Locus Journal of Academic Literature Review
Powered by locus media publishing
Vol. 5 No. 10, October 2026
P-ISSN: 2829-4262, E-ISSN: 2829-3827

Agricultural Workforce Transformation in Indonesia: Emerging Competency Requirements for Sustainable and Smart Agriculture

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Received 19 Agustus 2026 Initial submission → **Revised** 03 October 2026 Author revision → **Accepted** 14 October 2026 Editorial decision → **Published** 21 October 2026 Online publication

DOI: https://doi.org/10.56128/ljoalr.v5i10.1179

Abstract

Indonesia's agricultural workforce faces intersecting demographic, technological, and sustainability transitions, but their implications for competency development remain dispersed across disciplines. This scoping review maps Indonesian evidence published between 2016 and 2026, using a documented Scopus search complemented by semantic literature discovery using Elicit and reporting study selection with PRISMA-ScR. Forty-six studies were included in descriptive evidence mapping and thematic synthesis, with VOSviewer term co-occurrence analysis as a supplementary descriptive tool. The literature describes ageing, limited youth entry, labour reallocation, mechanisation, and digitalisation. In combination, these trends point to six interconnected competency domains: technical-production, digital-technological, managerial-entrepreneurial, social-communication, adaptive-problem-solving, and environmental or green capabilities. Readiness to apply them also depends on education, extension, infrastructure, finance, farmer organisations, and policy support. The integrated framework proposed here organises these relationships but has not been independently validated. The review is limited by heterogeneity among included designs, incomplete provenance of some screening and network-analysis details, and the predominantly descriptive nature of the evidence. Integrated competency development and enabling institutions are therefore plausible priorities for further research and context-specific workforce policy.

Keywords

agricultural competencies, generational renewal, green skills, mechanisation, rural employment, workforce readiness.

1. Introduction

Indonesia's agricultural sector is experiencing substantial demographic and structural change. An ageing farm population, declining participation of younger workers, rural–urban mobility, and the expansion of non-agricultural employment have raised concerns about labour availability and generational renewal (Nasrullah., 2024; Ngadi et al., 2023; Setyanti, 2021; Susilowati, 2016). These trends have increasingly positioned agricultural workforce transformation as an important issue

within broader debates on rural development, structural change, and the future of farming in Indonesia.

Alongside demographic change, a growing body of research has examined technological transformation in agriculture. Earlier studies focused largely on mechanisation and labour productivity, while more recent work increasingly addresses digital agriculture, precision farming, internet use, sensors, the Internet of Things (IoT), and other smart-farming applications (Hasan et al., 2023; Purba et al., 2021; Santoso et al., 2024; Yamauchi, 2016). This shift reflects a broader movement in agricultural research from questions of labour availability and production efficiency toward the implications of technological change for farmers, workers, and rural enterprises.

A parallel strand of literature has developed around human capabilities and sustainable agriculture. Studies have examined farmer knowledge, technology adoption, digital literacy, entrepreneurship, extension, climate adaptation, resilience, and environmentally oriented skills (Handayani et al., 2020; Perdinan et al., 2018; Zainuddin Rela et al., 2021). Collectively, this literature suggests growing recognition that agricultural transformation depends not only on technologies and production systems, but also on the capacities of people and institutions to respond to changing economic, technological, and environmental conditions.

Despite these advances, the literature remains fragmented across several research domains. Demographic restructuring, youth participation, mechanisation, digitalisation, sustainability, extension, and skill development are often investigated separately, making it difficult to understand how these processes jointly reshape agricultural work. In particular, limited synthesis has connected changes in workforce structure with emerging competency requirements and the wider conditions that support workforce adaptation. This fragmentation restricts the development of a coherent perspective on how Indonesia's agricultural workforce is being prepared for increasingly smart and sustainable production systems.

This study addresses that gap by integrating evidence on workforce restructuring, technological transformation, competency development, and sustainability transition within a single agricultural workforce perspective. Rather than simply cataloguing required skills, it examines how changes in the structure and nature of agricultural work are reshaping capability requirements and workforce preparedness. By treating labour transformation and competency development as interconnected dimensions of the same transition, the study aims to clarify the emerging competencies required for sustainable and smart agriculture, identify persistent readiness gaps, and draw implications for agricultural education, extension, and workforce development.

Three guiding questions structured this synthesis: (1) Which demographic, economic, technological, and environmental pressures are changing agricultural work in Indonesia? (2) Which competencies recur across research on farming, rural employment, smart agriculture, and sustainability? (3) Which individual and institutional conditions enable workers to acquire and apply these capabilities? These questions organise an evidence map rather than a causal test.

2. Research Methods

This study used a scoping review approach reported with reference to the PRISMA Extension for Scoping Reviews (PRISMA-ScR) (Tricco et al., 2018). The aim was to map heterogeneous evidence, identify concepts and gaps, and synthesise patterns rather than estimate intervention effects (Munn et al., 2018). Five stages guided the reported process: defining the objectives, identifying studies, selecting eligible reports, charting their characteristics, and synthesising findings. The resulting

synthesis is descriptive and interpretive, and the proposed competency framework should not be understood as an empirically tested model.

The literature search was conducted on 10 August 2026. Scopus was used as the primary bibliographic database because the research topic spans agricultural, social, economic, environmental, and technological disciplines. The search strategy was iteratively refined to achieve an appropriate balance between sensitivity and precision.

The final Scopus query was “Indonesia” AND ("agricultural workforce" OR "agricultural worker*" OR "agricultural labour" OR "agricultural labor" OR "farm worker*" OR "farm labour" OR "farm labor" OR "agricultural employment" OR "agricultural human capital" OR "agricultural skill*" OR "farmer skill*" OR "farmer competenc*") AND (skill* OR competenc* OR knowledge OR "human capital" OR transformation OR technolog* OR digital* OR mechanis* OR mechaniz* OR sustainab* OR "smart farming").

The reported search expression is reproduced above to document the original search strategy. Exact Scopus field tags, interface settings, export files, and query-history records were not available for independent methodological audit. Accordingly, the reported search is described transparently, without claiming complete independent reproducibility.

