



# Digital technologies and social inequalities in agriculture and rural contexts: a gap-oriented systematic mapping review

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## ABSTRACT

The digital transformation of agriculture has generated a rapidly expanding body of research, alongside growing concerns about its social and spatial implications for rural areas. While digital technologies such as precision farming, artificial intelligence, the Internet of Things, and big data are widely promoted as drivers of efficiency and sustainability, their implications for social inequality and inclusion remain unevenly examined.

This paper investigates research gaps in the literature on digital technologies in agriculture and rural contexts, with specific attention to how social, institutional, and distributive dimensions are addressed. Using a multi-level review design that combines bibliometric analysis, a meta-review of existing reviews, and a gap-oriented systematic mapping of original empirical studies, the paper synthesises international research published over the last decade.

The findings reveal a highly fragmented field in which technical and performance-oriented studies predominate, while social and governance-related aspects remain inconsistently integrated. Although recent research increasingly addresses issues such as gender, smallholder inclusion, and contextual diversity, significant conceptual, methodological, and governance-related gaps persist. Drawing on insights from digital inequality theory, technological justice, and the capabilities approach, the discussion interprets these gaps and identifies priority directions for future research and policy aimed at supporting more inclusive and equitable digital transitions in agriculture and rural areas. By identifying persistent research gaps and uneven empirical attention to rural inequalities, the study contributes to ongoing debates on inclusive digital transitions in agriculture and rural development.

## 1. Introduction

The ongoing digital transformation is reshaping agriculture and rural development on a global scale. Enabling technologies such as artificial intelligence (AI), the Internet of Things (IoT), big data, automation, and blockchain are increasingly promoted as key drivers of sustainability, efficiency, and resilience in agri-food systems (The World Bank, 2019). International organisations highlight their potential to enhance productivity, resource efficiency, transparency, and innovation, while opening new economic opportunities in rural areas (OECD, 2019; European Commission, 2025). The FAO (2022) emphasises that automation and digital tools can reduce drudgery, improve working conditions, and support new forms of entrepreneurship – particularly for women and youth – when embedded within inclusive governance and capacity-building frameworks.

Within the European Union, digitalisation is explicitly framed as a pillar of rural development. The Long-Term Vision for the EU's Rural Areas (European Commission, 2024) identifies digital connectivity and digital skills as essential conditions for achieving “stronger, connected, resilient and prosperous rural areas” by 2040. Complementary initiatives, such as the Smart Villages Strategy (European Commission, 2020), promote bottom-up digital pathways that align local needs with national and EU digital agendas. More broadly, the European Green Deal and the Sustainable Development Goals situate digitalisation within global transitions towards sustainability and inclusiveness (FAO, 2022; Campobasso et al., 2025). Digital technologies are also increasingly used across the agricultural policy cycle – from data generation and monitoring to evaluation and impact assessment – supporting more adaptive and evidence-based policymaking (OECD, 2019; OECD-FAO, 2023).

Despite these expectations, the social implications of digitalisation

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remain deeply contested, with a substantial body of research pointing to the risk of widening inequalities. Early debates on the digital divide focused primarily on access to information and communication technologies (Cullen, 2001; Warschauer, 2003; Marshall et al., 2020), but subsequent work expanded this perspective to include inequalities in skills, motivation, and outcomes. In low-resource contexts, digital divides are exacerbated by infrastructural and affordability constraints (ITU, 2022), while in more technologically advanced settings inequalities persist through differentiated uses and uneven digital capabilities (Vassilakopoulou and Hustad, 2023). Empirical studies further show that digitalisation can generate Matthew effects, whereby actors with greater initial resources are better positioned to benefit from technological change, reinforcing existing disparities (Perc, 2014; Tewathia et al., 2020; Gómez-Bengochea and Jung, 2024).

In agriculture, these dynamics often translate into asymmetric benefits across farm types and social groups. Large farms and technology providers tend to capture disproportionate advantages from digital transformation, widening gaps with smallholders and marginalized communities (UNCTAD, 2021). Gender disparities in digital literacy continue to disadvantage women farmers, while automation may displace low-skilled labour and concentrate value among capital-intensive actors. Emerging concerns related to data governance, privacy, and market concentration further highlight the risk of reinforcing power asymmetries along agri-food value chains (UNDP, 2025). This duality – between opportunities for inclusion and risks of exclusion – makes digitalisation in agriculture a critical domain for analysing social and spatial inequality. In this paper, spatial inequality refers to uneven territorial access to digital infrastructures, knowledge resources, and institutional support systems that shape how farmers and rural communities are able to access and benefit from digital technologies. As digital technologies become increasingly embedded in agricultural production and governance, the central question is no longer whether they will shape the future of agriculture, but how, for whom, and under what institutional conditions they will do so (Lioutas et al., 2021; Li et al., 2023; Luque-Reyes et al., 2025).

To situate these issues within broader analytical debates, the review engages with key concepts widely discussed in the literature on digitalisation and rural development, particularly digital inequality, technological justice, and capabilities. These concepts have been developed within different theoretical traditions, including Digital Inequality Theory (DiMaggio et al., 2001; van Dijk, 2020), Technology Justice perspectives (Smith and Stirling, 2018), and the Capabilities Approach (Sen, 1999; Nussbaum, 2003).

Digital inequality research extends the notion of the digital divide beyond access, highlighting inequalities in use, skills, and outcomes that shape how individuals and organisations benefit from digital technologies. In agricultural contexts, this perspective underscores how disparities in education, resources, and institutional support influence farmers' ability to translate digital access into meaningful socio-economic benefits (Rijswijk et al., 2021; Marshall et al., 2022; Eastwood et al., 2022; Wang et al., 2025).

Technology justice perspectives emphasise the distributive and governance dimensions of technological change, drawing attention to issues of participation, fairness, and accountability in the design and deployment of innovation. In digital agriculture, these debates highlight how technological trajectories may reinforce or challenge existing power relations within agri-food systems (Xie et al., 2024; Zhao et al., 2024; Sargani et al., 2025).

Finally, the Capabilities Approach provides a normative lens for assessing technological change in terms of people's real opportunities to access, understand, and use innovations in ways that expand their well-being and agency. From this perspective, digitalisation can enhance rural development only when farmers possess the capabilities and institutional support required to convert technological resources into meaningful opportunities (Kerras et al., 2020; Soma and Nuckchady, 2021; Steinke et al., 2024).

