital extension.

I. INTRODUCTION

Global efforts to limit warming to 1.5 degrees Celsius, most recently restated at the 26th Conference of the Parties (COP26) in Glasgow, reflect a wider recognition that the world's poorest and most vulnerable populations bear the heaviest burden of environmental crises they did little to create (Marambe, 2019; Matthews, 2021). For decades, climate change was treated as the principal external constraint on the production and productivity of smallholder farmers in sub-Saharan Africa. The COVID-19 pandemic, however, introduced a second and far more abrupt shock, one that did not displace the climate threat so much as compound it, intensifying the effects of climate variability and weak governance on extension service provision (Chapoto et al., 2012; Cook et al., 2021; Haggag, 2021; Maggio & Sitko, 2019; Ngoma et al., 2021; Siankwilimba, 2016; Sitko, 2017).

Viewed in this light, the pandemic is less a singular event than a revealing instance of the systemic shocks that agricultural extension must increasingly anticipate and absorb, and the lessons it offers extend to future climate, market, and health disruptions alike.

The literature offers two competing explanations for the persistently low productivity of smallholder farmers. One school attributes it principally to failing extension delivery systems weakened by the combined pressures of climate change and the pandemic (Cook et al., 2021; IFAD, 2021; Swinnen & McDermott, 2020). A second, by contrast, locates the fault less in delivery than in the prevailing extension business models themselves, which it argues privilege short-term gains over the components of long-term sustainability (Kumar et al., 2020; Raworth, 2017; Sterman, 1994). These accounts are not, in truth, mutually exclusive; they are better read as complementary diagnoses of a single systemic failure. Whichever is emphasised, the burden falls disproportionately on smallholder farmers in sub-Saharan Africa, most of whom depend directly on agriculture for their livelihoods (Ugochukwu, 2020).

Although the immediate human, social, and economic disruption of COVID-19 drew policy attention away from climate change (Michelena et al., 2020), it would be a mistake to treat the pandemic as the origin of the sector's fragility. On the contrary, the core demand-and-supply functions of extension were already enfeebled by chronic underfunding and low worker-to-farmer ratios well before 2020 (Ritter et al., 2017). Decades of investment in training programmes, input promotion, and improved varieties had produced ambiguous outcomes for food security, in large part because of the complexity of the market space in which smallholders operate. Far from contradicting this picture, evidence accumulating since the acute phase of the pandemic has reinforced it, documenting sustained disruption to agricultural supply chains, food security, and advisory systems, including for gender-specific market segments (H. Mahmood et al., 2024; Siankwilimba et al., 2023).

Against this background, the present review pursues three interlocking objectives. First, it critically examines the principal theoretical frameworks advanced to explain sustainable agricultural extension, weighing their respective strengths and blind spots. Second, it identifies and contrasts the factors that drive extension sustainability with those that constrain it under pandemic conditions. Third, it appraises the mitigation strategies adopted across extension systems and considers their implications for future delivery. The argument proceeds from the review approach, through the current status of extension in developing countries and a systems perspective on its sustainability, to directions for research and practice.

A. Research Gap and Contribution

Although a substantial literature has examined the effects of COVID-19 on agricultural production, food systems, and advisory services, comparatively few studies have synthesised these strands through the specific lens of extension sustainability in smallholder agricultural markets. Existing reviews have tended to treat digital agriculture, climate resilience, or pandemic-induced disruption in isolation, which has limited understanding of how these forces interact within extension systems. The rapid emergence of digital advisory tools, artificial intelligence applications, and hybrid delivery models since the acute phase of the pandemic has, moreover, altered the operating environment substantially relative to the earliest COVID-19 studies (High et al., 2025; Sen et al., 2025; Siankwilimba et al., 2023).

This review addresses these gaps by integrating theoretical, institutional, technological, and market-system perspectives within a single analytical framework. In doing so, it offers a systems-based interpretation of extension sustainability that foregrounds the interactions among livelihood capitals, support functions, governance arrangements, and adaptive delivery mechanisms operating under conditions of uncertainty and external shock. No previous review appears to have integrated sustainability theory, agricultural innovation systems, market-systems development, digital extension, and AI-enabled advisory services within a single framework for understanding extension resilience during and beyond the COVID-19 pandemic.

II. REVIEW APPROACH

This study adopts a structured narrative review design, which is appropriate for synthesising a heterogeneous and rapidly expanding body of evidence on a contemporary phenomenon. This choice follows established guidance on literature review as a research methodology, which recognises narrative and integrative reviews as legitimate and rigorous designs for consolidating a broad, interdisciplinary evidence base and for building conceptual understanding rather than aggregating effect sizes (Snyder, 2019). The review covered 90 peer-reviewed articles published in scientific journals together with 25 institutional and supplementary reports, spanning the period from 2019 to November 2021. For this revised synthesis, the evidence base was subsequently updated to incorporate key peer-reviewed literature published through early 2026, so that the conclusions reflect developments since the acute phase of the pandemic.

The reference list of this revised article accordingly comprises 127 sources in total: the original review corpus, consolidated and corrected during revision, together with eleven recent peer-reviewed sources published between 2023 and early 2026 and a small number of methodological and theoretical works added to support the revised analysis. Sources were drawn from academic

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databases and supplemented by reports from recognised government, multilateral, and private-sector websites. The original searches were conducted between 2019 and November 2021, and a supplementary search was undertaken in early 2026 to refresh the evidence base; no review protocol was registered for this synthesis. The evidence base is global in coverage, while the analytical focus rests on smallholder systems in sub-Saharan Africa, and evidence from other regions is used comparatively rather than assumed to generalise.

A. Search Strategy and Source Selection

The search drew on the principal bibliographic databases for the field, including Scopus, Web of Science, ScienceDirect, CAB Abstracts, AGRIS, and Google Scholar, together with selected institutional repositories. Searches combined the keywords agricultural extension, extension sustainability, agricultural advisory services, smallholder farmers, COVID-19, digital extension, e-extension, agricultural resilience, extension systems, and artificial intelligence in agriculture, linked with the Boolean operators AND and OR to refine the results. The records returned were screened by title, abstract, and full text against the objectives of the review, with greater analytical weight given to peer-reviewed empirical studies, systematic reviews, and authoritative reports from international organisations. Because the synthesis followed a structured narrative approach rather than a formal systematic review, no quantitative quality-scoring instrument was applied; sources were instead appraised for relevance, methodological clarity, and contribution to understanding extension sustainability under pandemic conditions. Sources were selected against explicit criteria. Records were included where they (i) addressed agricultural extension and advisory services, smallholder market systems, sustainability theory, or the effects of and responses to the COVID-19 pandemic in agriculture; (ii) took the form of peer-reviewed articles or authoritative institutional and development-sector reports; and (iii) were published in English within the review window of 2019 to November 2021, subsequently refreshed to early 2026. Records were excluded where they fell outside these themes, did not bear on extension delivery, or duplicated material already captured. The retained literature was organised thematically around four analytical strands: the current status of extension systems; systems and social-network perspectives; the components and drivers of sustainable delivery; and the financing, theoretical, digital, and workforce dimensions of sustainability. A narrative synthesis inevitably carries a degree of selection subjectivity; the findings are therefore presented as an interpretive synthesis rather than a statistical aggregation. Figure 1 sets out the flow of source identification, screening, and inclusion.

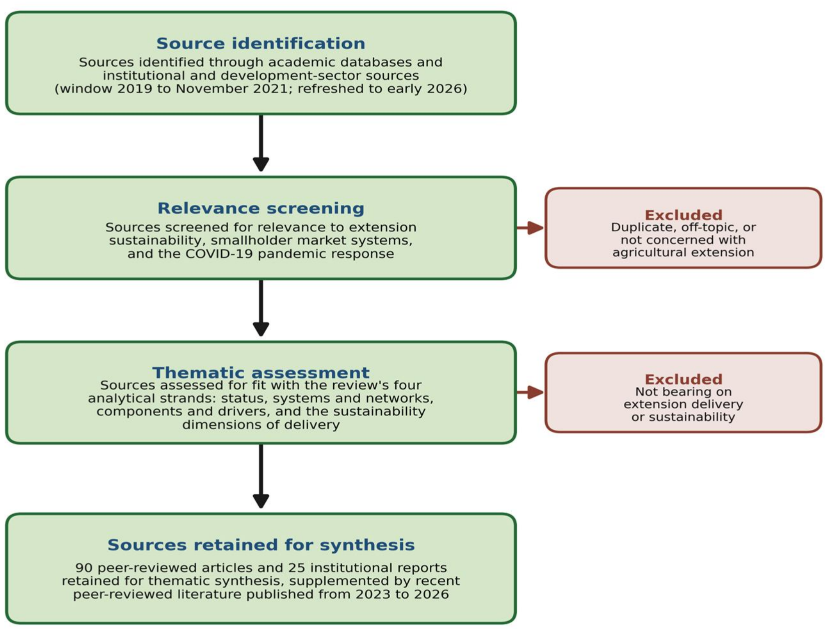

Figure 1. Structured narrative review process used in source selection. The diagram illustrates how sources were identified, screened, and organised for thematic synthesis. Because the study employed a structured narrative review rather than a systematic review, numerical tracking of records at each stage was not undertaken. Source: authors.

III. THE CURRENT STATUS OF AGRICULTURAL EXTENSION IN DEVELOPING COUNTRIES

Extension systems in many developing countries have operated for more than 60 years, and yet longevity has not translated into resilience; they continue to confront complex challenges that limit their capacity to serve a functional and sustainable smallholder market (Osumba et al., 2021). In response, many countries have moved away from purely public provision toward hybrid arrangements in which government and private-sector actors deliver services jointly (Taylor & Bhasme, 2018). Among the competing models for transferring information and technology, the transfer-of-technology (ToT) approach remains the most influential, premised on a largely one-directional flow of knowledge from scientists to farmers (Baloch & Thapa, 2019). As the discussion that follows shows, however, this linear logic sits increasingly uneasily with contemporary understandings of how farmers actually learn.

During the pandemic, many providers turned to electronic extension models built on digital technology (Haggag, 2021). Such models, however, do not transcend the older paradigms so much as recombine them, blending top-down and bottom-up logics while depending heavily on the available information and communication infrastructure (Phillips et al., 2019). Herein lies a central tension: where infrastructure is weak, as across much of rural sub-Saharan Africa, the very tool promoted to widen reach can instead exclude the farmers it is meant to serve, even as national programmes to accelerate digital transformation strive to broaden connectivity (World Bank, 2020). The success of any digital model therefore rests less on the technology itself than on the enabling environment that governments create, including public awareness of environmental and market dynamics (Adnan et al., 2017; Rezaei-Moghaddam & Salehi, 2010).

Set against the persistence of the ToT model, traditional extension has proved increasingly insufficient for promoting sustainable practices, because its older roles of transferring and disseminating technology no longer match present needs (Alabi & Ajayi, 2018).