The Scopus search yielded 223 records. Removal of 24 records outside the 2016–2026 publication period and 42 records classified as non-article document types left 157 records for title-and-abstract screening. These document-type restrictions applied to the reported Scopus screening stage; the combined final corpus also contains conference and review publications potentially identified by Elicit. The provenance and eligibility treatment of these source types cannot be fully established without the original screening records.

To complement keyword-based retrieval, an AI-assisted semantic search was conducted using Elicit Find Papers. Five natural-language prompts were used: (1) How is the agricultural workforce in Indonesia changing, and what skills and competencies are required for sustainable and smart agriculture?; (2) What changes are occurring in Indonesia's agricultural workforce in terms of employment, ageing, youth participation, labour availability, and workforce structure?; (3) How are digitalisation, mechanisation, automation, and smart farming changing agricultural work and skill requirements in Indonesia?; (4) What knowledge, skills, competencies, and human capital are required by farmers and agricultural workers in Indonesia?; and (5) What skills and competencies are required for Indonesian farmers and agricultural workers to adopt sustainable and climate-smart agricultural practices? The same 2016–2026 period was applied. Elicit identified 59 records; after removing 11 internal duplicates and three records already identified through Scopus, 45 additional unique records remained.

Elicit was employed to identify potentially relevant studies, not to replace eligibility assessment. The reported workflow documents the five semantic prompts and deduplication totals, but archived ranking thresholds, exported result lists, and study-level adjudication records were not available for further verification. This limits independent replication of the supplementary search.

Inclusion and exclusion criteria

Records were considered eligible when they (1) were published during 2016–2026, up to the September 2026 search date; (2) addressed Indonesia or contained substantive Indonesian agricultural evidence; (3) covered farmers, agricultural workers, agricultural employment, labour, human capital, or closely related workforce groups; and (4) supplied evidence on workforce transformation, competencies, technology adaptation, sustainability, or workforce readiness. The broad framing is consistent with a scoping review of population (agricultural workers and related groups), concept

(workforce transformation and capabilities), and context (Indonesian agriculture). Study designs were heterogeneous; conference and secondary publications appearing in the included set are described transparently, rather than misrepresented as independent primary studies.

Studies concerned exclusively with agronomic, biological, veterinary, health, or engineering outcomes, without a discernible workforce, learning, adoption, human-capital, or competency dimension, were outside the review scope. Reports with insufficient or inconsistent bibliographic information were also excluded. Detailed rules for the treatment of conference proceedings, review papers, and Elicit-only records were not retained in the supplied selection materials and should be verified from the authors' original screening documentation rather than reconstructed retrospectively.

Among the 157 Scopus records screened by title and abstract, 77 were retained and 80 excluded. The 77 retained records were combined with 45 unique Elicit records (59 initially found; 11 internal duplicates and three overlapping Scopus records removed), giving 122 reports sought for retrieval. The manuscript reports that all 122 full texts were retrieved, 76 were excluded after eligibility assessment, and 46 were included. Figure 1 partitions the 76 full-text exclusions into 42 without substantive agricultural workforce or competency focus, 18 predominantly technical or agronomic studies without a human-skills dimension, and 16 outside the analytical scope or with inconsistent information. These counts are internally consistent, but independent replication requires the underlying study-selection log, source-type decisions, and database exports.

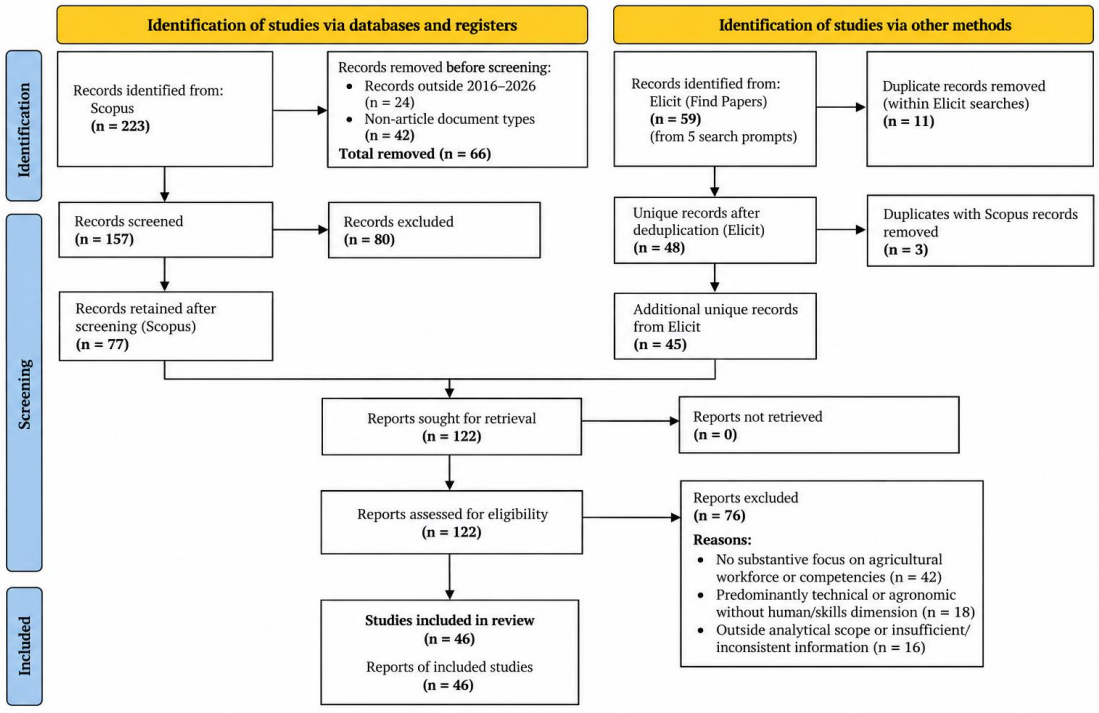


Figure 1. PRISMA-ScR flow diagram of study identification, screening, eligibility assessment, and inclusion.

Data extraction and analysis

A structured data-charting matrix was described for recording study characteristics, workforce groups, agricultural subsectors, demographic and structural changes, technological and sustainability transitions, competency requirements, barriers to learning and adoption, and implications for education, extension, and policy. Table 1 maps the contexts and analytical contributions of the 46 included reports. The underlying row-level charting file was not available for an independent cross-check of the full extraction process.