Rather than serving as formal analytical frameworks guiding the coding of studies, these perspectives provide a broader interpretive context for understanding how digital technologies reshape opportunities, power relations, and distributive outcomes in agriculture and rural areas (Kosior, 2020; Lv et al., 2025).

They serve as interpretive lenses to contextualise and synthesise the research gaps identified through the review. Together, they reinforce the view of digitalisation as a socio-technical process shaped by infrastructures, institutions, cultural norms, and networks of actors, rather than as a neutral technological transition (Klerkx, 2020). This understanding aligns with calls for responsible and inclusive innovation, which emphasise anticipation, reflexivity, and responsiveness in the governance of technological change (Stilgoe et al., 2013).

Against this backdrop, a growing number of studies examine digitalisation in agriculture, yet the resulting evidence remains highly fragmented. While adoption drivers and technical performance are extensively analysed, far fewer contributions systematically address the social, ethical, and political dimensions of digitalisation. In particular, the literature lacks an integrated synthesis of how issues of social and spatial inequality are conceptualised, empirically investigated, and governed across different strands of research. This fragmentation limits cumulative knowledge building and obscures where critical gaps persist (Omulo and Kumeh, 2020; Qiu et al., 2025; Suh, 2025).

To address this limitation, the present study adopts a gap-oriented systematic mapping review. This approach focuses explicitly on identifying areas where existing literature remains fragmented, underexplored, or conceptually underdeveloped, rather than only synthesising established findings. By combining a bibliometric analysis, a meta-review of existing reviews, and a systematic mapping of original empirical studies, the paper aims to structure existing knowledge and identify areas of high, partial, and low coverage with respect to inequality-related dimensions of digital agriculture. The overarching aim of the study is therefore to identify, systematise, and interpret research gaps in the literature on digital technologies and social inequality in agriculture and rural contexts.

From this perspective, digitalisation in agriculture can be understood not only as a process of technological diffusion but also as a socio-technical transformation shaped by institutions, power relations, and the distribution of capabilities in rural contexts. To operationalise this objective, the review combines different analytical steps that examine both the structure of the literature and the persistence of research gaps across empirical and review studies. The analysis is guided by the following research questions.

- RQ1. How has the academic literature on digital technologies in agriculture and rural contexts addressed issues of social and spatial inequality, and how are these themes distributed across technical, social, and institutional research strands?
- RQ2. Which research gaps related to social and spatial inequalities have been identified by existing reviews on digitalisation in agriculture and rural contexts, and how are these gaps conceptualised?
- RQ3. To what extent do original empirical studies address the gaps identified in the literature, and which dimensions of social and spatial inequality remain partially explored or largely neglected in rural contexts?

The remainder of the paper is structured as follows. Section 2 presents the methodological design and review steps. Section 3 reports the results of the bibliometric mapping, meta-review, and systematic mapping. Section 4 discusses the implications of the identified gaps using the three conceptual perspectives. Section 5 concludes by summarising the main findings and outlining directions for future research.

This study contributes to the literature on digital agriculture and rural development in three ways. First, it integrates bibliometric analysis, meta-review, and gap-oriented systematic mapping to provide a structured overview of research gaps in digital agriculture. Second, it

highlights persistent social and spatial inequalities in the diffusion and outcomes of digital technologies across rural contexts. Third, it interprets these patterns through a socio-political perspective that emphasises the redistributive nature of digitalisation processes in agriculture.

## 2. Methodology

### 2.1. Review design, data collection and analytical stages

This study adopts a gap-oriented systematic mapping review design, structured in three sequential and complementary stages (summarised in Table 1). The integration of these stages is intended to produce a comprehensive synthesis of the academic literature and a structured identification of research gaps related to social and spatial inequality in digital agriculture.

The three steps are not merged into a single analytical layer. Instead, they are connected through a triangulation logic. Step 1 provides a descriptive baseline of how the field is distributed across topics, methods, and contexts. Step 2 identifies and structures the research gaps emerging from the review literature. Step 3 then assesses how far recent empirical studies contribute to addressing those gaps. This triangulation supports a cumulative and transparent understanding of where inequality-related dimensions are well covered, partially explored, or largely neglected in the academic literature.

### 2.2. PRISMA 2020 Protocol, search strategy and screening

This section details the review protocol, search strategy, and screening procedures adopted to ensure transparency, reproducibility, and consistency with PRISMA 2020 guidelines. The review protocol follows the PRISMA 2020 guidelines to ensure transparency and reproducibility (Page et al., 2021). The literature search was conducted on 1 July 2025 and includes publications up to (and including) 1 July 2025.

#### 2.2.1. Databases and search string

Two multidisciplinary databases were used: Scopus and Web of Science. The search strategy combined controlled vocabulary and free-text terms. The core query was:

“(agriculture OR agricultural) AND (digital\* OR robot\* OR automated OR “climate-smart” OR “artificial intelligence”) AND (technolog\* OR precision OR enabling OR innovat\*) AND (social OR territorial OR spatial OR rural OR “inner area\*” OR “inner region\*” OR size\* OR dimension\*) AND (farm\* OR small\* OR capital OR labor OR power) AND (inequalit\* OR disparit\* OR gap OR exclusion OR risk\*) AND

**Table 1**  
Three-step review design <sup>(a)</sup>.

Step	Purpose	Tools/sources	Output
Step 1 – Descriptive bibliographic mapping	Describe the scope and distribution of the literature (topics, keywords, trends, geographic focus)	Scopus; Web of Science; VOSviewer; MAXQDA	Thematic domains and temporal/geographic patterns
Step 2 – Meta-review (review of reviews)	Synthesise gaps identified and discussed in existing reviews	MAXQDA	Typology of research gaps + coverage levels
Step 3 – Gap-oriented systematic mapping (primary studies)	Map how empirical studies address the identified gaps	MAXQDA	Evidence map linking gaps to empirical coverage and remaining blind spots

<sup>a</sup> Source: author elaboration.

(polic\* OR recomendation\* OR impact\* OR conflict\* OR “social conflict\*” OR vulnerab\*)”.