The vocabulary of the field has shifted accordingly, moving from an early preoccupation with production, to efficiency, and more recently to sustainability and inclusion (Ugochukwu, 2020). This evolution carries a corresponding redefinition of roles: whereas farmers were once treated as passive recipients, they are now recognised as active participants in learning and as entrepreneurs whose innovation adoption shapes extension outcomes, while extension workers are migrating from instructors toward facilitators, advisors, and consultants (Davis et al., 2020; Pambudy, 2018; Quisumbing et al., 2014).

The pandemic, paradoxically, also reframed extension as a domain of mutual benefit rather than one-way instruction (Cooper et al., 2021; FAO, 2021). Providers combined agricultural messaging with public-health guidance, reinforcing preventive measures while preserving the commercial relationships on which their services depend (Zabaniotou, 2020). This convergence is best read as the acceleration of a longer movement toward demand-led, social-capital-rich extension in which farmers figure as part of the solution rather than the problem (Beez, 2014; Maulu et al., 2021). In other words, for agricultural systems to remain sustainable, extension and advisory services must increasingly interlock with health systems, distributing reliable information that protects livelihoods and lives alike (Venkatramanan et al., 2019). The emergence of new viral variants exposed just how fragile that interlock can be, straining extension through staff illness and loss, lockdowns, travel restrictions, an abrupt shift to online delivery, and the closure of farmer field activities (Biondi et al., 2021).

IV. AGRICULTURAL EXTENSION AS AN OPEN SOCIAL NETWORK SYSTEM

A growing consensus now holds that extension is most effective and sustainable when it operates within a system that serves the smallholder market and its many stakeholders (Rahmandad et al., 2021; Sweeney & Sterman, 2000). The contrast with earlier practice is stark. Whereas linear models cast government and private providers in a hierarchical role and treated farmers as problems to be solved, contemporary thinking recognises those same farmers as custodians of indigenous knowledge and as active contributors to addressing the challenges of climate change and disease. On this reading, extension is less a delivery pipeline than an open social network system through which information and technology circulate among interdependent actors (Ceschin & Gaziulusoy, 2019).

Figure 2 synthesises this conception, situating the extension system between its livelihood-capital inputs and its sustainability outcomes, within an external environment of shocks and subject to continuous feedback.

Viewed through a systems-dynamics lens, a sustainable extension system must be appraised as a whole rather than as a sum of separable parts (Stockmann et al., 2021). What matters, accordingly, is not the performance of individual units but how the components fit together, how they relate to one another, and how the system interacts with its wider environment (Ferretti & Grosso, 2019; Roling & de Jong, 1998). Outputs, on this account, are shaped by inputs that are themselves conditioned by time and context as the components interact (Nganga et al., 2020).

The pandemic offers a vivid illustration: the external shock obliged extension organisations to make internal and external adjustments simply to keep functioning (Bates et al., 2021), and in doing so triggered cascading economic, environmental, social, political, and technological change (Adnan & Nordin, 2021; Baloch & Thapa, 2019). Digital extension, indeed, emerged less as a deliberate strategy than as an adaptive response to mitigation measures promoted by health ministries and the World Health Organisation (Barnes, 2020). Alongside climate change, the proximate forces reshaping extension during this period, physical distancing, lockdowns, masking, sanitisation, and quarantine, operated within longer-term structural influences such as market liberalisation, decentralisation, advances in information and communication technology, and biotechnology (Alabi & Ajayi, 2018; Varahachalam et al., 2021). Crucially, as these systems evolve, both intended and unintended feedbacks become signals of change that warrant close observation.

This systems view has been carried further by the Agricultural Innovation Systems (AIS) perspective, which widens the analytical lens to the interactions among researchers, farmers, agribusinesses, policymakers, and civil-society organisations (Klerkx et al., 2012; World Bank, 2012). Unlike conventional extension, which centres on the transfer of knowledge from research to farmers, AIS frameworks foreground co-creation, experimentation, and learning across multiple actors, and they treat innovation platforms as deliberate spaces for negotiation and joint problem-solving. Read in this light, the open social network advanced here is less a rival to the AIS account than a market-systems specification of it, one that situates extension within, rather than apart from, the wider innovation system.

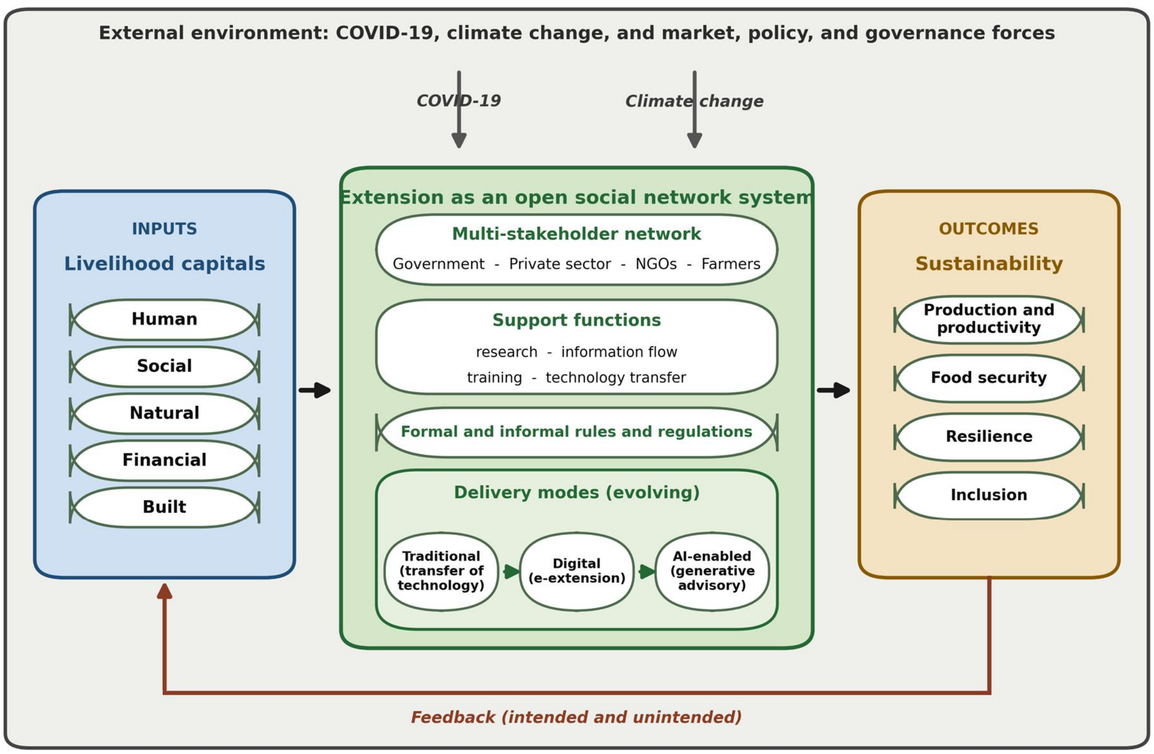

Figure 2. Conceptual framework of agricultural extension as an open social network system. Livelihood-capital inputs are converted, through a multi-stakeholder network governed by support functions and by formal and informal rules, into sustainability outcomes; the delivery modes through which this occurs evolve from traditional transfer of technology toward digital and AI-enabled forms. The system operates within an external environment of shocks, notably COVID-19 and climate change, and is regulated by intended and unintended feedback. Source: authors.

Two propositions follow from this framework, each stated so that it can in principle be tested empirically. Proposition 1 holds that extension sustainability increases as livelihood capitals, support functions, governance arrangements, and adaptive delivery mechanisms become more tightly coupled through positive feedback; this implies a measurable positive association between the degree of integration among these components and indicators of system performance such as service continuity, farmer adoption, and recovery time following a shock.

Proposition 2 holds that an extension system becomes more vulnerable whenever any one of these pillars is disconnected from the others and from the wider system; this implies that systems exhibiting weak linkages, for instance digital delivery without supporting connectivity, or financing without embedded market relationships, should show larger performance losses when disturbed. Stated in these terms, the model moves from description toward propositions that could be examined through comparative case studies, longitudinal tracking of extension systems across successive shocks, or network analysis of the linkages among components.

For empirical purposes, the constructs in both propositions can be operationalised through observable indicators. Coupling, in Proposition 1, can be proxied by the number and activity of institutional linkages per provider, the share of advisory content delivered through two or more channels, and the presence of embedded advisory arrangements within commercial transactions. System performance can be tracked through service continuity, measured as the proportion of planned farmer contacts maintained during a shock; recovery time, measured as the interval before delivery volumes return to pre-shock levels; and farmer adoption of promoted practices. Disconnection, in Proposition 2, is observable where digital delivery expands faster than rural connectivity and digital literacy, where financing is concentrated in a single public or donor source, where worker-to-farmer ratios fall far below the FAO benchmark, or where advisory services operate without market linkages; the proposition predicts that systems exhibiting any of these disconnections will show larger declines in continuity and slower recovery when a shock arrives.

V. DRIVERS OF A SUSTAINABLE EXTENSION DELIVERY SYSTEM

If extension is to be sustainable, it must draw on environmental and institutional assets that are actually available at the point of implementation, rather than on those assumed by external designers (Hasheminasab et al., 2020). Through its educational role, extension can advance sustainability by equipping farmers of every kind with the knowledge, skills, and resources to operate efficiently. Equally important, and often neglected, is the supply side: continuous training and capacity development for the providers themselves strengthens their ability to respond to the twin pressures of climate change and disease, and so underpins the institutional and community reorganisation that sustainable agriculture demands.

Achieving sustainability therefore obliges extension systems first to identify their assets, then to assess those assets' vulnerability to internal and external shocks, and finally to strengthen them or relieve the stresses upon them (Maulu et al., 2024; Meera et al., 2012). The pandemic tested every category of livelihood capital at once, the human, social, natural, financial, and built (Rude et al., 2020; Zambrano-Monserrate et al., 2020). Of these, human capital, comprising skills, education, and indigenous knowledge, is arguably the most consequential, being tightly coupled to community health and indispensable to sustaining extension (Grove et al., 2020; Todaro & Smith, 2015). Social capital, understood as the networks within and beyond a community and the participation they enable, complements rather than substitutes for it (Tengapoe et al., 2024). Recent evidence from Senegal reinforces the supply-side case: access to agricultural advisory services raised yields among smallholder farmers, even where effects on input uptake were more modest, underscoring advisory provision as a driver of farm performance (Ricome et al., 2025). Notably, the very conception of human capital has widened to encompass information, connectivity, training, automation, communication, and emerging digital capabilities (Sima et al., 2020).