Evidence was analysed by descriptive mapping and qualitative thematic synthesis informed by Braun and Clarke (2006). The synthesis involved familiarisation with eligible studies, coding of relevant findings, comparison of recurring concepts, and grouping into wider analytical categories. The review questions and charting domains provided an initial structure; the resulting competency categories were developed interpretively across heterogeneous sources. Individual studies could inform more than one domain. The available methodological record does not establish independent dual coding or formal inter-coder reliability testing.

VOSviewer was used for complementary descriptive mapping of terms drawn from study titles and abstracts (van Eck & Waltman, 2010). The reported analysis applied full counting and a minimum occurrence threshold of four. Of 1,623 terms initially identified, 106 met the threshold, 64 were shortlisted for relevance screening, and 53 remained in the visualised network. The map contains nine clusters, 360 links, and total link strength of 2,103. Term co-occurrence is interpreted as a lexical representation of the literature, not as evidence of causal relationships or validation of the competency framework. The network input, thesaurus and exclusion decisions, software version, and layout settings require confirmation from the original analysis files for full reproducibility.

3. Results and Discussion

3.1. Characteristics of the included studies

The review included 46 publications dated between 2016 and September 2026. Of these, 36 (78.3%) were published from 2021 onward, including 28 during 2023–2026. The largest annual counts were reported for 2025 (n = 10), 2024 (n = 9), and 2023 (n = 7). These descriptive counts indicate increasing attention within the selected corpus; they should not be interpreted as a complete bibliometric profile of all Indonesian agricultural-workforce scholarship.

The evidence covered both national-level analyses and localised case studies across diverse agricultural settings. Several studies used large-scale datasets such as SAKERNAS, SUSENAS, and agricultural census data, while others focused on specific provinces, districts, or farming communities. The reviewed studies addressed a wide range of subsectors, including rice, cocoa, dairy, oil palm, rubber, organic agriculture, and rural agribusiness, as well as broader agricultural labour and workforce issues. Farmers and smallholders were the most frequently studied groups, alongside youth and millennial farmers, agricultural workers, women, students and graduates, extension actors, and agribusiness entrepreneurs.

Study designs and source types were heterogeneous: national labour-force analyses, surveys, structural-equation models, qualitative and participatory studies, interviews, mixed-method research, reviews, and conference contributions. Accordingly, evidence was mapped by relevance to workforce questions rather than combined statistically or treated as equivalent causal evidence. Table 1 retains the 46 source entries and identifies their analytical contributions; its descriptions are concise interpretive summaries, not assessments of methodological quality.

Table 1. Characteristics and analytical contribution of the 46 studies included in the scoping review

No.	Study	Context / evidence base	Analytical contribution
1	Akhmad et al. (2025)	East Nusa Tenggara; qualitative study of migrant infrastructure and Javanese entrepreneurship	Shows how migration networks, local opportunities, technology, and community acceptance shape rural livelihood diversification and entrepreneurial adjustment.
2	Asmara et al. (2024)	Indonesia; panel analysis of agricultural labour participation before and during COVID-19	Identifies economic determinants of changes in agricultural labour participation and highlights the sensitivity of agricultural employment to macroeconomic shocks.

No.	Study	Context / evidence base	Analytical contribution
3	Corinna et al. (2025)	Indonesia; scoping review of agricultural digitalisation and social engagement	Synthesises how IoT, AI, GIS, sensors, drones, and digital information are shifting farming toward more data-driven decision-making.
4	Hadiana et al. (2019)	West Java dairy cooperatives; farm survey with regression/ANOVA/ANCOVA	Shows that mechanisation can raise labour efficiency and herd capacity while increasing the need to train available farm labour in improved dairy practices.
5	Handayani et al. (2020)	Agribusiness vocational education; quantitative survey of food- industry perceptions	Identifies green-skill requirements including environmental awareness, innovation, communication, adaptability, and waste-management capability.
6	Harniati et al. (2023)	West Java; smart-greenhouse hydroponic farming case across several locations	Provides evidence on technology-intensive protected agriculture and the technical, managerial, and business capabilities needed to operate smart greenhouse systems.
7	Haryati et al. (2024)	Malang; agricultural students, comparing agribusiness and agroecotechnology backgrounds	Links demographic and educational characteristics to youth farming intention and points to combined agribusiness, technical, digital, and sustainability competencies.
8	Hasan et al. (2023)	Aceh; descriptive qualitative study of agricultural students and alumni	Identifies digital-farming competencies spanning information search, digital communication, content creation, transactions, problem solving, security, and smart-farming literacy.
9	Hendrastiti et al. (2023)	Bengkulu watershed communities; local women and climate/disaster resilience	Adds a gendered resilience perspective to adaptation, livelihood security, and community capacity under climate and disaster pressures.
10	Hendrawan et al. (2024)	Jambi; survey of oil-palm smallholders with latent-class analysis	Shows that smallholder resilience combines practical farming skills, sustainable-practice knowledge, problem solving, adaptation, innovation, and crisis management.
11	Susilowati (2016)	Indonesia; review of ageing farmers and declining young agricultural labour	Establishes ageing and weak generational replacement as a structural workforce challenge requiring regeneration, education, and policy responses.
12	Iskandar et al. (2026)	West Java; agricultural social- enterprise ecosystem analysis using interviews and network analysis	Shows that workforce capability is embedded in wider actor networks involving production knowledge, technology, post-harvest skills, branding, distribution, and institutional coordination.
13	Jayathilake et al. (2023)	Transnational smallholder-rubber study including Indonesia	Relates farmer and worker income and land-use outcomes to socioeconomic conditions, providing evidence on the livelihood context within which workforce decisions are made.
14	Kusnandar et al. (2021)	Ciwidey, West Java; participatory action research with farmer-trader groups	Demonstrates a self-directed extension model in which farmers identify learning needs, test solutions, evaluate outcomes, and adapt practices collaboratively.
15	Hermawati et al. (2025)	Indonesian agricultural MSMEs; quantitative analysis of technology adoption, digital literacy, policy, and financial performance	Links digital literacy and agricultural technology adoption with enterprise performance and emphasises enabling government policy.
16	Nur et al. (2024)	Bonda Raya, Gorontalo; quantitative study of maize farmers	Shows that education and extension participation are associated with adoption of sustainable agricultural practices, underscoring learning support for sustainability transitions.
17	Nabhani et al. (2016)	Southern East Java; survey of cocoa farmers across 13 farmer centres	Connects mobile-broadband adoption with an ageing farmer population and highlights agrotechnopreneurship, ICT, market access, and technology-use capabilities.