The search was restricted to peer-reviewed journal articles, published in English, between 2015 and 2025. In addition, eight articles were added through snowballing (backward/forward reference checking) to enhance coverage of highly relevant contributions.

While the search string was intentionally designed to capture literature explicitly engaging with inequality-related dimensions of digitalisation in agriculture, we acknowledge that keyword-based strategies may introduce a degree of terminological bias. Influential social science contributions that address digital agriculture through concepts such as advisory systems, skills, knowledge, learning, or innovation networks may not explicitly use terms related to inequality or the digital divide and may therefore fall outside the scope of the initial query. This limitation is inherent to systematic, keyword-driven reviews and is addressed in part through targeted snowballing and through explicit discussion of methodological limitations.

#### 2.2.2. Deduplication, pre-screening and screening procedure

The selection process was structured in three steps.

1. Deduplication and pre-screening removal. Records retrieved from the two databases were merged and duplicates removed. A preliminary exclusion step removed clearly ineligible records based on document type and obvious topic mismatch (e.g., non-agricultural digitalisation; purely technical domains with no socio-economic, governance, or inequality-related content).
2. Title/abstract screening. Remaining records were screened on titles and abstracts using predefined inclusion and exclusion criteria.
3. Full-text eligibility assessment. Potentially eligible papers were read in full and included only if they met all criteria.

Studies were included if they.

- (i) addressed digitalisation and enabling technologies in agriculture, agri-food systems, or rural development contexts; and
- (ii) engaged explicitly with socio-economic, institutional/governance, territorial, spatial, equity, inclusion, vulnerability, or distributive dimensions.

Studies were excluded if they.

- (i) focused exclusively on technical performance without any social/inequality dimension;
- (ii) addressed ICT/digitalisation outside agriculture/agri-food; or
- (iii) lacked sufficient relevance to the review questions.

After deduplication and screening, the final corpus consisted of 24 review papers (Step 2) and 60 empirical studies (Step 3). The PRISMA flow diagram (Fig. 1) summarises identification, screening, and inclusion stages.

Given the multi-stage nature of the review, standardisation was ensured through: (i) an agreed review protocol and shared inclusion/exclusion criteria defined at the outset; (ii) a common coding framework (codebook) applied across steps; and (iii) periodic cross-checks and team discussions to resolve ambiguous cases and ensure consistent interpretation of categories throughout screening, coding, and gap classification (Kuckartz and Rädiker, 2019).

### 2.3. Step 1: Descriptive bibliographic mapping

Step 1 provides a descriptive mapping of the scope and distribution of the literature (rather than an analysis of “framing”). The mapping covers the entire corpus (reviews + empirical studies) and aims to identify major topics, temporal patterns, keyword clusters, and geographic focus.

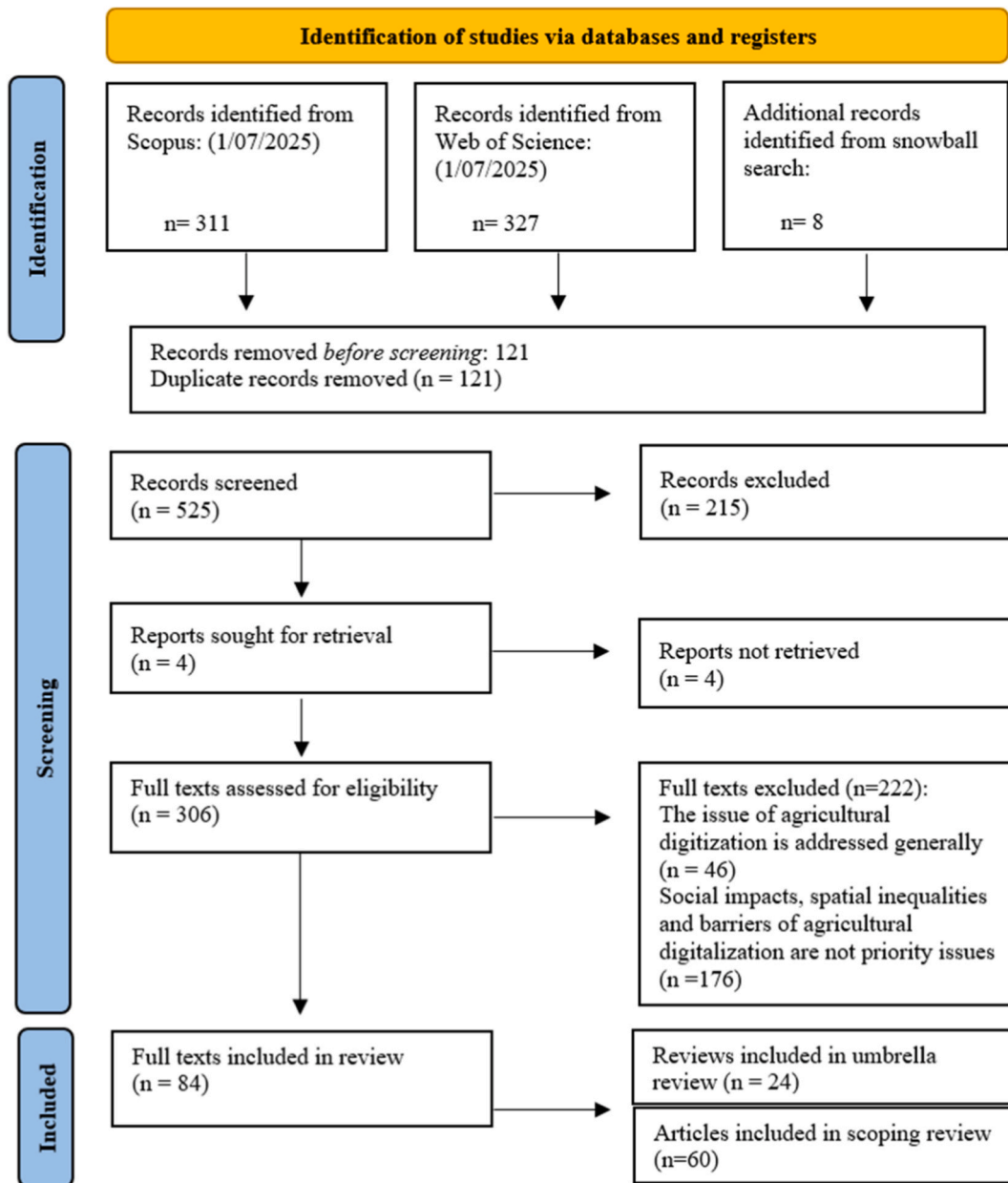


Fig. 1. PRISMA 2020 flow diagram. Source: author elaboration.