Natural capital, by contrast, must be maintained in good health if it is to support life and livelihoods, a requirement that assigns extension a stewardship role in shaping messages around sound environmental practice (Chinsembu, 2021; Todaro & Smith, 2015). Financial and built capital, including community infrastructure, complete the asset base, and, importantly, each form of capital tends to raise the productivity of the others within a single systems process (Hovmand, 2014). Here too the pandemic proved instructive: the expanded use of information technology extended the reach of health and advisory services, for instance through telemedicine, and signalled a broader shift toward an Industry 4.0 model in which human intelligence, new technologies, information, and innovation combine to transform information sharing (Bakken et al., 2019; Sima et al., 2020).

VI. COMPONENTS OF A SUSTAINABLE EXTENSION SYSTEM

If a system is the sum of components that together furnish structure and function, then defining the goals and objectives of a programme is among the most consequential responsibilities a provider holds (Nedumaran & Ravi, 2019). Here too the field has moved on: participatory approaches have restored viability to extension by strengthening adaptive management, local social capital, and stakeholder platforms for negotiation and learning (Cook et al., 2021). As climate and pandemic pressures intensified, moreover, adaptive thinking shifted from a desirable attribute to a precondition for achieving food security through continuous learning (Kogo et al., 2020).

The objectives that orient extension toward sustainability span a wide spectrum, from the effective transfer of technology to the building of strong rural organisations, the shaping of research and policy agendas, and the enforcement of collective decisions on resource management (Ibrahim, 2019). Sound resource management, in turn, helps replenish the natural environment and so underwrites long-run agricultural development (Cao et al., 2021; Moguilevsky et al., 2021; Roe et al., 2020). Within this paradigm a clear implication follows: sustainable agriculture cannot be achieved through conventional methods alone but instead requires the deliberate facilitation of learning (Nkuyubwatsi, 2016; Olorunfemi, 2024). Contemporary practice reflects this shift, emphasising group exchange, networking, social and participatory learning, the use of indicators to render environmental problems visible, regular field observation, and experiential methods (Omulo & Kumeh, 2020).

Yet a tension runs through the organisational landscape. Although most organisations remain oriented toward output, equity, or stability, only a minority have formed explicitly to pursue long-term sustainability (Keding et al., 2021). Because progress on policy goals such as food security and environmental sustainability has been slow, public extension models have lost standing even in countries as different as the United States and China (Wang et al., 2020). In response, provision has diversified well beyond the state, drawing in private firms and non-governmental organisations that supply technology transfer, advisory, training, advertising, and information services across a broad subject range, including, tellingly, disease-related public-health messaging (N. Mahmood et al., 2021).

Two features in particular distinguish organisations that succeed at this from those that do not, namely decentralisation and pluralism (Birner et al., 2009). The most effective providers operate as adaptive, learning organisations whose members act as agents of organisational learning in response to internal and external change (Beers et al., 2014; Campo et al., 2010). Such providers add value to their services and thereby empower their clients, as farmer associations and non-governmental organisations applying market-systems approaches demonstrate (Friel et al., 2017). Linking agricultural to health messaging, simplifying content for women and youth, and deploying methods such as role-play can further improve assimilation and widen inclusion (Glover et al., 2019; Tisenkopfs et al., 2015; Todaro & Smith, 2015). Ultimately, then, sustainability in extension is inseparable from the harmonisation of social, environmental, and economic interests, together with ethics, transparency, and accountability toward all stakeholders, precisely because health, economic, environmental, and social systems are interconnected and cannot easily be prised apart (Ibrahim, 2019).

VII. FINANCING SUSTAINABLE EXTENSION DURING THE PANDEMIC

As nations scrambled to slow the spread of the virus, the World Health Organisation commended widespread adherence to physical distancing, lockdowns, sanitisation, and mass vaccination, and announced a roadmap mobilising substantial resources, reported at the time as on the order of US$50 billion, to support the global health, trade, and finance response, complementing earlier emergency funding channelled to affected countries through its donors and partners (Sheth, 2020; World Health Organisation, 2020, 2021). Generous as such headline figures appear, development analysts have long questioned the channels through which extension itself is financed, contending that they have not consistently benefited all market players (Jane et al., 2011).

A distinct school of donor practice frames the problem differently. Development financing agencies such as Sida, UKAID, and USAID hold that sustainability in extension depends on a functional interaction between private-sector actors and farmers, underpinned by appropriate rules, regulations, and support functions such as research and information flow (DFID & SDC, 2014). On this view, earlier government-led models proved less sustainable precisely because they were not embedded in viable commercial relationships; the proper role of donors and governments, accordingly, is to catalyse value-adding relationships, through embedded extension information, technology transfer, transparent and formalised contracts, and assured market off-take, that give smallholders the confidence to invest (Beez, 2014). The pandemic only sharpened this logic, rendering private-sector engagement with commercial clients at the base of the pyramid more important, not less (Howell et al., 2018; Prahalad, 2005). Beyond the traditional donor axis, South-South cooperation has further reshaped extension capacity, with China investing in the training of government extension staff and the transfer of affordable technologies to smallholders in parts of Africa, including Zambia (Vaidyanathan et al., 2021). Tellingly, donor-funded growth and extension projects did not merely endure the pandemic but adapted to it, shifting toward remote engagement and more flexible implementation (Lenaghan & Heffern, 2021). Table 1 sets out the principal financing models discussed here and their comparative sustainability potential.

TABLE 1. *Comparative profile of the principal financing models for agricultural extension.*

Financing model	Advantages	Weaknesses	Sustainability potential
Public extension	Wide coverage	Fiscal dependence	Moderate
Donor-funded	Innovation support	Funding uncertainty	Low to moderate
Private embedded services	Commercial incentives	Limited reach	High
Public-private partnerships	Shared risk and resources	Coordination complexity	High
Market-systems facilitation	Long-term incentives	Dependence on functioning markets	Very high

Source: authors' synthesis. Sustainability potential denotes the authors' qualitative judgement of each model's capacity to persist without continuous external subsidy.

Read across these models, the evidence reviewed suggests that market-systems facilitation and public-private partnership arrangements offer the strongest prospects for long-term sustainability, since they align the incentives of extension providers, farmers, and market actors while reducing dependence on continuous external subsidy.

The Zambian experience offers a concrete illustration of the market-systems facilitation model. Musika Development Initiatives, a Zambian market-development organisation that has operated for more than a decade, deliberately facilitates rather than delivers extension: instead of fielding advisory agents of its own, it provides technical advice and early-stage catalytic support to agribusinesses that embed extension information, demonstration, technology transfer, and market services within their commercial relationships with smallholder suppliers and customers, consistent with the Making Markets Work for the Poor (M4P) methodology (Beez, 2014; DFID & SDC, 2014; Mutambara, 2015). Because the advisory content travels with input supply, output purchase, and aggregation transactions rather than with a project budget, delivery is sustained by the commercial interest of the partner, which is the durability property that distinguishes embedded provision from supply-driven arrangements. Peer-reviewed evidence from Zambian market systems similarly ties the sustainability of extension under pandemic conditions to private-sector participation and multi-sector coordination (Siankwilimba et al., 2023). In shock conditions such arrangements are also, in principle, less exposed than dedicated field programmes, because the advice moves with commercial exchanges that continue wherever markets keep functioning.

At the multilateral level, agriculture and the sustainability of advisory services have featured in climate negotiations since the 1992 United Nations Framework Convention on Climate Change and the subsequent Paris Agreement (Marambe, 2019). Progress, however, has been incremental rather than transformative. Between 2012 and 2017 the Subsidiary Body for Scientific and Technological Advice reviewed agricultural matters, culminating in the first substantive decision at COP23 in Bonn in 2017 and the establishment of the Koronivia Joint Work on Agriculture (Matthews, 2021). That roadmap was carried forward to COP26 in Glasgow in 2021, where the pandemic figured as an additional complication to sustained agricultural development and where affordable, accessible food security was reaffirmed, if not yet secured, as a global priority. Figure 3 sets these milestones out on a timeline.

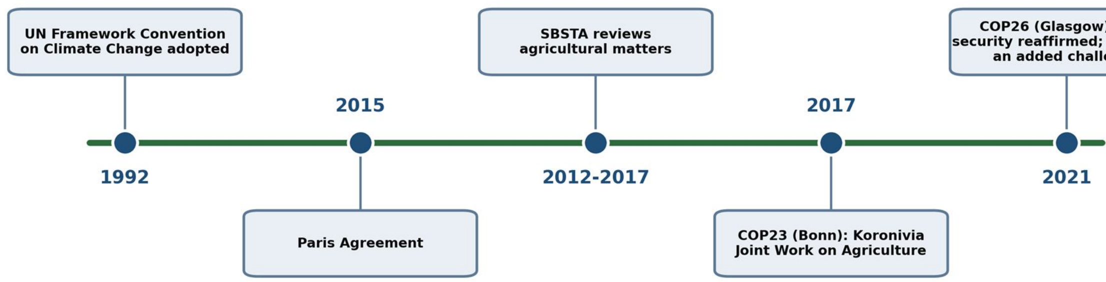

Figure 3. Timeline of the principal multilateral climate and agriculture milestones bearing on the financing and sustainability of advisory services, from the 1992 UN Framework Convention on Climate Change to COP26 in Glasgow in 2021. Source: authors.

VIII. THEORETICAL PERSPECTIVES ON SUSTAINABILITY

Definitions of sustainability and sustainable development proliferate across the literature, each reflecting a particular disciplinary orientation (Albert, 2019; Millan et al., 2019; Shaukat et al., 2021). Far from being a mere semantic inconvenience, this very diversity has been read as a signal of the complexity and urgency of the underlying problem (Shaukat et al., 2021). Within the extension literature the two terms are frequently used interchangeably (Giroud & Ivarsson, 2020; Keating, 2020; Murray et al., 2017), yet a useful distinction can be drawn: sustainability denotes a condition of continuation in the face of complex challenges, whereas sustainable development denotes the process of moving toward a desired future state (Mutambara, 2015; Todaro & Smith, 2015).

Since the 1987 Brundtland report first brought sustainable development to wide public and policy attention (FAO, 2018), scholars working from its three pillars have emphasised sharply different facets. Those writing from an economic and business standpoint locate sustainability where demand and supply interact to produce a competitive market that balances profit, people, and planet (Bensch et al., 2021; Sterman, 1994). Ecological perspectives, by contrast, foreground regenerative design, in which natural resources are used and renewed without generating waste or pollution and in which messaging aligns with climate-smart agriculture (Butterfield et al., 2019; Raworth, 2017). Divergent as these emphases are, they converge on a shared anxiety about the degradation of the planetary systems on which human life depends, and on a shared call for environmental stewardship at every level of development (Whitmee et al., 2015). It is on this common ground that holistic and regenerative management frameworks have been proposed to manage land and reduce erosion, consistent with the climate-smart agriculture promoted by the FAO and with the emissions-reduction agenda reaffirmed at COP26 (FAO, 2013; Matthews, 2021; Roberts et al., 2021).