No.	Study	Context / evidence base	Analytical contribution
18	Nasrullah (2024)	Indonesia; 2023 Agricultural Census-based econometric analysis across 514 regencies/cities	Links youth-labour scarcity and farmer ageing to higher mechanisation intensity, showing mechanisation as a response to demographic pressure.
19	Ngadi et al. (2023)	Indonesia; national analysis of youth mobility, job choice, and agricultural ageing	Documents declining young-worker participation and a rising older-worker share, while highlighting digital and information skills as part of agricultural regeneration.
20	Nurdiyanto & Rofi (2020)	Central Sulawesi; multilevel analysis of youth agricultural employment	Shows declining youth participation in agriculture and identifies individual, household, and regional factors associated with young people remaining in agricultural work.
21	Nurliza et al. (2025)	West Kalimantan; mixed-method study of 98 rural household agribusinesses	Identifies digital-literacy, marketing, and branding gaps and supports tailored, experiential training with continuing post-training support.
22	Offermans & Glasbergen (2017)	Indonesia; sustainability certification and farmer-welfare analysis in coffee and palm oil	Shows that sustainability schemes interact with farmer welfare and that training and education remain important for translating standards into livelihood benefits.
23	Oktaviani et al. (2023)	Indonesia; qualitative/content analysis of youth participation in sustainable agriculture	Synthesises barriers and strategies for youth engagement, connecting regeneration with innovation, technology, sustainability, and supportive institutions.
24	Pandangwati et al. (2024)	Special Region of Yogyakarta; qualitative farmer interviews on agroecological transition	Shows that sustainable transition depends on farmer planning, experimentation, contextual adaptation, and institutional support rather than technology adoption alone.
25	Patria (2025)	Indonesia; systematic review of digital precision agriculture	Synthesises opportunities and constraints in precision agriculture, especially digital infrastructure, access, capability development, and institutional support.
26	Perdinan et al. (2018)	Indonesia; review and key- informant evidence on climate- smart rice actions	Identifies climate-information use, variety selection, water and nutrient management, and preventive pest management as capabilities for climate-smart rice production.
27	Prastiwi et al. (2025)	Indonesia; national labour-force data on farmers in the digital era	Shows limited farmer internet use and highlights education, infrastructure, and multi-actor support as prerequisites for digital workforce readiness.
28	Pratiwi et al. (2022)	Coffee and cocoa communities; rural knowledge-network analysis of transmigration and ethnicity	Shows that agricultural knowledge access depends on farmers' network positions and supports inclusive, two-way extension and peer learning.
29	Purba et al. (2021)	Batubara Regency, North Sumatra; mechanised irrigated-rice case study	Demonstrates strong labour-saving effects of mechanised transplanting and harvesting and shows how labour scarcity can accelerate machinery adoption.
30	Purba et al. (2025)	Indonesia; gender and rural- transformation analysis	Highlights gendered access to income, education, health, and agricultural participation, with implications for targeted skills development and inclusive rural transformation.
31	Purbohadi et al. (2026)	Yogyakarta; semi-automated IoT monitoring in commercial mushroom farming	Shows how sensor-based monitoring changes farmers' observation and decision routines, requiring digital interpretation alongside practical production knowledge.
32	Rahman et al. (2017)	West Java and Bangladesh; smallholder tree-farming study	Highlights institutional, knowledge, and market constraints affecting sustainable land management and smallholder capacity to adopt tree-based practices.

No.	Study	Context / evidence base	Analytical contribution
33	Rammohan & Tohari (2023)	Indonesia; nationally representative difference-in- differences analysis of the Village Fund Program	Provides evidence on rural poverty and labour-force participation, showing how public investment and local development interventions can reshape rural work opportunities.
34	Santoso et al. (2024)	Five Indonesian provinces; farmer survey analysed with PLS-SEM	Shows moderate readiness for precision agriculture and identifies gaps in IT, GPS/sensor use, map reading, information interpretation, training, and technology access.
35	Sasmita et al. (2025)	Bogor Regency; survey of millennial farmers using PLS-SEM	Shows that digital motivation, knowledge, skills, online participation, and individual adaptiveness jointly support adaptive performance among millennial farmers.
36	Setyanti (2021)	Indonesia; shift-share and probit analysis using SAKERNAS microdata	Frames agricultural workforce change as part of structural transformation, linking sectoral productivity, education, and workers' movement across agriculture, industry, and services.
37	Shrestha & Coxhead (2018)	Indonesia; national review with emphasis on resource- and plantation-producing regions	Shows how resource-led growth affects labour allocation and education incentives, with implications for long-term human-capital formation in rural areas.
38	Sukma et al. (2025)	Indonesia; 2022 SAKERNAS analysis using Heckman selection modelling	Finds that internet use is associated with higher farm earnings while documenting an older, low- education workforce and unequal digital access.
39	Surono (2025)	Indonesia; rapid assessment and occupational competency mapping for organic farming	Maps competency gaps between industry needs and education, combining practical organic-production skills, technology, certification, sustainability, and management capabilities.
40	Susilowati et al. (2021)	Eight provinces; 1,155 rural households across four ecosystem types	Documents declining agricultural employment shares and growing non-farm participation, showing that workforce transition differs across rural ecosystems.
41	Tamsan & Yusriadi (2022)	South and West Sulawesi; quantitative SEM study of extension and farmer productivity	Shows that problem solving, persuasion, and systematic planning mediate the relationship between extension quality and farmer productivity.
42	Warr & Yusuf (2024)	Indonesia; computable general equilibrium modelling of pandemic-related labour shifts	Shows how de-urbanisation and sectoral labour reallocation during COVID-19 affected rural and urban economies, illustrating the responsiveness of agricultural labour to external shocks.
43	Wasono et al. (2024)	Bakalan Village, East Java; explanatory survey and multiple regression	Shows how farmer knowledge, attitudes, and skills influence decisions to participate in IPM field-school practices, highlighting the role of learning in sustainable pest management.
44	Yamauchi (2016)	Indonesia; household- and village- panel analysis across 98 villages	Shows that rising rural wages encourage labour-saving mechanisation and can strengthen scale advantages for larger farms.
45	Yunus et al. (2021)	Multiple Indonesian locations; quantitative study of information media, farmer knowledge, and skills	Shows that information channels and ICT adaptation are associated with farmer knowledge and practical skill development, with variation across locations.
46	Zainuddin Rela et al. (2021)	Morosi, Southeast Sulawesi; cross- sectional survey with PLS analysis	Develops a farming-community resilience model combining economic, social-capital, environmental, community-competence, and information/communication dimensions.