Keyword co-occurrence analysis and visualisation were conducted in VOSviewer, while MAXQDA supported systematic organisation and coding of documents to identify dominant themes and research foci (Kuckartz and Rädiker, 2019). Fig. 2 illustrates the temporal concentration of publications in recent years, without implying changes in thematic orientation or research quality.

Table 2 summarises the main topics identified during this stage.

While early studies (2015–2020) were predominantly conducted in Global North contexts, more recent contributions increasingly focus on the Global South and emerging economies, reflecting a diversification of empirical settings in the literature.

Fig. 3 reports the distribution of main topics across publication years, highlighting the coexistence of technical, social, and governance-related strands.

Citation counts vary widely, reflecting both the presence of a small number of highly cited contributions and a large share of recent publications with limited citation accrual.

Fig. 4 shows the uneven geographical distribution of empirical

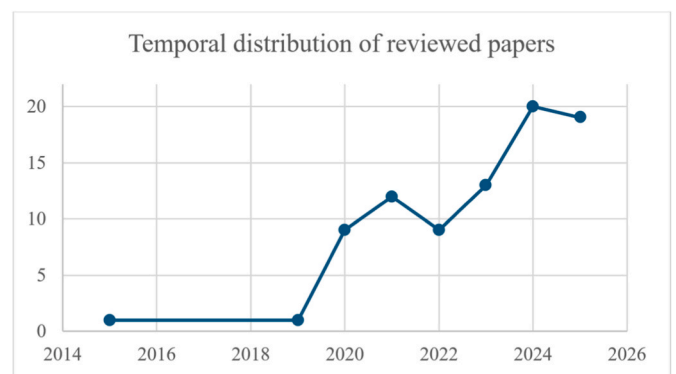


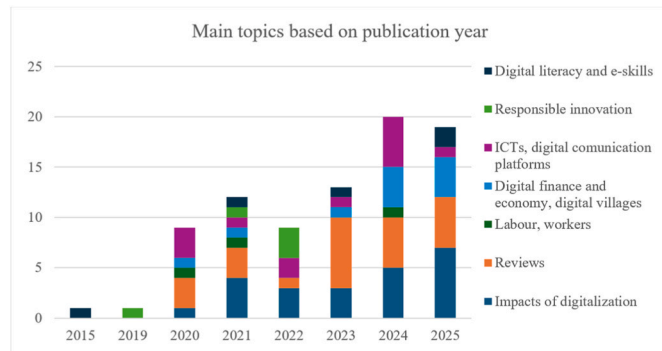
Fig. 2. Temporal distribution of reviewed papers (2015–2025).

studies across world regions.

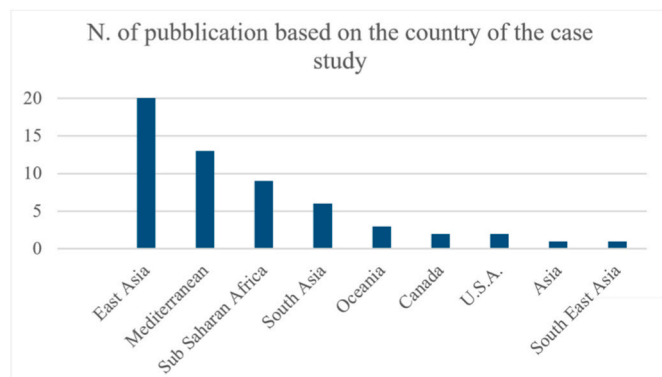
**Table 2**  
Main topics in the analysed corpus (\*).

Main topics	N of documents
<b>Primary studies:</b>	
General impacts of digitalisation	23
ICTs, digital communication platforms	13
Digital finance and economy, digital villages	11
Digital literacy and e-skills	5
Responsible innovation	5
Labour, workers	3
<b>Total</b>	<b>60</b>
<b>Reviews:</b>	
<b>Total</b>	<b>24</b>

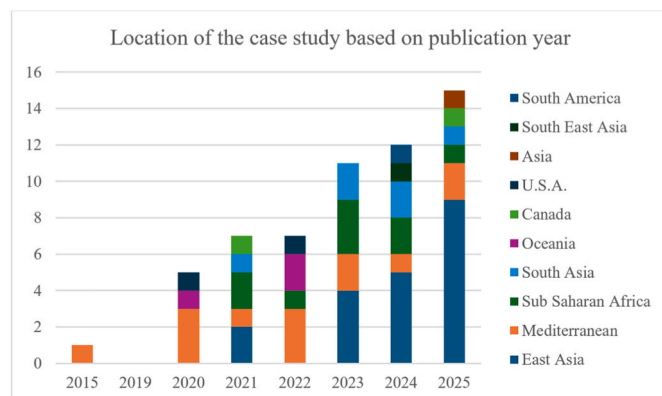
<sup>a</sup> Source: author elaboration.



**Fig. 3.** Distribution of main research topics by publication year.



**Fig. 4.** Geographic distribution of case-study-based publications.



**Fig. 5.** Temporal evolution of case-study locations by publication year.

Fig. 5 documents how empirical attention has diversified geographically over time.

**2.4. Step 2: Meta-review of existing reviews and gap classification**

Step 2 consists of a meta-review (review of reviews) aimed at synthesising how existing systematic and narrative reviews conceptualise research gaps in digital agriculture. This approach is increasingly used to assess the maturity and limitations of complex interdisciplinary fields (Aromataris et al., 2015; Faulkner et al., 2022). The meta-review covers the 24 reviews included in the final corpus.

Nodes represent keywords and links indicate co-occurrence relationships; clusters reflect thematic proximity rather than causal relations (Fig. 6).

All reviews were imported into MAXQDA and coded to extract statements related to methodological and thematic gaps. Based on this coding, we systematised gaps into.