Resilience theory offers a further perspective on extension sustainability under conditions of uncertainty. Rather than privileging efficiency or stability alone, it emphasises the capacity of a system to absorb shocks, adapt to changing circumstances, and continue functioning through disruption (Bates et al., 2021; Stockmann et al., 2021). The pandemic underscored the value of adaptive capacity, learning, redundancy, and institutional flexibility within extension systems. On a resilience reading, sustainable extension is not merely the maintenance of existing functions but also the capacity to transform and innovate when confronted with major external disturbance.

A. Integrating the Sustainability Perspectives

Taken individually, none of these perspectives captures the full complexity of extension systems operating under pandemic conditions. Economic accounts illuminate incentives and market efficiency but tend to understate environmental constraints and social dynamics (Bensch et al., 2021; Sterman, 1994). Ecological approaches foreground environmental stewardship yet address institutional and financial realities less fully (Butterfield et al., 2019; Raworth, 2017). Social-capital perspectives explain the role of trust, collective action, and stakeholder participation but accommodate technological change only weakly, whereas systems theory offers a more holistic account by recognising the interactions among actors, institutions, technologies, and environmental forces (Rahmandad et al., 2021; Stockmann et al., 2021). Extension sustainability is therefore best understood through an integrated framework that combines economic viability, ecological stewardship, social inclusion, and systemic adaptability, an interpretation consistent with contemporary resilience thinking and one that provides a firmer basis for designing systems able to withstand future disruption.

IX. DIGITAL EXTENSION SERVICES AND SUSTAINABILITY

The pandemic accelerated a global redefinition of how extension information is delivered. Relationships between public and private models are being reconfigured in response to disease and other drivers, such that extension is increasingly defined by the manner in which it conveys information and technology to farmers and other stakeholders (Alvi et al., 2021). One consequence has been a pragmatic blending of centralisation and decentralisation, in place of an either-or choice between them. As the value of information and product quality has risen, so correspondingly has the demand for transparency, governance, and accountability across the delivery ecosystem (Chen et al., 2020).Traceability has therefore moved to the centre of the sustainability question, since farmers and buyers alike are often willing to pay a premium for goods and information they can trust. Distributed-ledger and blockchain approaches exemplify the principle, allowing trusted participants to inspect transactions and thereby reinforcing democratisation, transparency, and accountability in electronic trade (Moser et al., 2018; Patil & Puranik, 2019). Promising as these systems are, however, their diffusion among smallholders is likely to be slow, constrained by infrastructure gaps and high rural illiteracy. Even so, digital business models have already demonstrated a capacity to overcome some of the cross-border impediments the pandemic created.

Evidence accumulating since the pandemic has clarified both the promise and the limits of digital delivery, and the balance between them is instructive. Systematic reviews report that interactive digital extension services can improve learning, productivity, and the cost-effectiveness of delivery; yet the same reviews find these benefits persistently constrained by uneven connectivity, weak digital ecosystems, and low digital literacy among smallholders (Gumbi et al., 2023; Sen et al., 2025). More recently still, generative artificial intelligence has begun to enter the advisory landscape, offering personalised and locally relevant information in settings where human extension resources are scarce. Its capacity to support smallholder learning remains contested, however, because alignment with participatory and ethical extension goals, equitable access, and appropriate governance is far from settled (High et al., 2025). Taken together, these developments suggest that the reconfiguration begun under pandemic conditions is consolidating into a durable transformation rather than a temporary expedient. Table 2 sets these three delivery modes side by side, comparing them across the dimensions that bear most directly on sustainability.

TABLE 2. Comparative profile of traditional, digital, and AI-enabled agricultural extension.

Dimension	Traditional (transfer of technology)	Digital (e-extension)	AI-enabled (generative advisory)
Direction of knowledge flow	Largely one-way, from scientists and agents to farmers	Two-way but mediated by platforms and connectivity	Interactive, personalised, and available on demand
Primary medium	Face-to-face contact, field days, lead farmers	Mobile phones, messaging, apps, video, and online platforms	Conversational agents, image recognition, and retrieval-based advisory
Infrastructure dependence	Low	High (connectivity and devices)	Very high (connectivity, data, and computation)
Reach relative to staffing	Constrained by worker-to-farmer ratios	Scalable, though unevenly distributed	Potentially high where access exists
Principal strength	Trust, context sensitivity, and hands-on demonstration	Speed, scale, and traceability	Personalisation, constant availability, and language localisation
Principal risk	Limited coverage and slow diffusion	Exclusion of low-connectivity and low-	Unresolved questions of equity, accuracy, and

Dimension	Traditional (transfer of technology)	Digital (e-extension)	AI-enabled (generative advisory)
		literacy farmers	governance
Illustrative evidence	Baloch & Thapa (2019); Davis et al. (2020)	Gumbi et al. (2023); Sen et al. (2025); World Bank (2020)	High et al. (2025)

Source: authors, synthesised from the cited literature. The three modes are best read as cumulative and overlapping rather than as discrete successive stages.

A. *Artificial Intelligence and the Future of Advisory Services*

Recent advances in artificial intelligence extend these possibilities beyond conventional digital communication. AI-enabled advisory systems can support extension workers and farmers with real-time agronomic recommendations, climate-risk assessment, pest and disease diagnostics, market intelligence, and personalised decision support, and large language and conversational models have shown potential to widen access to agricultural knowledge where extension staff remain too few (High et al., 2025). Set against this promise, however, are substantial concerns over data quality, algorithmic transparency, digital exclusion, infrastructure requirements, and ethics. Unless digital literacy and access improve in step, AI-based advisory provision risks reinforcing the very inequalities it might otherwise relieve (Gumbi et al., 2023; Sen et al., 2025). For this reason, artificial intelligence is best regarded as a complement to, rather than a substitute for, human extension personnel, and hybrid models that pair human expertise with AI-assisted decision support appear the more credible route to resilient and inclusive systems in the years ahead.

Realising that promise will depend on governance. If AI-enabled advisory systems are to remain trustworthy, questions of data ownership, algorithmic transparency, accountability, privacy, and bias will require sustained attention from governments, extension agencies, and technology providers alike (High et al., 2025).

X. EXTENSION WORKFORCE CAPACITY AND SUSTAINABILITY

Extension workers occupy the interface between research and farmers and are, in that sense, a critical component of any delivery system; their persistent shortage relative to the farmers they serve is correspondingly damaging (Lamontagne-Godwin et al., 2017; Ministry of Agriculture, 2016). Cross-country comparison reveals stark disparities, though these emerge most clearly in the ratio of officers to farmers rather than in raw headcounts. Available evidence suggests that China maintains one of the world's largest public agricultural extension systems, on the order of one million agents working across national, county, township, and village levels (Hu et al., 2009), and India and Ethiopia likewise field comparatively large workforces.

The United States, by contrast, runs a much smaller Cooperative Extension System of roughly 13,000 to 15,000 professional staff, within a wider network of about 32,000 across all programme areas (Congressional Research Service, 2024); yet because it serves a far smaller farming population, a modest headcount need not imply a thin service. India fields some 143,863 extension professionals, but at a worker-to-farmer ratio of roughly 1:1,162 that still falls below its own recommended range of 1:400 to 1:750 (Nedumaran & Ravi, 2019). The lesson is that absolute workforce size reveals little on its own; what bears on sustainability is the adequacy of staffing relative to the farmers who must be reached. Because countries differ substantially in how extension personnel are defined and enumerated, these workforce counts should be interpreted cautiously, as reported estimates intended primarily for illustrative comparison rather than as directly comparable figures.

The African cases complicate any simple equation of staffing with success. Ethiopia operates one of the most densely staffed systems in sub-Saharan Africa, with roughly 21 workers per 10,000 farmers, equivalent to about 1:476, organised around farmer training centres and grassroots groups (Bouet et al., 2020; Ministry of Agriculture, Ethiopia, 2014; Otsuka & Fan, 2021); more than 70,000 workers have been trained there, of whom some 45,000 remain active. And yet Ethiopia continues to grapple with poverty and inequality, and its system was significantly disrupted by the pandemic, a discrepancy that demonstrates how workforce numbers alone cannot guarantee sustainable outcomes (Chakraborty & Maity, 2020). At the other end of the spectrum, only Mozambique among the countries reviewed exceeds the Food and Agriculture Organization benchmark of one officer per 400 farmers, at about 1:320, whereas Zambia, with 2,523 workers covering some 2,701 agricultural camps and roughly 2.5 million farmers, sits at a ratio near 1:1,136, far short of the benchmark (Makanday Centre, 2020; Mwanamwenge & Cook, 2019; Ng'ombe et al., 2020). Such advisory deficits are not merely administrative: limited and poorly resourced advisory provision is itself among the factors constraining smallholder adoption of climate-smart agriculture in southern Africa (Mutengwa et al., 2023). Table 3 summarises the reported figures and ratios for the countries examined, and Figure 4 plots these worker-to-farmer ratios against the Food and Agriculture Organization benchmark.

TABLE 3. Reported agricultural extension workforce and worker-to-farmer ratios in selected countries, ordered from the largest reported workforce to the smallest.

Country	Number of extension workers	Worker-to-farmer ratio
China	About 1,000,000	Not reported
India	143,863	1:1,162
Ethiopia	70,000	1:476
United States	About 13,000-15,000	Not reported
Tanzania	7,000	1:500 to 1:1,172
Zimbabwe	6,159	1:1,800
Kenya	5,470	1:1,093
Zambia	2,523	1:1,136
Malawi	2,415	1:1,279 to 1:1,642
Ghana	1,244	1:1,500
Mozambique	1,068	1:320

Source: Compiled by the authors from Davis and Franzel (2018), Feed the Future (2018), Makanday Centre (2020), and Moore et al. (2015), with the United States and China figures updated from the Congressional Research Service (2024) and Hu et al. (2009) respectively. The United States figure refers to professional Cooperative Extension staff, with about 32,000 employed across all programme areas, of which agricultural agents and specialists are a subset. Figures are as reported in the cited sources and are not always derived on a comparable basis.