3.2. Conceptual structure of the literature

The reported VOSviewer output comprises 53 terms distributed across nine clusters, with 360 links and a total link strength of 2,103 (Figure 2). Terms such as technology, labour, employment, income, rural transformation, resilience, policy, and community occupy visible positions in the graph. These graphical relationships reflect term co-occurrence within the analysed text records; they should

not be interpreted as demonstrating the magnitude, direction, or causality of workforce change in Indonesian agriculture.

The cluster structure also highlights several recurring research concentrations. One part of the network is centred on labor, employment, land, real wage, mechanization, and the non-agricultural sector, reflecting structural and labour-market change. Another concentration connects technology, digital literacy, precision agriculture, internet, and government policy, indicating increasing attention to digital and technological capability. Terms such as youth, young farmer, millennial farmer, sustainable agriculture, green skill, climate change, resilience, and smallholder farmer further show that generational renewal and sustainability are becoming increasingly connected to discussions of agricultural workforce development.

Overall, the network is consistent with the qualitative observation that workforce transformation is being studied alongside technology adoption, demographic change, sustainability, and institutional support. The nine VOSviewer clusters are a descriptive map of terminology, not predefined constructs or validation of the six-domain competency framework. The substantive thematic claims below are drawn from the underlying study descriptions, with VOSviewer serving only as contextual corroboration.

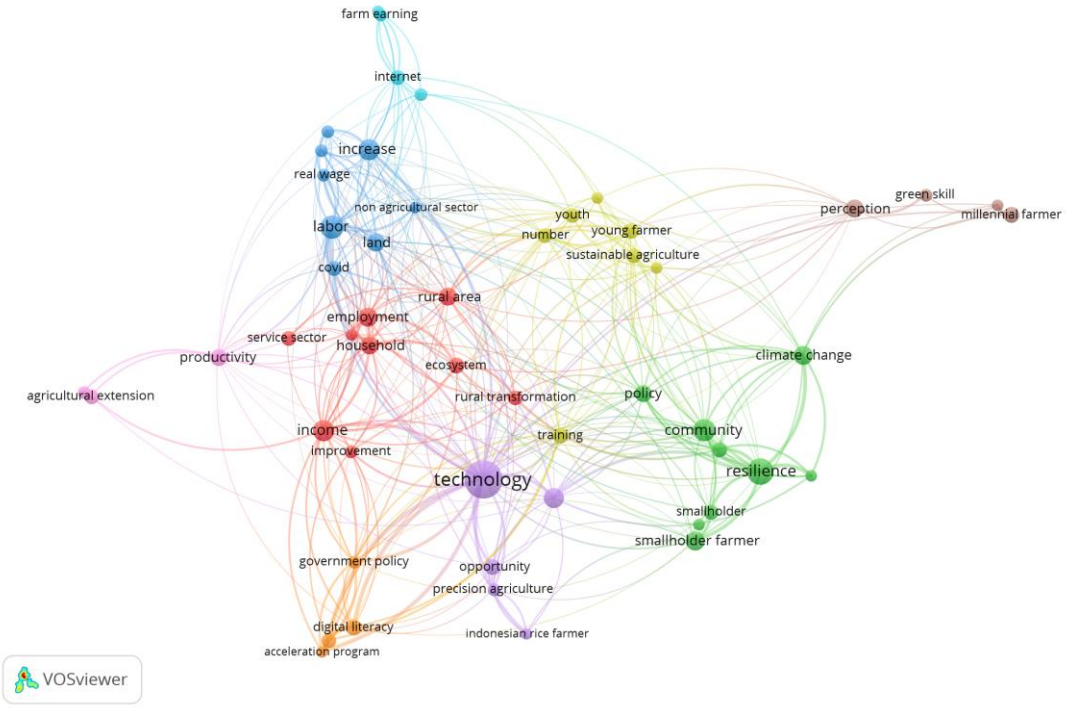


Figure 2. Term co-occurrence network of the literature on agricultural workforce transformation in Indonesia.

Note. Node size represents term occurrence, line thickness indicates link strength, and colours represent VOSviewer clusters.

3.3. Demographic and structural transformation of the agricultural workforce

The reviewed studies show a clear pattern of ageing, declining youth participation, and weakening generational replacement in Indonesian agriculture. Susilowati (2016) reported a relatively small share of farmers below 35 years compared with older age groups, while Ngadi et al. (2023) documented a long-term increase in older agricultural workers. More recent Agricultural Census evidence similarly indicates that younger farmers remain under-represented, with substantial regional variation in workforce age structure (Nasrullah., 2024). Regional studies also point to declining

agricultural participation among youth, particularly where non-farm employment offers more attractive alternatives (Nurdiyanto & Rofi, 2020).

This demographic shift is closely linked to broader structural changes in rural employment. Several studies show that younger and better-educated workers are increasingly moving toward manufacturing, services, and urban employment, while agricultural work becomes more concentrated among older workers (Ngadi et al., 2023; Setyanti, 2021; Susilowati et al., 2021). Migration, limited land access, income instability, and the perceived low attractiveness of farming further contribute to this transition. Education creates a particular tension: it can improve farmers' capacity to engage with technology, but it also broadens employment opportunities outside agriculture.

The evidence therefore suggests that Indonesia's agricultural workforce challenge is not only demographic but structural. Ageing reflects a wider reallocation of labour across sectors and locations, shaped by income prospects, education, mobility, and occupational preferences. Farmer regeneration will therefore depend not only on attracting young people into agriculture, but also on making agricultural work more productive, technologically engaging, and economically competitive.