- (i) Methodology-related gaps (e.g., generic vs specific methodologies; methodological innovation), and
- (ii) Thematic research gaps (e.g., governance and social sustainability; vulnerable groups; labour; education; financial technologies).

To increase transparency (as requested by reviewers), each gap was assigned a coverage level based on three criteria (Table 3).

1. Frequency: how many studies/reviews explicitly address the gap;
2. Diversity: whether the gap is examined across multiple contexts, populations, or settings;
3. Depth: whether the literature provides substantial empirical/theoretical engagement rather than passing mentions.

The heatmap visualises the distribution of low, medium, and high coverage gaps as identified in existing reviews (Fig. 7).

Coverage levels were defined as follows.

- High coverage (largely addressed): multiple studies consistently engage with the gap across contexts and/or methods, though integration may still be needed.
- Medium coverage (partially covered): the gap is addressed by a limited number of studies and/or in narrow contexts or methods.
- Low coverage (largely unexplored): only sporadic or isolated evidence exists; the gap remains a priority for future research.

The meta-review serves as the first analytical step to identify how previous review articles have conceptualised research gaps on digital technologies and social inequality in agriculture. By synthesising these review-level findings, the meta-review provides a structured baseline against which the subsequent gap-oriented mapping of primary studies can be compared. Fig. 7 illustrates how the gaps identified in prior reviews were operationalised and traced across the empirical literature analysed in the third step of the review process.

**2.5. Step 3: Gap-oriented systematic mapping of primary studies**

Building on Steps 1 and 2, Step 3 conducts a gap-oriented systematic mapping of the 60 empirical studies. Systematic mapping aims to describe and visualise the landscape of available research rather than evaluate causal effects or intervention effectiveness (Campbell et al., 2023; Khalil et al., 2025). The “gap-oriented” element extends this approach by using the gap framework developed in Step 2 as an explicit analytical grid to assess empirical coverage.

**2.5.1. Coding procedure and gap attribution**

Each empirical study was coded in MAXQDA using a structured coding scheme capturing.

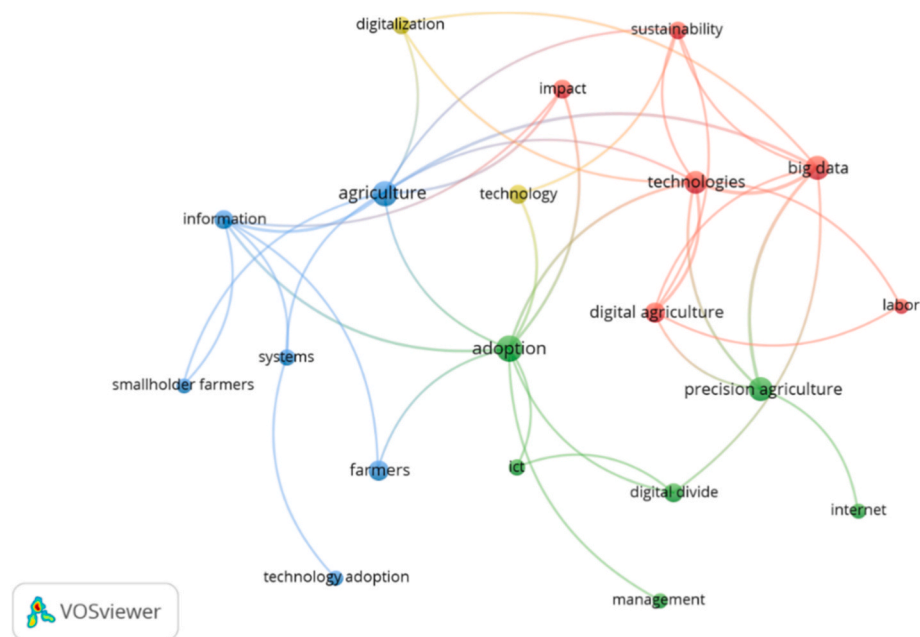


Fig. 6. Keyword co-occurrence network of the analysed literature (VOSviewer).

- (i) main topic(s);
- (ii) primary methodology (e.g., qualitative case study, survey/econometrics, mixed methods, modelling); and
- (iii) main inequality-relevant findings (e.g., access/skills/outcomes; gender; labour; governance/data; territorial inequalities).

On this basis, each study was linked to one or more research gaps identified in Step 2. The resulting cross-table provides an evidence map indicating where empirical research contributes to closing gaps and where gaps remain open (Table 4).

## 2.6. Methodological limitations

As with any systematic review, this study has limitations. First, it relies on published peer-reviewed literature indexed in Scopus and Web of Science and may therefore under-represent grey literature and practitioner reports. Second, keyword-based searches may fail to capture some influential social science contributions that address digital agriculture through concepts such as advisory systems, skills, knowledge, or capacities without explicitly using inequality-related terminology. Third, systematic mapping provides a structured overview of the research landscape but does not assess causal impacts of digitalisation in practice. Therefore, the identified gaps reflect patterns in the academic literature rather than the real-world distribution of digital inequalities.

A further limitation relates to the methodological approach used to identify research gaps. Gap-oriented systematic mapping provides a structured overview of underexplored areas in the literature, but alternative approaches – such as expert-based horizon scanning, Delphi methods, or participatory research agenda-setting – could generate different priorities. Future research could therefore combine systematic mapping with participatory or foresight-based approaches to strengthen the identification of emerging research needs.

## 3. Results

### 3.1. From fragmented evidence to structured research patterns

In line with the first and second research questions, this section synthesises the main patterns emerging from the meta-review and the gap-oriented systematic mapping, highlighting how previously

identified research gaps are currently addressed by empirical studies. Rather than reiterating individual findings, the analysis focuses on aggregate patterns that characterise the state of research on digital agriculture and social inequality.

Fig. 8 compares gap coverage after integrating evidence from primary studies, without altering the original gap definitions. In particular, Fig. 8 builds directly on the gap classification presented in Fig. 7 by incorporating evidence from primary studies.

Overall, the literature reveals a field that is rapidly expanding yet structurally fragmented. This fragmentation is particularly evident when considering the rural contexts in which digital technologies are embedded, where institutional conditions, territorial infrastructures, and socio-economic characteristics strongly shape patterns of technological adoption and inequality. While scholarly interest in digitalisation and enabling technologies has increased markedly over the last five years, methodological approaches and thematic emphases remain uneven. Technical and adoption-oriented studies continue to dominate, whereas social, institutional, and distributive dimensions are addressed more selectively and often in isolation.