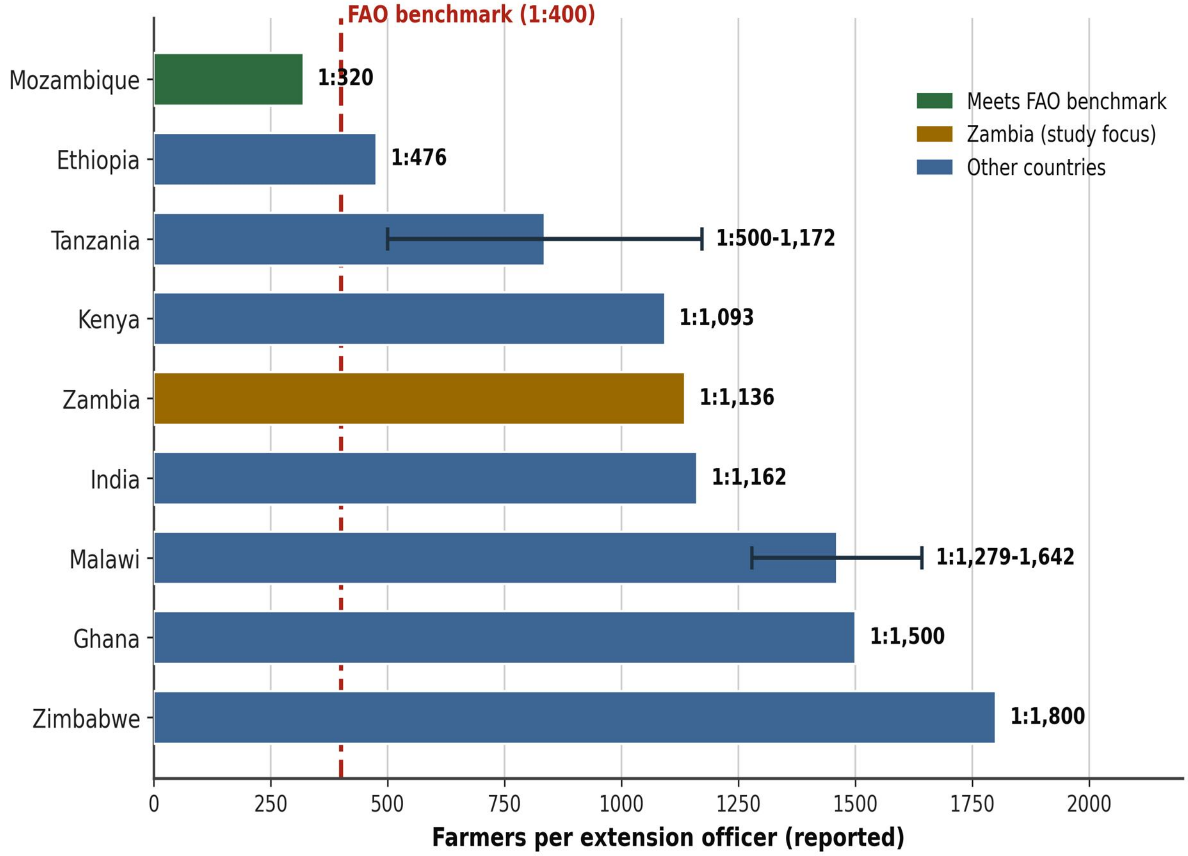

Figure 4. Reported worker-to-farmer ratios in selected developing countries, shown as the number of farmers per extension officer and ordered from the most to the least favourable. The dashed line marks the Food and Agriculture Organization benchmark of one officer per 400 farmers; only Mozambique falls below it, whereas Zambia, the focus of this review, sits well above it. The horizontal markers for Tanzania and Malawi indicate the reported ranges. The United States and China are omitted because no ratio was reported for them. Source: authors, from the data in Table 3.

Using the worker-to-farmer ratio as the sole gauge of extension performance is, on the evidence above, clearly inadequate, and the size of the gap suggests that digital delivery still has far to travel before it can be relied upon at scale across developing countries. More optimistically, as digital models mature, effective ratios should contract. The implication is not that digital tools should displace traditional ones, but that they should be integrated into established approaches such as farmer-to-farmer extension and farmer field schools so that both remain viable, a recognition that widespread digitalisation is already redefining the roles of extension workers and lead farmers alike (Davis et al., 2020).

XI. DISCUSSION

Read together, the evidence supports three central and mutually reinforcing claims. First, extension sustainability is best understood through a combination of theoretical lenses rather than any single one, since the economic, ecological, systems, and social-capital perspectives each capture only a facet of an irreducibly multi-dimensional phenomenon. Second, and contrary to the framing that dominated early commentary, the pandemic acted less as a novel cause of fragility than as an accelerant of weaknesses already present in extension systems, among them chronic underfunding, thin staffing, and uneven infrastructure. Third, the responses that proved most durable were not those that defended a single delivery channel but those that treated extension as an open, adaptive system and coupled agricultural messaging with public-health information.

Table 4 consolidates the synthesis across the review's four analytical strands, summarising the principal findings, the relative strength of the supporting evidence, and the priority gaps that remain for future research.

TABLE 4. *Synthesis of evidence and research gaps across the review's four analytical strands.*

Analytical strand	Key findings from the synthesis	Strength of evidence	Priority research gaps
Current status of extension systems	Transfer-of-technology models persist but are increasingly inadequate; worker roles are shifting from instruction toward facilitation and brokerage, and the pandemic exposed the fragility of supply-driven delivery.	Well established	Limited longitudinal evidence on whether role shifts translate into sustained farmer outcomes after a shock.
Systems and social-network perspectives	Treating extension as an open social network governed by support functions and rules clarifies how multi-stakeholder coordination, social capital, and feedback shape resilience.	Conceptually strong, empirically thin	Few studies test systems or network propositions empirically at smallholder scale.
Components and drivers of sustainable delivery	Sustainability rests on aligning human, social, natural, financial, and built capital, on decentralisation and pluralism, and on continuous capacity development; advisory access has been linked to higher yields.	Moderate and growing	Interactions among drivers, and the relative weight of each capital under shock conditions, remain under-quantified.
Financing, theoretical, digital, and workforce dimensions	Market-systems facilitation and public-private partnership appear the most durable financing routes; digital and AI-enabled tools widen reach but can deepen exclusion; workforce ratios remain far from the FAO benchmark, and headcounts mask quality and connectivity.	Mixed; digital and AI evidence still emerging	Cost-effectiveness of hybrid models, rigorous evaluation of AI-enabled advice, and the digital inclusion of women and youth are largely untested.

Source: authors' synthesis of the reviewed literature. Strength-of-evidence ratings reflect the authors' qualitative appraisal of the consistency and volume of supporting evidence rather than a formal quality score.

These claims carry concrete practical implications. Investment in digital infrastructure and in the digital literacy of workers and farmers alike is a precondition if digital extension is to widen rather than narrow inclusion. Financing arrangements that build genuine commercial relationships, with embedded advisory content and assured market access, appear more resilient than purely public, supply-driven models. And workforce planning, finally, should look beyond headline ratios to the quality, adaptability, and connectivity of the people who staff the system. Framing extension as a market system whose resilience can be measured and deliberately strengthened offers one practical route to anticipating and absorbing future shocks (Siankwilimba et al., 2023).

Two further observations run through the evidence. The first concerns the uneven character of adaptation: extension systems with stronger financial and technological endowments moved relatively quickly toward digital and remote advisory models, whereas many public systems in low-income countries struggled to sustain delivery, particularly in remote areas where connectivity and digital literacy were thin (Gumbi et al., 2023; World Bank, 2020). The second concerns the nature of sustainability itself. Arrangements that appeared effective under normal conditions frequently proved fragile once a major shock arrived, which suggests that sustainability is better conceived as a dynamic property, an adaptive capacity, than as a static measure of operational efficiency (Bates et al., 2021; Stockmann et al., 2021). These conclusions both echo and extend the existing literature. They align with Davis et al. (2020), who characterised extension as shifting from technology transfer toward facilitation, and they corroborate Gumbi et al. (2023) on the persistence of digital-inclusion barriers, while extending that work by tying those barriers explicitly to chronic workforce shortages and to the financing arrangements that underpin delivery.

The synthesis also resonates with the broader innovation-systems literature. It is consistent with Klerkx et al. (2012), who argued that innovation arises through interaction among multiple actors rather than through linear technology transfer, and with the World Bank (2012) analysis that emphasises innovation platforms as a means of sustaining advisory services under changing conditions.

A more critical reading must also hold the tensions in view. Ethiopia maintains one of the densest extension workforces in sub-Saharan Africa, yet continues to struggle with poverty and proved highly exposed to pandemic disruption, which confirms that staffing numbers alone do not secure sustainable outcomes (Chakraborty & Maity, 2020). The digital tools promoted to widen reach can, at the same time, deepen exclusion among women, poorer households, and geographically isolated farmers where connectivity and digital literacy remain limited, so that the same instrument both includes and excludes (Gumbi et al., 2023; Sen et al., 2025). And donor-funded models, however effective during implementation, frequently falter once external financing ends, which is precisely why embedded and market-based arrangements appear the more durable (Beez, 2014; DFID & SDC, 2014). Read together, these contradictions reinforce rather than weaken the central argument that sustainability is a systemic property, not an attribute of any single input.

XII. POLICY AND PRACTICE IMPLICATIONS

The evidence carries clear implications for the actors who shape extension systems. For governments, the priority is twofold: to address the workforce deficits documented above by recruiting and retaining extension staff, and to invest in the rural digital infrastructure without which digital and AI-enabled delivery cannot reach the farmers who most need it (World Bank, 2020). Governments should also embed extension planning within broader agricultural innovation systems and establish governance frameworks for AI-enabled advisory services that address transparency, accountability, privacy, and equitable access (High et al., 2025). For universities and training institutions, the implication is curricular, since extension curricula require revision to equip the next generation of advisors with digital and data competencies, including a working literacy in artificial intelligence and its limitations (Mutengwa et al., 2023).

For donors, the analysis suggests that support is most durable when it is directed toward hybrid models that combine human advisory capacity with digital tools, and toward the market relationships that allow services to persist after funding ends, rather than toward standalone projects (Beez, 2014; DFID & SDC, 2014). For the private sector, the opportunity lies in expanding embedded advisory services that pair commercial incentives with genuine reach into smallholder markets (Howell et al., 2018; Prahalad, 2005). Across these groups, the recurring lesson is that resilient extension depends less on any single intervention than on the coordinated alignment of public investment, training, financing, and commercial provision. In Zambia specifically, the immediate priorities are to improve the extension worker-to-farmer ratio, to expand rural internet coverage, and to strengthen partnerships among government, agribusinesses, and farmer organisations (Makanday Centre, 2020; World Bank, 2020).

XIII. LIMITATIONS

Several limitations should be acknowledged. The synthesis followed a structured narrative review rather than a formal systematic review or meta-analysis, so some degree of selection subjectivity remains. Publication bias may also favour studies reporting successful interventions over accounts of failure, and the reliance on English-language sources may under-represent experiences documented in other languages. Finally, because extension systems are evolving rapidly in the wake of the pandemic, some developments, particularly in artificial intelligence and digital agriculture, are likely to outpace the evidence currently available in the peer-reviewed literature. Furthermore, because the review synthesises evidence from multiple geographical contexts, differences in institutional arrangements, extension mandates, and definitions of extension personnel may limit direct comparability across countries; workforce statistics and performance indicators should therefore be read as indicative rather than definitive measures of sustainability.