3.4. Mechanisation and digitalisation are reconfiguring agricultural work

The transformation of agricultural work is occurring through two interrelated technological processes. Mechanisation reduces labour requirements for selected production tasks, while digitalisation increases the role of information, monitoring, and technology-assisted decision-making. In rice farming, mechanised transplanting and harvesting substantially reduced the number of workers required compared with manual operations (T. Purba et al., 2021). Similar labour-saving effects were reported in dairy farming, where machinery enabled larger production capacity without proportional increases in labour (Hadiana et al., 2019). At a broader level, rising agricultural wages and shortages of younger workers were also associated with greater mechanisation, suggesting that machinery increasingly functions as a response to changing rural labour conditions (Nasrullah., 2024).

Digital technologies are changing agricultural work in a different way. Studies of precision agriculture, IoT, internet use, and digital farming indicate increasing reliance on digital information, sensors, online communication, and data-supported management (Hasan et al., 2023; Purbohadi et al., 2026; Santoso et al., 2024). Internet access has also been associated with better economic outcomes among agricultural workers, although adoption remains uneven. Digital transformation is constrained by education, age, connectivity, investment costs, access to training, and regional infrastructure, resulting in substantial differences in technology readiness across farming communities.

Taken together, the reviewed studies suggest that technological change does not simply substitute machinery for workers. It reallocates tasks and increases the importance of equipment operation, data interpretation, information management, and decisions under uncertainty. However, effects differ across commodities, regions, and farm sizes; case-study findings should not be generalised mechanically to the entire national workforce. The next section considers competency domains implied by these heterogeneous settings.

3.5. Emerging competencies: from farming skills to a multidimensional competency portfolio

The evidence suggests that competency requirements in Indonesian agriculture are becoming increasingly diverse and multidimensional. Production knowledge remains essential, but it is increasingly accompanied by digital, managerial, entrepreneurial, social, and adaptive capabilities. This reflects the changing nature of agricultural work, where farmers and agricultural workers are expected to operate within more technology-intensive, information-rich, and market-oriented production systems.

Technical competence still forms the core of agricultural work, including crop and livestock management, machinery operation, cultivation practices, and the application of production

technologies. However, these skills are increasingly intertwined with digital capabilities. Studies on precision and smart agriculture identify competencies related to smartphones, internet use, GPS, sensors, digital platforms, data interpretation, and technology-assisted decision-making (Hasan et al., 2023; Purbohadi et al., 2026; Santoso et al., 2024). Digital competence therefore extends beyond basic device operation and includes searching for information, evaluating its relevance, communicating online, conducting digital transactions, and using data to support farm decisions.

Managerial and entrepreneurial capabilities also feature prominently in the reviewed evidence. Modern agricultural work increasingly requires farmers to manage inputs, costs, markets, and business opportunities while adapting production to changing consumer and market demands. Studies highlight the importance of farm management, product development, e-commerce, marketing, entrepreneurship, and value addition as part of contemporary agricultural capability (Hermawati et al., 2025; Hermawati et al., 2025; Ngadi et al., 2023). These findings suggest that agricultural workers are progressively expected to act not only as producers but also as business managers and market participants.

Social and adaptive competencies form another important dimension. Problem solving, communication, persuasion, planning, cooperation, information seeking, and the ability to respond to uncertainty were repeatedly identified across studies (Tamsan & Yusriadi, 2022; Zainuddin Rela et al., 2021). Such capabilities become increasingly important as farmers face rapid technological change, unstable markets, and environmental risks.

Across the evidence, five recurrent capability groups relate to technology and work organisation: (1) technical and production; (2) digital and technological; (3) managerial and entrepreneurial; (4) social and communication; and (5) adaptive and problem-solving competence. Section 3.6 adds green and environmental capabilities as a sixth connected domain. This six-domain grouping is an analytical synthesis of the reviewed literature—not a validated occupational taxonomy or measured national competency distribution.

3.6. Sustainability adds green and adaptive competency requirements

The available evidence suggests that sustainability is adding a distinct green and adaptive dimension to agricultural competence. These capabilities are not always labelled explicitly as "green skills", but they appear in studies of sustainable farming, climate adaptation, resilience, and vocational preparation. Handayani et al. (2020), for example, identified environmental awareness, innovation, adaptability, communication, and waste-management capability as important for agribusiness graduates, while Perdinan et al. (2018) highlighted climate-informed planning, water management, soil-nutrient management, and preventive pest management.

Sustainability-related competence also involves the ability to adjust practices under changing conditions. Studies on agroecological transition and community resilience emphasise experimentation, contextual learning, problem solving, cooperation, and access to information as important for adaptation (Pandangwati et al., 2024; Zainuddin Rela et al., 2021). Farmer education and extension participation further influence the adoption of environmentally oriented practices (Nur et al., 2024).

The evidence therefore points to a competency set combining environmental knowledge, sustainable production practices, resource management, climate responsiveness, and adaptive problem solving. However, these capabilities remain fragmented across the literature and are rarely consolidated into a clear agricultural green-skills framework. This suggests a need to translate sustainability requirements more explicitly into competency standards, curricula, extension programmes, and workforce-development strategies.

3.7. Competency gaps and workforce-readiness gaps

The evidence synthesised in this review suggests that workforce readiness is not reducible to individual skill deficits. Farmers' opportunities to use precision agriculture and improved production practices are also shaped by training, connectivity, physical infrastructure, access to finance, and institutional support. Santoso et al. (2024) described differences in precision-agriculture readiness linked to both capabilities and access, while Sukma et al. (2025) examined inequalities in internet use and agricultural earnings. Such observational associations do not by themselves establish that training or internet access causes improved outcomes.

Extension and learning systems remain important in closing these gaps. Studies indicate that farmer knowledge and skills are strengthened through extension, trusted information sources, continued technical guidance, and collaboration with government and agricultural institutions (Wasono et al., 2024; Yunus et al., 2021). In digital agribusiness, Nurliza et al. (2025) similarly identified low digital proficiency, weak infrastructure, and insufficient post-training support as major constraints.