Three main patterns emerge from the synthesis.

First, methodological fragmentation persists. Although recent studies increasingly employ mixed methods, participatory tools, and socio-institutional perspectives, cross-country comparability and cumulative knowledge building remain limited. The absence of shared protocols – particularly for assessing adoption dynamics, data governance, and AI applications – continues to constrain synthesis beyond case-specific insights.

Second, the literature exhibits a persistent thematic imbalance. Governance, labour, and education have gained visibility, but they remain secondary to productivity, sustainability, and efficiency-oriented analyses. Even where social issues are explicitly addressed, they are often treated as contextual variables rather than as central analytical dimensions shaping digital transitions.

Third, geographical asymmetries remain pronounced. These asymmetries reflect broader forms of spatial inequality in rural areas, where differences in infrastructure, connectivity, institutional support, and market access shape uneven opportunities to benefit from digital technologies. Most empirical evidence originates from East Asia and Europe, while research in the Global South, despite increasing, remains highly context-dependent and unevenly distributed across regions. This

**Table 3**  
Research gaps identified through the meta-review <sup>(a)</sup>.

METHODOLOGY	Research Gap	No. of reviews	Coverage level	Citation	
<b>Generic methodologies</b>	Interdisciplinary and transdisciplinary works	4	Low	Bazargani and Deemyad (2024); Klerkx et al. (2019); Miller et al. (2025); Usigbe et al. (2024)	
	Broadening the literature search	2	Low	Yuan and Sun (2024); Martin et al. (2022)	
	Scarcity of social science literature on digital agriculture	1	Medium	Klerkx et al. (2019)	
	Cross-regional and long-term studies to determine the effects of widespread distribution of technology	2	Low	Finger (2023); Majid et al. (2025)	
	<b>Specific methodologies</b>	Standardized methodologies across primary studies to assess adoption determinants	1	Low	Kroupová et al. (2025)
		Meta-analysis of ICTs and precision agriculture	1	High	Kroupová et al. (2025)
		Field-based validation for AI technologies in complex agricultural environments	1	Low	Miller et al. (2025)
	<b>Methodological innovation</b>	Managing big amount of data in research	1	Low	Finger (2023)
		Need for new scientific disciplines	1	Low	Klerkx et al. (2019)
		Participatory approaches to enact principles of responsible governance	1	Medium	Prutzer et al. (2023)
Approaches to evaluate autonomy and resilience regarding robots and AI		2	Low	Mallinger and Baeza-Yates (2024); Martin et al. (2022)	
Frameworks, design requirements and fairness principles to guide responsible model development		1	High	Mallinger and Baeza-Yates (2024)	
New conceptualisation of digital agriculture (socio-cyber-physical system)		1	Low	Klerkx et al. (2019)	
Methods for evaluating the environmental performance of smart farming		2	Low	Lioutas and Charatsari (2020); Selvi et al. (2025)	
<b>THEMATIC RESEARCH</b>		<b>Governance and social sustainability</b>	Big data social sustainability and ownership regulation	3	Medium
	Practical governance solutions		1	Low	Lemay and Boggs (2024)
	Cybersecurity, ethics and transparency of AI		2	Medium	Ryan (2023); Miller et al. (2025)
	Effects of technological advancement on human-nature relations		1	Medium	Bazargani and Deemyad (2024)
	<b>Technical research</b>	Attention to public physical infrastructures	1	Low	Lemay and Boggs (2024)
		Effects of IoT on agricultural extension services	1	High	Jarial (2023)
		Compatibility and vulnerability of IoT devices	1	Low	Jarial (2023)
		Effects of cumulative applications of AI technologies	1	Medium	Usigbe et al. (2024)
	<b>Vulnerable groups</b>	Links among digitalisation and diverse agricultural models and food sovereignty movements	2	Low	Hackfort (2021); Klerkx et al. (2019)
		Energy-efficient and biodegradable sensing systems	1	Low	Miller et al. (2025)
Effects of CSA on marginalized groups		1	Low	Usigbe et al. (2024)	
Effects of digital transformation in smallholder agriculture		1	High	Yuan and Sun (2024)	
Affordable open platforms enabling smallholder farmers participation		1	Low	Miller et al. (2025)	
Potential gains from using big data for smallholder farmers		1	Low	Lioutas and Charatsari (2020)	
Gender-based benefits of adopting agricultural technologies		1	Medium	Gumucio et al. (2020)	
Gender-based structural constraints in accessing climate information and IoT		2	Low	Gumucio et al. (2020); Jarial (2023)	
<b>Context-based research</b>	Changes in gender roles due to climate information access	1	Medium	Gumucio et al. (2020)	
	Effects of digital agriculture on power relations	1	High	Hackfort (2021)	
	Context- specific research	5	Medium	Gumucio et al., (2020); Jellason et al. (2021); Kroupová et al. (2025); Nguyen et al. (2025); Usigbe et al. (2024)	
	Research in developing and emerging countries	4	Medium	Klerkx et al. (2019); Otitoju et al. (2023); Izuogu et al. (2023); Prutzer et al. (2023)	
	Research in Sub Saharan Africa	3	High	Jellason et al. (2021); Kudama et al. (2021); Izuogu et al. (2023)	
	Evaluating opportunities and solutions to develop CSA in Asia	1	Medium	Nguyen et al. (2025)	
	<b>Labour and employment</b>	Broader labour transformation arising from automation	2	High	Bazargani and Deemyad (2024); Martin et al. (2022)
Effects of robotisation by employment and social status, and farm/off-farm professional environment		1	Low	Martin et al. (2022)	
Effects of full-time/part-time status on technology adoption		1	Low	Lemay and Boggs (2024)	
Effects of AI on employment		1	Low	Ryan (2023)	
<b>Education</b>	Educational interventions tailored to livestock farmers needs	1	High	Majid et al. (2025)	
	<b>Financial technologies</b>	Effects of financial technologies in agriculture	1	High	Mapanje et al. (2023)

<sup>a</sup> Source: author elaboration.