XIV. CONCLUSION AND FUTURE DIRECTIONS

Sustainability theories and frameworks are indispensable to understanding how rural extension services are evolving under recurrent shocks such as COVID-19. The pandemic constrained the delivery of extension and advisory services and, with it, smallholder production and productivity, even as it paradoxically accelerated the adoption of digital platforms. The lesson is that the sustainability of extension resides in its capacity to keep providing information under stress, which in turn calls for a decisive move away from reductionist thinking toward holistic, systems-based models whose performance depends on the fit between components and their environment.

A thoroughgoing rethinking of extension components is therefore required, one that defines new functions, methods, and objectives oriented toward long-term viability (Davis, 2020). Future systems are likely to operate through hybrid arrangements that combine face-to-face engagement with digital and increasingly AI-enabled advisory services, and their sustainability will depend not on technological innovation alone but on parallel investment in human capacity, institutional learning, inclusive governance, diversified financing, and rural digital infrastructure. Future research should therefore interrogate these hybrid models more closely, with sustained attention to infrastructure, inclusion, and the changing roles of extension workers, so that smallholder farmers remain resilient to future pandemics, climate shocks, and market disruption while continuing to contribute to food security, poverty reduction, and sustainable development.

A. Future Research Priorities

Five priorities follow from this synthesis. The first is rigorous evaluation of the effectiveness of AI-enabled extension, where enthusiasm currently outruns evidence. The second is the digital inclusion of women and youth, who are most exposed to exclusion as delivery digitises. The third is the cost-effectiveness of hybrid advisory systems relative to the models they are replacing. The fourth is the interaction of climate and pandemic shocks, which this review has treated as compounding but which remains under-quantified. The fifth is the market-system financing of extension, and in particular the conditions under which embedded and facilitated models prove more durable than public or donor-led provision.

Sustainable agricultural extension in the post-pandemic era will depend not merely on the technologies it adopts but on its capacity to integrate human, institutional, technological, financial, and ecological resources within resilient and adaptive systems. Ultimately, the resilience of agricultural extension will be determined by its ability to connect farmers, markets, institutions, and knowledge systems in ways that remain adaptive, equitable, and sustainable under conditions of continuing uncertainty.

XV. DECLARATIONS

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2) Conflicts of interest. The first and third authors are professionally affiliated with Musika Development Initiatives, the organisation cited as an illustrative case in the discussion of financing models. The authors declare no other conflicts of interest.
3) Data availability. No new data were created or analysed in this synthesis; all sources reviewed are cited in the reference list. Data sharing is therefore not applicable.
4) Declaration of generative AI use. Generative artificial intelligence tools were used to assist with drafting, editing, and formatting of the revised manuscript. The authors reviewed, verified, and edited all content and take full responsibility for the integrity and accuracy of the work.
5) Author contributions (CRediT). E. Siankwilimba: Conceptualization; Methodology; Investigation; Writing - original draft. E. S. Mwaanga: Methodology; Writing - review and editing. J. Munkombwe: Investigation; Writing - review and editing. C. Mumba: Validation; Supervision. B. M. Hang'ombe: Supervision; Writing - review and editing.
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REFERENCES

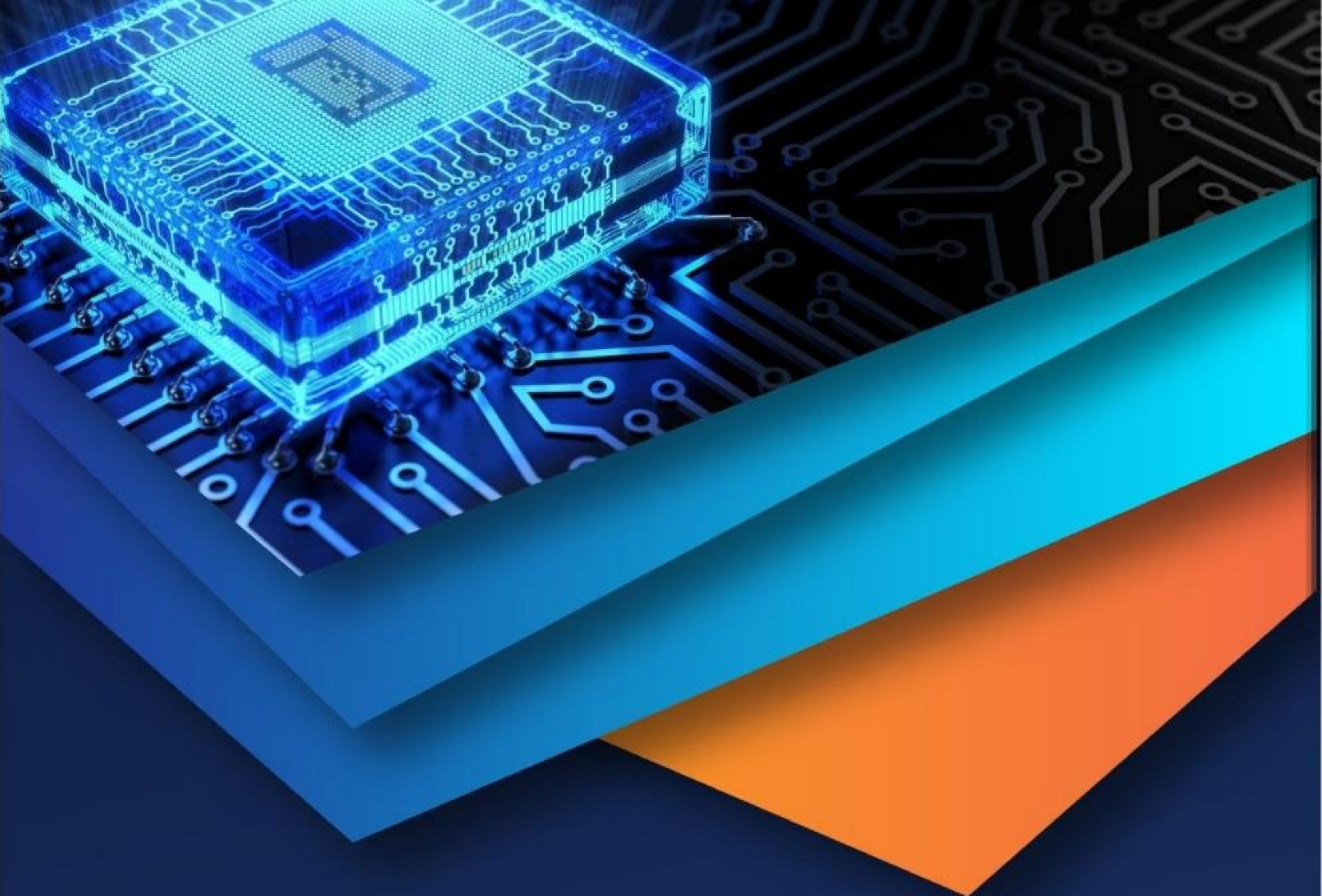
[1] Adnan, N., Md Nordin, S., Rahman, I., & Noor, A. (2017). Adoption of green fertilizer technology among paddy farmers: A possible solution for Malaysian food security. Land Use Policy, 63, 38-52.
[2] Adnan, N., & Nordin, S. M. (2021). How COVID-19 affects the Malaysian paddy industry? Adoption of green fertilizer as a potential resolution. Environment, Development and Sustainability, 23(6), 8089-8129.
[3] Alabi, O. S., & Ajayi, A. O. (2018). Assessment of desired competencies of agricultural extension agents in sustainable agriculture development activities in southwest Nigeria. Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development, 18(3), 11-20.
[4] Albert, M. (2019). Sustainable frugal innovation: The connection between frugal innovation and sustainability. Journal of Cleaner Production, 237, 117747.
[5] Alvi, M., Barooah, P., Gupta, S., & Saini, S. (2021). Women's access to agriculture extension amidst COVID-19: Insights from Gujarat, India and Dang, Nepal. Agricultural Systems, 188, 103035.
[6] Bakken, S., Marden, S., Arteaga, S. S., Grossman, L., Keselman, A., Le, P.-T., ... Farhat, T. (2019). Behavioral interventions using consumer information technology as tools to advance health equity. American Journal of Public Health, 109, 79-85.
[7] Baloch, M. A., & Thapa, G. B. (2019). Review of the agricultural extension modes and services with a focus on Balochistan, Pakistan. Journal of the Saudi Society of Agricultural Sciences, 18(2), 188-194.
[8] Barnes, S. J. (2020). Information management research and practice in the post-COVID-19 world. International Journal of Information Management, 55, 102175.
[9] Bates, A. E., Primack, R. B., Biggar, B. S., Bird, T. J., Clinton, M. E., Command, R. J., ... Duarte, C. M. (2021). Global COVID-19 lockdown highlights humans as both threats and custodians of the environment. Biological Conservation, 263, 109175.