These findings suggest that agricultural transformation involves a broader workforce-readiness gap, where individual competence must be matched by an enabling environment. Skills alone are insufficient when farmers lack connectivity, equipment, finance, extension services, or institutional support. Improving readiness therefore requires simultaneous investment in human-capital development and the systems that allow those capabilities to be applied in practice.

3.8. Implications for agricultural education, extension, and workforce development

The reviewed evidence indicates that agricultural education and training need to move beyond conventional production-oriented instruction. Emerging workforce requirements increasingly combine technical knowledge with digital literacy, business management, communication, problem solving, and environmental capabilities. Studies on vocational education, precision agriculture, and digital farming highlight the need for curricula that expose learners to digital tools, data-based decision-making, entrepreneurship, and sustainable production practices rather than treating these capabilities as separate additions to traditional agricultural training (Handayani et al., 2020; Hasan et al., 2023; Santoso et al., 2024).

Extension services also appear to require a broader role. Rather than functioning primarily as channels for transferring technical recommendations, extension increasingly supports learning, information access, technology adoption, and adaptive decision-making. Evidence from farmer-skills and technology-adoption studies shows that continued guidance, trusted information sources, and locally relevant training can strengthen farmers' ability to apply new practices and technologies (Tamsan & Yusriadi, 2022; Wasono et al., 2024); Yunus et al., 2021). This is particularly important where differences in education, age, digital access, and infrastructure influence how farmers engage with new technologies.

Workforce-development strategies therefore need to combine upskilling and reskilling with stronger enabling systems. Training programmes should address technical, digital, managerial, social, adaptive, and green competencies, while being supported by connectivity, extension services, finance, farmer organisations, and institutional coordination. The evidence suggests that preparing Indonesia's agricultural workforce for sustainable and smart agriculture requires a continuous learning system rather than isolated training interventions, with education, extension, industry, and government playing complementary roles.

3.9. An integrated framework of agricultural workforce transformation

The synthesis of the 46 studies suggests that agricultural workforce transformation in Indonesia can be understood as a sequence of interconnected pressures, responses, and capability requirements.

Demographic ageing, declining youth participation, labour scarcity, changing rural employment opportunities, climate pressures, and market change create structural pressures on the agricultural sector. In response, farms and rural enterprises increasingly adopt mechanisation, digital technologies, and sustainability-oriented practices, which alter both the organisation and content of agricultural work. The result is a gradual shift away from work that is predominantly manual and production-focused toward activities that are more technology-intensive, information-dependent, market-oriented, and adaptive.

This changing work environment generates a broader competency profile. The reviewed evidence points to six interrelated domains: technical and production competence; digital and technological competence; managerial and entrepreneurial competence; social and communication competence; adaptive and problem-solving competence; and green or environmental competence. These domains should not be viewed as independent skill sets. For example, effective use of precision agriculture requires both technical production knowledge and digital capability, while sustainable farming may require environmental knowledge, experimentation, communication, and adaptive decision-making. The competency requirements of future agricultural workers therefore reflect the interaction between technological, economic, environmental, and social changes rather than a single process of skill upgrading.

The proposed framework also separates possession of a capability from readiness to apply it. Its enabling environment includes education, extension, infrastructure, finance, farmer organisations, access to markets, and policy support. It offers a synthesis of relationships described in heterogeneous publications, not an estimated causal pathway or empirically validated model. Figure 3 should therefore be interpreted as a conceptual organising framework that generates propositions for subsequent testing across regions, commodities, and occupational roles.

Table 2.
Illustrative competency domains and enabling conditions synthesised from the included evidence

Domain	Illustrative competency requirements	Selected evidence in reviewed corpus
Technical and production	Crop/livestock management; machinery operation; production-system adaptation	Hadiana et al. (2019); Purba et al. (2021)
Digital and technological	Digital information search; GPS/sensors; data interpretation; digital transactions	Hasan et al. (2023); Santoso et al. (2024)
Managerial and entrepreneurial	Input and cost management; marketing; value addition; rural enterprise development	Nabhani et al. (2016); Hermawati et al. (2025)
Social and communication	Collaboration; extension dialogue; persuasion; knowledge sharing	Tamsan & Yusriadi (2022); Yunus et al. (2021)
Adaptive and problem-solving	Planning; experimentation; resilience; coping with market and climate uncertainty	Hendrawan et al. (2024); Zainuddin Rela et al. (2021)
Green and environmental	Climate-informed decisions; soil/water stewardship; waste and pest management	Handayani et al. (2020); Perdinan et al. (2018)

Note. This table is a narrative synthesis of illustrative examples; it does not report counts of independent studies per domain, a measured national skills profile, or a validated competency standard. Across domains, enabling conditions include education, extension, connectivity, finance, producer organisations, market access, and supportive policy.