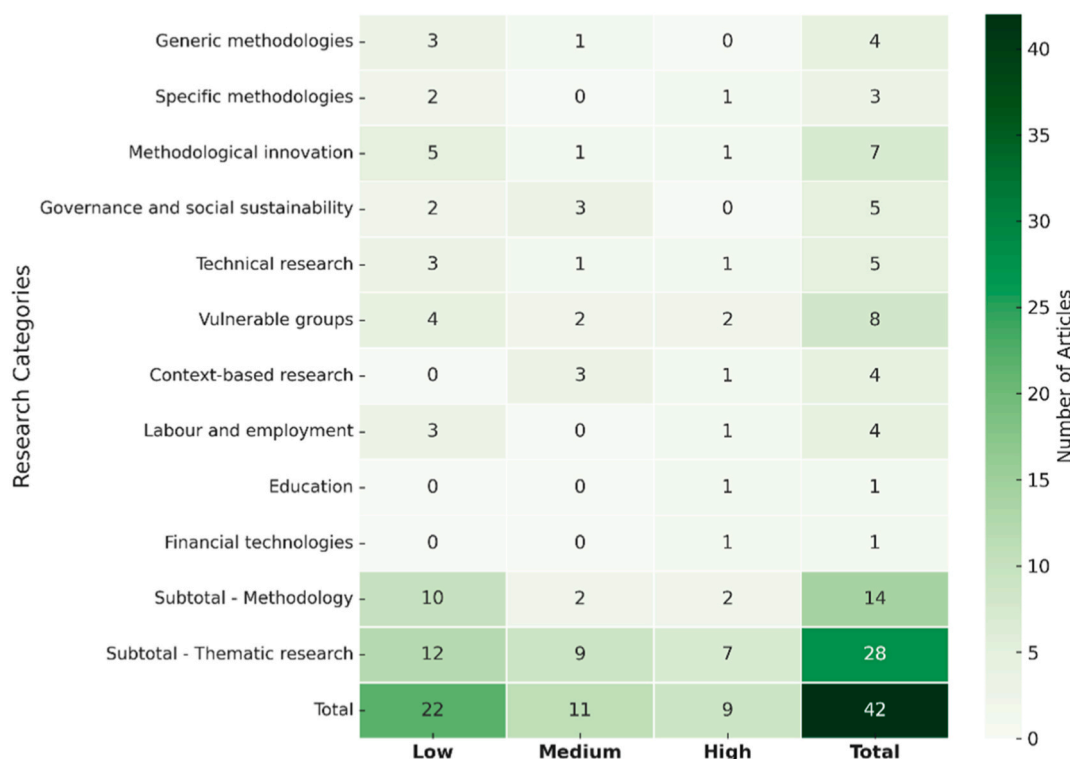


Fig. 7. Coverage levels of research gaps identified through the meta-review.

confirms that empirical attention has diversified geographically, without yet converging toward systematic comparative analysis.

The gap-oriented systematic mapping illustrates how these patterns translate into changes in gap coverage relative to the meta-review. Gaps classified as low coverage decrease substantially, while medium- and high-coverage gaps increase, indicating partial consolidation of the field. This shift is particularly evident for gaps related to vulnerable groups and context-based research, reflecting a gradual broadening of empirical focus beyond purely technical concerns. In contrast, gaps related to methodological standardisation, AI validation in complex environments, and data-intensive research practices remain largely unresolved.

Taken together, these results show that recent empirical research has contributed to incremental progress rather than structural convergence. Advances are visible, but they remain uneven across methodological and thematic domains. Digital agriculture is still analysed primarily through a technical and adoption-oriented lens, with limited integration of perspectives capable of systematically unpacking inequality, power relations, and redistribution. This evidence provides a structured answer to the second research question, clarifying which gaps are being addressed and which continue to constrain cumulative understanding.

### 3.2. Power, redistribution, and contextualised digital inequalities

Together, these perspectives can be interpreted as complementary strands within a broader political economy approach to digital agriculture, helping to explain how technological change redistributes capabilities, resources, and opportunities across rural territories.

Building on these results, this section interprets the identified research gaps through a broader socio-political lens. The patterns emerging from the review synthesis highlight recurring concerns related to unequal access to digital resources, the distributive implications of technological change, and the capabilities required to benefit from digital innovation. These themes resonate with several strands of scholarship that examine digital transformation through the lenses of digital inequality, technological justice, and human capabilities. Rather

than applying these perspectives as formal analytical frameworks, the discussion uses them as interpretive reference points to contextualise how digitalisation may reinforce or mitigate social and spatial inequalities in agriculture and rural contexts.

A first key implication concerns power and redistribution. Across regions and technologies, the literature consistently shows that digitalisation reshapes control over data, knowledge, and decision-making. While access to digital tools has expanded, inequalities increasingly emerge at the level of data ownership, analytical capacity, and algorithmic transparency. This pattern reflects a broader shift from traditional access-based digital divides toward more complex forms of “data divides”, where benefits depend increasingly on control over data, analytical capacity, and algorithmic transparency.

From a technology justice perspective, these findings highlight the limits of inclusion strategies focused solely on access and adoption. Issues related to governance – including data ownership, platformisation, transparency, and institutional accountability – are increasingly discussed in the literature on digital agriculture. However, most contributions remain conceptual or case-specific, and systematic empirical analyses of governance arrangements remain relatively limited. Without participatory governance mechanisms and transparent data regimes, digital innovations may reproduce dependency rather than empowerment. This resonates with recent political economy analyses of digital agriculture, which emphasise that technological change is inherently redistributive and shaped by governance choices rather than neutral market dynamics (Bronson, 2019; Carolan, 2020; Klerkx and Rose, 2020).