[10] Beers, P. J., Hermans, F., Veldkamp, T., & Hinssen, J. (2014). Social learning inside and outside transition projects: Playing free jazz for a heavy metal audience. NJAS - Wageningen Journal of Life Sciences, 69, 5-13.
[11] Beez, P. (2014). The operational guide for the Making Markets Work for the Poor (M4P) approach.
[12] Bensch, G., Kluve, J., & Stoterau, J. (2021). The market-based dissemination of energy-access technologies as a business model for rural entrepreneurs: Evidence from Kenya. Resource and Energy Economics, 66, 101248.
[13] Biondi, B., Barrett, C. B., Mazzocchi, M., Ando, A., Harvey, D., & Mallory, M. (2021). Journal submissions, review and editorial decision patterns during initial COVID-19 restrictions. Food Policy, 105, 102167.
[14] Birner, R., Davis, K., Pender, J., Nkonya, E., Anandajayasekeram, P., Ekboir, J., ... Cohen, M. (2009). From best practice to best fit: A framework for designing and analyzing pluralistic agricultural advisory services worldwide. The Journal of Agricultural Education and Extension, 15(4), 341-355.
[15] Bouet, S., Odjo, P., & Zaki, C. (2020). Africa agriculture trade monitor 2020. African Growth and Development Policy Modeling Consortium.
[16] Butterfield, J., Bingham, S., & Savory, A. (2019). Holistic management handbook (3rd ed.). Island Press.
[17] Campo, P. C., Bousquet, F., & Villanueva, T. R. (2010). Modelling with stakeholders within a development project. Environmental Modelling and Software, 25(11), 1302-1321.
[18] Cao, S., Xia, C., Suo, X., & Wei, Z. (2021). A framework for calculating the net benefits of ecological restoration programs in China. Ecosystem Services, 50, 101325.
[19] Ceschin, F., & Gaziulusoy, I. (2019). Design for sustainability: A multi-level framework from products to socio-technical systems. Taylor and Francis.
[20] Chakraborty, I., & Maity, P. (2020). COVID-19 outbreak: Migration, effects on society, global environment and prevention. Science of the Total Environment, 728, 138882.
[21] Chapoto, A., Haggblade, S., Hichaambwa, M., Kabwe, S., Longabaugh, S., Sitko, N., & Tschirley, D. (2012). Agricultural transformation in Zambia: Alternative institutional models for accelerating agricultural productivity growth and commercialization.
[22] Chen, T., Ding, K., Hao, S., Li, G., & Qu, J. (2020). Batch-based traceability for pork: A mobile solution with 2D barcode technology. Food Control, 107, 106770.
[23] Chinsembu, K. C. (2021). Phytomedicines and nutraceuticals in the clinical management of COVID-19. International Science and Technology Journal of Namibia, 14, 1-8.
[24] Congressional Research Service. (2024). The agricultural cooperative extension system: An overview (CRS Report No. R48071).
[25] Cook, B. R., Satizabal, P., & Curnow, J. (2021). Humanising agricultural extension: A review. World Development, 140, 105337.
[26] Cooper, G. S., Rich, K. M., Shankar, B., Rana, V., Ratna, N. N., Kadiyala, S., ... Nadagouda, S. B. (2021). Identifying win-win-win futures from inequitable value chain trade-offs: A system dynamics approach. Agricultural Systems, 190, 103096.
[27] Davis, K. (2020). Thinking about the future is challenging but liberating. Journal of International Agricultural and Extension Education, 23(1), 1-45.
[28] Davis, K., Babu, S. C., & Ragas, C. (2020). Agricultural extension: Global status and performance in selected countries. International Food Policy Research Institute.
[29] Davis, K., & Franzel, S. (2018). Extension and advisory services in 10 developing countries: A cross-country analysis.
[30] DFID, & SDC. (2014). The operational guide for the Making Markets Work for the Poor (M4P) approach (2nd ed.).
[31] FAO. (2013). Climate-smart agriculture sourcebook. Food and Agriculture Organization.
[32] FAO. (2018). Shaping the future of livestock (Report No. I8384EN). Food and Agriculture Organization.
[33] FAO. (2021). The White/Wiphala paper on Indigenous Peoples' food systems. Food and Agriculture Organization.
[34] Feed the Future. (2018). Mozambique: Desk study of extension and advisory services.
[35] Ferretti, V., & Grosso, R. (2019). Designing successful urban regeneration strategies through a behavioral decision aiding approach. Cities, 95, 102376.
[36] Friel, S., Pescud, M., Malbon, E., Lee, A., Carter, R., Greenfield, J., ... Meertens, B. (2017). Using systems science to understand the determinants of inequities in healthy eating. PLoS ONE, 12(11), e0188872.
[37] Giroud, A., & Ivarsson, I. (2020). World investment report 2020: International production beyond the pandemic. Journal of International Business Policy, 3(4), 465-468.
[38] Glover, D., Sumberg, J., Ton, G., Andersson, J., & Badstue, L. (2019). Rethinking technological change in smallholder agriculture. Outlook on Agriculture, 48(3), 169-180.
[39] Grove, B., Archibald, T., & Davis, K. (2020). Extension and advisory services: Supporting communities before, during, and after crises. Global Agricultural Productivity Report, 1-4.
[40] Gumbi, N., Gumbi, L., & Twinomurinzi, H. (2023). Towards sustainable digital agriculture for smallholder farmers: A systematic literature review. Sustainability, 15(16), 12530. https://doi.org/10.3390/su151612530
[41] Haggag, W. M. (2021). Agricultural digitalization and rural development in COVID-19 response plans: A review article. International Journal of Agricultural Technology, 17(1), 67-74.
[42] Hasheminasab, H., Gholipour, Y., Kharrazi, M., Streimikiene, D., & Hashemkhani, S. (2020). A dynamic sustainability framework for petroleum refinery projects with a life cycle attitude. Sustainable Development, 28(5), 1033-1048.
[43] High, C., Singh, N., & Nemes, G. (2025). Artificial intelligence for agricultural extension: Supporting transformative learning among smallholder farmers. Journal of Development Policy and Practice. Advance online publication. https://doi.org/10.1177/24551333251345224
[44] Hovmand, P. S. (2014). Community based system dynamics. Springer.
[45] Howell, R., van Beers, C., & Doorn, N. (2018). Value capture and value creation: The role of information technology in business models for frugal innovations in Africa. Technological Forecasting and Social Change, 131, 227-239.
[46] Hu, R., Yang, Z., Kelly, P., & Huang, J. (2009). Agricultural extension system reform and agent time allocation in China. China Economic Review, 20(2), 303-315.
[47] Ibrahim, A. M. (2019). A method to support leadership effectiveness in a construction project organisation in Nigeria [Doctoral dissertation, University of Liverpool].
[48] IFAD. (2021). Transforming food systems for rural prosperity: Rural development report 2021.

[49] Jane, M., Gibbon, D., Ingram, J., Reed, M., Short, C., & Dwyer, J. (2011). Organising collective action for effective environmental management and social learning in Wales. Journal of Agricultural Education and Extension, 17(1), 69-83.
[50] Keating, B. A. (2020). Crop, soil and farm systems models: Science, engineering or snake oil revisited. Agricultural Systems, 184, 102903.
[51] Keding, G. B., Gramzow, A., Ochieng, J., Laizer, A., Muchoki, C., Onyango, C., ... Yang, R.-Y. (2021). Nutrition integrated agricultural extension: A case study in Western Kenya. Health Promotion International, 36, 1-13.
[52] Klerkx, L., van Mierlo, B., & Leeuwis, C. (2012). Evolution of systems approaches to agricultural innovation: Concepts, analysis and interventions. In I. Darnhofer, D. Gibbon, & B. Dedieu (Eds.), Farming Systems Research into the 21st Century: The New Dynamic (pp. 457-483). Springer. https://doi.org/10.1007/978-94-007-4503-2_20
[53] Kogo, B. K., Kumar, L., & Koech, R. (2020). Climate change and variability in Kenya: A review of impacts on agriculture and food security. Environment, Development and Sustainability, 23(1), 23-43.
[54] Kumar, A., Luthra, S., Mangla, S. K., & Kazancoglu, Y. (2020). COVID-19 impact on sustainable production and operations management. Sustainable Operations and Computers, 1, 1-7.
[55] Lamontagne-Godwin, J., Williams, F., Bandara, W. M. P. T., & Appiah-Kubi, Z. (2017). Quality of extension advice: A gendered case study from Ghana and Sri Lanka. Journal of Agricultural Education and Extension, 23(1), 7-22.
[56] Lenaghan, T., & Heffern, A. (2021). How donor-funded economic growth projects are adapting to the challenges of COVID-19. DAI.
[57] Maggio, G., & Sitko, N. (2019). Knowing is half the battle: Seasonal forecasts, adaptive cropping systems, and the mediating role of private markets in Zambia. Food Policy, 89, 101781.
[58] Mahmood, H., Furqan, M., Meraj, G., & Hassan, M. S. (2024). The effects of COVID-19 on agriculture supply chain, food security, and environment: A review. PeerJ, 12, e17281. https://doi.org/10.7717/peerj.17281
[59] Mahmood, N., Arshad, M., Mehmood, Y., Faisal Shahzad, M., & Kachele, H. (2021). Farmers' perceptions and the role of institutional arrangements in climate change adaptation: Insights from rainfed Pakistan. Climate Risk Management, 32, 100288.
[60] Makanday Centre. (2020). Data shows extension services the most neglected in agriculture. Makanday Center for Investigative Journalism, Zambia.
[61] Marambe, B. (2019). Agriculture negotiations under the United Nations Framework Convention on Climate Change (UNFCCC). Sri Lanka Journal of Food and Agriculture, 5(2), 1.
[62] Matthews, A. (2021). Are the COP26 climate change negotiations ready to embrace agriculture? EuroChoices, 20(2), 4-10.
[63] Maulu, S., Hasimuna, O. J., Chibesa, M., Bbole, I., Mphande, J., Mwanachingwala, M., Nawanzi, K., Chibeya, D., Siavwapa, S., Mbewe, J., Namukonda, L., Balungu, F., Mumbula, I., Kabika, M., Mweemba, S., Sikanyenyene, M., Siankwilimba, E., Imbwae, I., & Mweetwa, H. M. (2024). Perceived effects of climate change on aquaculture production in Zambia: Status, vulnerability factors, and adaptation strategies. Frontiers in Sustainable Food Systems, 8, 1348984. https://doi.org/10.3389/fsufs.2024.1348984
[64] Maulu, S., Hasimuna, O. J., Mutale, B., Mphande, J., & Siankwilimba, E. (2021). Enhancing the role of rural agricultural extension programs in poverty alleviation: A review. Cogent Food and Agriculture, 7(1), 1886663.
[65] Meera, S. N., Balaji, V., Muthuraman, P., Sailaja, B., & Dixit, S. (2012). Changing roles of agricultural extension: Harnessing information and communication technology (ICT) for adapting to stresses envisaged under climate change. In Crop stress and its management (pp. 585-605). Springer.
[66] Michelena, X., Borrell, H., Lopez-Corbeto, M., Lopez-Lasanta, M., Moreno, E., Pascual-Pastor, M., ... Marsal, S. (2020). Incidence of COVID-19 in a cohort of adult and paediatric patients with rheumatic diseases. Seminars in Arthritis and Rheumatism, 50(4), 564-570.
[67] Millan, A., Limketkai, B., & Guarnaschelli, S. (2019). Financing the transformation of food systems under a changing climate. CGIAR.
[68] Ministry of Agriculture. (2016). The national agricultural extension and advisory services strategy 2016-2020.
[69] Ministry of Agriculture, Ethiopia. (2014). National strategy for Ethiopia's agricultural extension system: Vision, systemic bottlenecks and priority interventions. Federal Democratic Republic of Ethiopia.
[70] Moguilevsky, D., Fernandez, N. V., Puntieri, J. G., Outes, V., & Fontenla, S. B. (2021). Surviving after an eruption: Ecosystem dynamics and mycorrhizae in Nothofagus pumilio forests affected by the 2011 Puyehue Cordon-Caulle tephra. Forest Ecology and Management, 479, 118535.
[71] Moore, A., Ferguson, O., & Lolig, V. (2015). Assessment of extension and advisory services in Ghana's Feed the Future zone of influence.
[72] Moser, A., Korstjens, I., Ballandies, M. C., Dapp, M. M., Degenhart, B. A., Helbing, D., ... Pardi, A. (2018). Finance 4.0: A socio-ecological finance system. Springer.
[73] Murray, A., Skene, K., & Haynes, K. (2017). The circular economy: An interdisciplinary exploration of the concept and application in a global context. Journal of Business Ethics, 140(3), 369-380.
[74] Mutambara, S. (2015). Making Markets Work for the Poor (M4P) approach and smallholder irrigation farming. Irrigation and Drainage Systems Engineering, 4(1), 1-9.
[75] Mutengwa, C. S., Mnkeni, P., & Kondwakwenda, A. (2023). Climate-smart agriculture and food security in southern Africa: A review of the vulnerability of smallholder agriculture and food security to climate change. Sustainability, 15(4), 2882. https://doi.org/10.3390/su15042882
[76] Mwanamwenge, M., & Cook, S. (2019). Beyond maize: Exploring agricultural diversification in Zambia from different perspectives.
[77] Nedumaran, S., & Ravi, N. (2019). Agriculture extension system in India: A meta-analysis. Research Journal of Agricultural Sciences, 10(3), 473-479.
[78] Ng'ombe, J. N., Tembo, M. C., & Masasi, B. (2020). Are they aware, and why? Bayesian analysis of predictors of smallholder farmers' awareness of climate change and its risks to agriculture. Agronomy, 10(3), 376.
[79] Nganga, W. B., Ng'etich, K. O., Macharia, M. J., Kiboi, N. M., Adamtey, N., & Ngetich, K. F. (2020). Multi-influencing-factors evaluation for organic-based soil fertility technologies out-scaling in Upper Tana Catchment in Kenya. Scientific African, 7, e00216.
[80] Ngoma, H., Finn, A., & Kabisa, M. (2021). Climate shocks, vulnerability, resilience and livelihoods in rural Zambia. World Bank.
[81] Nkuyubwatsi, B. (2016). Positioning extension massive open online courses (xMOOCs) within the open access and the lifelong learning agendas in a developing setting. Journal of Learning for Development, 3(1), 14-36.
[82] Olorunfemi, O. D. (2024). Sustainable agricultural practices in sub-Saharan Africa: A review of adoption trends, impacts, and challenges among smallholder farmers. Sustainability, 16(22), 9766. https://doi.org/10.3390/su16229766