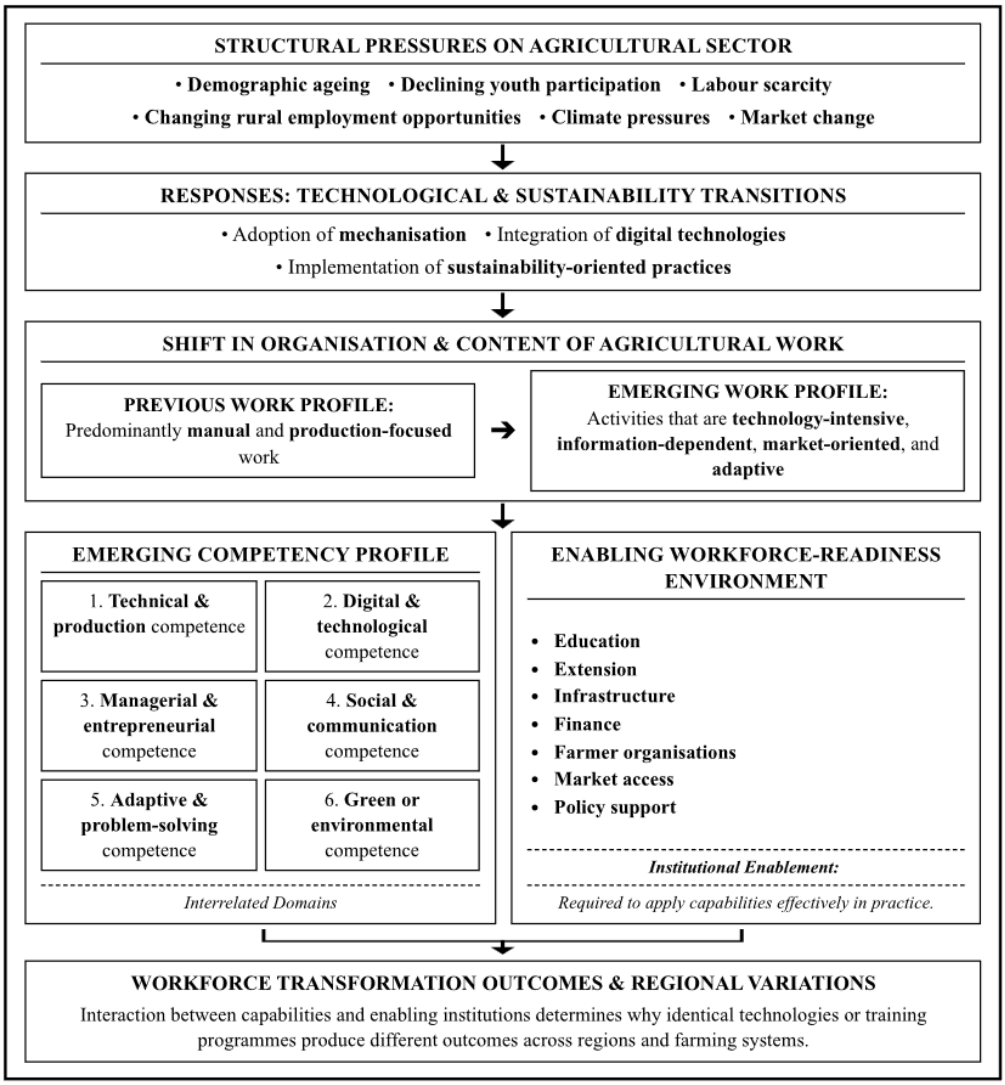


Figure 3. Integrated framework of agricultural workforce transformation and emerging competency requirements in Indonesia.

3.10. Research gaps and future research agenda

The review reveals that evidence on agricultural workforce transformation in Indonesia remains fragmented across labour, technology, education, and sustainability research. Many studies examine individual components, such as ageing, youth participation, mechanisation, digital adoption, or extension, without analysing how these processes interact over time. Longitudinal evidence is particularly limited, making it difficult to determine how workers move into, remain in, or leave agriculture and how their competencies evolve during technological and structural change. Future studies should therefore combine labour-market, household, and occupational perspectives to trace workforce transitions across regions, commodities, and generations.

A second gap concerns the direct measurement of agricultural competencies. Although the reviewed studies identify technical, digital, managerial, social, adaptive, and environmental capabilities, these are rarely assessed through integrated competency frameworks or linked to occupational standards. Digital skills are increasingly visible in studies of smart and precision agriculture, whereas green competencies are more often embedded implicitly within research on sustainability, climate adaptation, and resilience (Handayani et al., 2020; Santoso et al., 2024). Future research should develop and validate competency frameworks that specify what agricultural workers

need to know and perform, and examine how competency requirements differ by subsector, technology level, and occupational role.

Finally, greater attention is needed to variation in workforce readiness. The evidence suggests important differences related to age, education, gender, region, infrastructure, farm characteristics, and access to institutional support, yet these dimensions are not consistently examined together. Future research should assess how education, extension, connectivity, finance, and farmer organisations interact with individual competencies to enable or constrain technology and sustainability transitions. Such work would move the literature beyond documenting workforce problems toward identifying which combinations of skills and enabling conditions are required for different groups of agricultural workers to participate effectively in Indonesia's transition toward sustainable and smart agriculture.

3.11. Methodological limitations and interpretation

Several limitations qualify the findings. First, the 46-source corpus represents a documented selection rather than a comprehensive census of Indonesian research on agricultural employment and competencies. Reliance on Scopus and Elicit may have omitted relevant national databases, local-language publications, and grey literature. Second, heterogeneity of source types and study designs constrains direct comparison, while the complete screening log, data-charting file, and VOSviewer exports were not available for independent audit. Third, the competency domains overlap conceptually, and the framework has not undergone empirical validation, inter-rater reliability testing, or occupational benchmarking. Finally, descriptive associations across studies do not establish whether particular training interventions or workforce characteristics cause technological adoption or sustainability outcomes. The findings should therefore guide context-sensitive hypotheses and further empirical investigation rather than serve as universal policy prescriptions.

4. Conclusion

This scoping review brings together 46 sources on demographic change, labour reallocation, mechanisation, digitalisation, and sustainability transitions affecting Indonesia's agricultural workforce. The literature suggests six interconnected competency domains: technical and production; digital and technological; managerial and entrepreneurial; social and communication; adaptive and problem-solving; and green and environmental capabilities. The synthesis also distinguishes individual competencies from the enabling environment needed to deploy them, including education, extension, connectivity, finance, producer organisations, market access, and policy support. These findings reflect interpretive mapping of heterogeneous evidence; they do not quantify the national prevalence of skill gaps or establish causal impacts of specific interventions. Future research should test and validate the proposed framework using occupation-specific and longitudinal evidence, evaluate variation across regions and demographic groups, and examine how capacity-building interacts with institutional support. More complete access to the original Scopus–Elicit screening files and VOSviewer inputs would strengthen the transparency and reproducibility of the evidence base.

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Publication Declarations

Author Contributions	:	Dyah Ayu Suryaningrum: Conceptualization, Methodology, Investigation, Data Curation, Formal Analysis, Visualization, Writing – Original Draft, and Writing – Review & Editing. The author reviewed and approved the final manuscript.
Funding	:	This research received no external funding.
Competing Interests	:	The authors declare no competing interests.
Ethics and Consent	:	This study employed a scoping review of previously published literature. No human participants were recruited, and no new identifiable personal data were collected. Informed consent from research participants was therefore not applicable to this review.
Data Availability	:	The evidence base consists of 46 publications included in the scoping review. The manuscript reports the search strategy, study-selection counts, thematic synthesis, and descriptive term-mapping results. The underlying study-screening log, data-charting file, and VOSviewer input and export files were not available for independent methodological audit at the time of manuscript preparation.
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