[83] Omulo, G., & Kumeh, E. M. (2020). Farmer-to-farmer digital network as a strategy to strengthen agricultural performance in Kenya. Technological Forecasting and Social Change, 158, 120120.
[84] Osumba, J., Recha, J., & Oroma, G. (2021). Transforming extension and service delivery through bottom-up climate resilient farmer field school approach to agribusiness in Eastern Africa. Preprints.
[85] Otsuka, K., & Fan, S. (Eds.). (2021). Agricultural development: New perspectives in a changing world. International Food Policy Research Institute.
[86] Pambudy, R. (2018). The development of adopting innovation on entrepreneurship status of Madura cattle farmers. Tropical Animal Science Journal, 41(2), 147-156.
[87] Patil, S. S., & Puranik, P. Y. L. (2019). Blockchain technology. International Journal of Trend in Scientific Research and Development, 3(4), 573-574.
[88] Phillips, P. W. B., Relf-Eckstein, J. A., Jobe, G., & Wixted, B. (2019). Configuring the new digital landscape in western Canadian agriculture. NJAS - Wageningen Journal of Life Sciences, 90-91, 100295.
[89] Prahalad, C. K. (2005). The fortune at the bottom of the pyramid. Wharton School Publishing.
[90] Quisumbing, A. R., Meinzen-Dick, R., Raney, T. L., Croppenstedt, A., Behrman, J. A., & Peterman, A. (2014). Closing the knowledge gap on gender in agriculture. In Gender in agriculture (pp. 3-28). Springer.
[91] Rahmandad, H., Lim, T. Y., & Sterman, J. (2021). Behavioral dynamics of COVID-19: Estimating underreporting, multiple waves, and adherence fatigue across 92 nations. System Dynamics Review, 37(1), 5-31.
[92] Raworth, K. (2017). Doughnut economics: Seven ways to think like a 21st century economist. Chelsea Green Publishing.
[93] Rezaei-Moghaddam, K., & Salehi, S. (2010). Agricultural specialists' intention toward precision agriculture technologies. African Journal of Agricultural Research, 5(11), 1191-1199.
[94] Ricome, A., Faye, A., Fall, C. S., & Gomez-y-Paloma, S. (2025). The impact of access to agricultural advisory services on input use and farm performance: Evidence from Senegal. Agribusiness, 41(3), 896-914. https://doi.org/10.1002/agr.21932
[95] Ritter, C., Jansen, J., Roche, S., Kelton, D. F., Adams, C. L., Orsel, K., ... Barkema, H. W. (2017). Invited review: Determinants of farmers' adoption of management-based strategies for infectious disease prevention and control. Journal of Dairy Science, 100(5), 3329-3347.
[96] Roberts, R., Elkington, J., & Rodrigues, J. (2021). Aligning finance for the net-zero economy: Innovation and transformation.
[97] Roe, D., Dickman, A., Kock, R., Milner-Gulland, E. J., Rihoy, E., & 't Sas-Rolfes, M. (2020). Beyond banning wildlife trade: COVID-19, conservation and development. World Development, 136, 105121.
[98] Roling, N., & de Jong, F. (1998). Learning: Shifting paradigms in education and extension studies. The Journal of Agricultural Education and Extension, 5(3), 143-161.
[99] Rude, J., Beninger, S., Francis, J. N. P., Adhikari, J., Timsina, J., Khadka, S. R., ... Zhou, G. (2020). COVID-19 impacts on agriculture and food systems in Nepal: Implications for SDGs. Business Horizons.
[100] Sen, L. T. H., Phuong, L. T. H., Chou, P., Dacuyan, F. B., Nyberg, Y., & Wetterlind, J. (2025). The opportunities and barriers in developing interactive digital extension services for smallholder farmers as a pathway to sustainable agriculture: A systematic review. Sustainability, 17(7), 3007. https://doi.org/10.3390/su17073007
[101] Shaukat, M. B., Latif, K. F., Sajjad, A., & Eweje, G. (2021). Revisiting the relationship between sustainable project management and project success: The moderating role of stakeholder engagement and team building. Sustainable Development, 29(6), 2034-2051.
[102] Sheth, J. (2020). Impact of COVID-19 on consumer behavior: Will the old habits return or die? Journal of Business Research, 117, 280-283.
[103] Siankwilimba, E. (2016). Effects of climate change induced electricity load shedding on smallholder agricultural enterprises in Zambia: The case of five Southern Province districts. Journal of Agriculture and Research, 8(8), 1-151.
[104] Siankwilimba, E., Hiddlestone-Mumford, J., Hoque, M. E., Hang'ombe, B. M., Mumba, C., Hasimuna, O. J., Maulu, S., Mphande, J., Chibesa, M., Moono, M. B., Muhala, V., Cavaliere, L. P. L., Faccia, A., & Prayitno, G. (2023). Sustainability of agriculture extension services in the face of COVID-19: A study on gender-specific market systems. Cogent Food & Agriculture, 9(2), 2284231. https://doi.org/10.1080/23311932.2023.2284231
[105] Sima, V., Gheorghe, I. G., Subic, J., & Nancu, D. (2020). Influences of the Industry 4.0 revolution on human capital development and consumer behavior: A systematic review. Sustainability, 12(10), 4035.
[106] Sitko, N. J. (2017). The politics of food security. Oxford University Press.
[107] Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. Journal of Business Research, 104, 333-339. https://doi.org/10.1016/j.jbusres.2019.07.039
[108] Sterman, J. D. (1994). Learning in and about complex systems. System Dynamics Review, 10(2-3), 291-330.
[109] Stockmann, C., Winkler, H., & Kunath, M. (2021). Robustness assessment in production systems. Journal of Manufacturing Technology Management, 32(4), 932-951.
[110] Sweeney, L. B., & Sterman, J. D. (2000). Bathtub dynamics: Initial results of a systems thinking inventory. System Dynamics Review, 16(4), 249-286.
[111] Swinnen, J., & McDermott, J. (2020). COVID-19 and global food security. EuroChoices, 19(3), 26-33.
[112] Taylor, M., & Bhasme, S. (2018). Model farmers, extension networks and the politics of agricultural knowledge transfer. Journal of Rural Studies, 64, 1-10.
[113] Tengapoe, K., Baddianaah, I., & Yaradua, A. S. (2024). Access to social capital and smallholder agricultural practices: The case of smallholder farmers in North-Western Ghana. Cogent Food & Agriculture, 10(1), 2353670. https://doi.org/10.1080/23311932.2024.2353670
[114] Tisenkopfs, T., Kunda, I., Sumane, S., Brunori, G., Klerkx, L., & Moschitz, H. (2015). Learning and innovation in agriculture and rural development. Journal of Agricultural Education and Extension, 21(1), 13-33.
[115] Todaro, M. P., & Smith, S. C. (2015). Economic development (12th ed.). Pearson.
[116] Ugochukwu, N. C. (2020). A review of agricultural extension and advisory services in sub-Saharan African countries: Progress with private sector involvement. Journal of Agribusiness and Rural Development.
[117] Vaidyanathan, V., Cheelo, C., Chulu, M., Nalwimba, N., Muyobozi, G. T. M., Tong, S., & Agarwal, W. M. (2021). China-Zambia economic relations: Perspectives from the agricultural sector (Monograph No. 6). Institute of Chinese Studies.
[118] Varahachalam, S. P., Lahooti, B., Chamaneh, M., Bagchi, S., Chhibber, T., Morris, K., ... Kaushik, A. (2021). Nanomedicine for SARS-CoV-2: State-of-the-art and future prospects. International Journal of Nanomedicine, 16, 539-560.

[119]Venkatramanan, V., Shah, S., & Prasad, R. (2019). Global climate change and environmental policy: Agriculture perspectives. Springer.
[120]Wang, Y., Wang, R., & Yao, Z. (2020). Mechanism of action of policy networks on the performance of university-based agricultural extensions. Journal of Agricultural Education and Extension, 26(5), 423-441.
[121]Whitmee, S., Haines, A., Beyrer, C., Boltz, F., Capon, A. G., De Souza Dias, B. F., ... Yach, D. (2015). Safeguarding human health in the Anthropocene epoch: Report of the Rockefeller Foundation-Lancet Commission on planetary health. The Lancet, 386(10007), 1973-2028.
[122]World Bank. (2012). Agricultural innovation systems: An investment sourcebook. World Bank.
[123]World Bank. (2020). Accelerating digital transformation in Zambia. World Bank.
[124]World Health Organisation. (2020). Coronavirus disease (COVID-19) donors and partners. World Health Organisation.
[125]World Health Organisation. (2021). New US$50 billion health, trade and finance roadmap to end the pandemic and secure a global recovery.
[126]Zabaniotou, A. (2020). A systemic approach to resilience and ecological sustainability during the COVID-19 pandemic. Global Transitions, 2, 116-126.
[127]Zambrano-Monserrate, M. A., Ruano, M. A., & Sanchez-Alcalde, L. (2020). Indirect effects of COVID-19 on the environment. Science of the Total Environment, 728, 138813.



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