A second implication relates to capabilities and capacity-building. The prominence of context-based studies – particularly in the Global South – shows that digital outcomes depend less on technology itself than on education, institutional support, and collective learning environments. From a capabilities perspective, digitalisation enhances well-being only when farmers possess the real opportunities to access, understand, and use technologies in ways aligned with their own priorities. The persistence of gaps in education, advisory systems, and peer-learning infrastructures therefore represents a structural constraint on

**Table 4**  
Evidence map linking gaps to empirical studies (°).

Gap category	Research gap	Empirical studies addressing the gap	Coverage (Step 3)
Methodology – Generic	Interdisciplinary & transdisciplinary approaches	Kuhn et al. (2025); Metta et al. (2022); Pappa (2024); Zscheischler et al. (2022)	Partial
	Scarcity of social science perspectives	Jakku et al. (2022); Klerkx and Rose (2020); Prause (2021); Melo-Velasco et al. (2025)	Partial
	Cross-regional/longitudinal studies	Herdon et al. (2015); Mehrabi et al. (2021); Liu and Liu (2023); Tamirat et al. (2023)	Partial
Methodology – Specific	Standardised adoption frameworks	Addison et al. (2024); Khanna et al. (2022); Michels et al. (2020); Ngigi and Muange (2022)	Partial
Methodology – Innovation	Field validation of AI technologies	Hua et al. (2023); Xu et al. (2024)	Low
	Managing large amounts of data in research	No empirical studies explicitly address this gap	Absent
Governance & social sustainability	Participatory governance methods	Jakku et al. (2022); Tithi et al. (2021); Kuhn et al. (2025)	Partial
	Data ownership, transparency, power	Carolan (2020); Hackfort (2023); Sodano (2021); Jakku et al. (2022)	Partial
Technical research	Cumulative AI/IoT effects	Khanna et al. (2022); Luo et al. (2025); Ruder et al. (2025)	Partial
Vulnerable groups	Smallholder inclusion	Liu and Liu (2023); Ye (2025); Guan et al. (2024); Meng and Li (2025)	Partial
	Gendered digital inequalities	Ngigi and Muange (2022); Udisha and Philomina (2024); Addison et al. (2024)	Partial
Context-based research	Global South & emerging economies	Mendes et al. (2024); Kerras et al. (2022); Maniriho (2024); Radenovic et al. (2025)	High
Labour & employment	Automation and labour restructuring	Prause (2021); Carolan (2020); Martens and Zscheischler (2022); Luo et al. (2025)	Partial
Education	Capacity building & learning	Herdon et al. (2015); Liu and Zhou (2023); Kuhn et al. (2025)	Partial
Financial technologies	Digital finance & inclusion	Liu and Liu (2023); Ma et al. (2024); Su et al. (2021); Ye (2025)	High

<sup>a</sup> Source: author elaboration.

inclusive digital transitions.

Finally, the review highlights the context-dependence of digital justice. Cross-regional comparison suggests that digitalisation follows divergent pathways: in high-income contexts, debates focus on automation, labour displacement, and ethics; in emerging economies, attention centres on connectivity, finance, and basic capabilities. This divergence implies that policy frameworks cannot be universally transferred. Strategies that promote innovation and efficiency in Europe may exacerbate dependency or exclusion elsewhere unless adapted through local governance, co-design, and knowledge co-production.

In sum, the findings support a reframing of digital agriculture not merely as a technological transition, but as a governance regime in which questions of redistribution, accountability, and autonomy are as

central as productivity and efficiency. By clarifying where evidence has consolidated and where gaps persist, this review contributes to ongoing debates in rural studies on just transitions, social inequality, and the political economy of rural digitalisation.

#### 4. Discussion: interpreting patterns of inequality in digital agriculture

Building on the interpretive insights developed in Section 3.2, this concluding section synthesises the main findings of the multi-level review and reflects on their implications for research and policy. Rather than reiterating descriptive results, it draws together how the existing literature has conceptualised and empirically addressed social inequality in digital agriculture, and highlights the key dimensions that remain insufficiently explored.

Across the literature, digitalisation emerges not simply as a process of technological diffusion, but as a set of socio-technical transformations with uneven social and spatial distributive outcomes. Importantly, these dynamics unfold primarily within rural contexts, where institutional infrastructures, advisory systems, and territorial networks shape how digital technologies are accessed, interpreted, and used by farmers and rural communities. While recent studies increasingly acknowledge social dimensions, the synthesis confirms that inequalities related to power, capabilities, and governance remain only partially integrated into mainstream analyses. This finding aligns with critical contributions in rural studies and agri-food scholarship, which argue that digital transitions tend to reproduce pre-existing structural asymmetries unless explicitly governed toward inclusive and redistributive objectives (Bronson, 2019; Carolan, 2020; Klerkx and Rose, 2020; Wang et al., 2025).

Against this background, the discussion is structured around the three guiding research questions. First, it examines how existing reviews have framed issues of social and spatial inequality and identified related research gaps. Second, it assesses the extent to which empirical studies address these gaps. Third, it considers which dimensions remain insufficiently explored and discusses the implications for theory and policy in rural contexts.

With reference to RQ1 (How has the academic literature on digital technologies in agriculture and rural contexts addressed issues of social and spatial inequality, and how are these issues distributed across technical, social, and institutional research strands?) the meta-review confirms a consistent message across prior reviews: the literature has historically been dominated by adoption and performance narratives, while inequality-related dimensions remain less systematically examined. Reviews repeatedly identify gaps in (i) governance and data ownership, (ii) labour and employment transformation, (iii) education and capacity-building, (iv) methodological standardisation and cross-regional comparability, and (v) sustained attention to vulnerable groups (smallholders, women, youth) beyond descriptive accounts. This aligns with influential strands in rural digitalisation scholarship arguing that technological change cannot be understood without examining institutions, intermediaries, and power relations shaping inclusion, access, use, and outcomes (e.g., Klerkx and Rose, 2020; Carolan, 2020; Bronson, 2019; Hackfort, 2021; Udisha and Ambily Philomina, 2024).

A central gap highlighted by reviews concerns the tendency to treat “inclusion” as access and adoption, rather than as distributive outcomes and voice in governance. This resonates with Digital Inequality Theory, which conceptualises inequalities not only as “access gaps” but as differentiated use, skills, and outcomes (DiMaggio et al., 2001; van Dijk, 2020). In parallel, Technology Justice perspectives stress that the distribution of benefits depends on who shapes technological pathways and rules of data governance (Smith and Stirling, 2018; Marra and Carlson, 2002; Khamtavee et al., 2024; Liu et al., 2025). Finally, the Capabilities Approach frames inclusion as the real freedom to convert digital resources into valued functionings requiring institutional support and learning environments rather than connectivity alone (Sen, 1999;

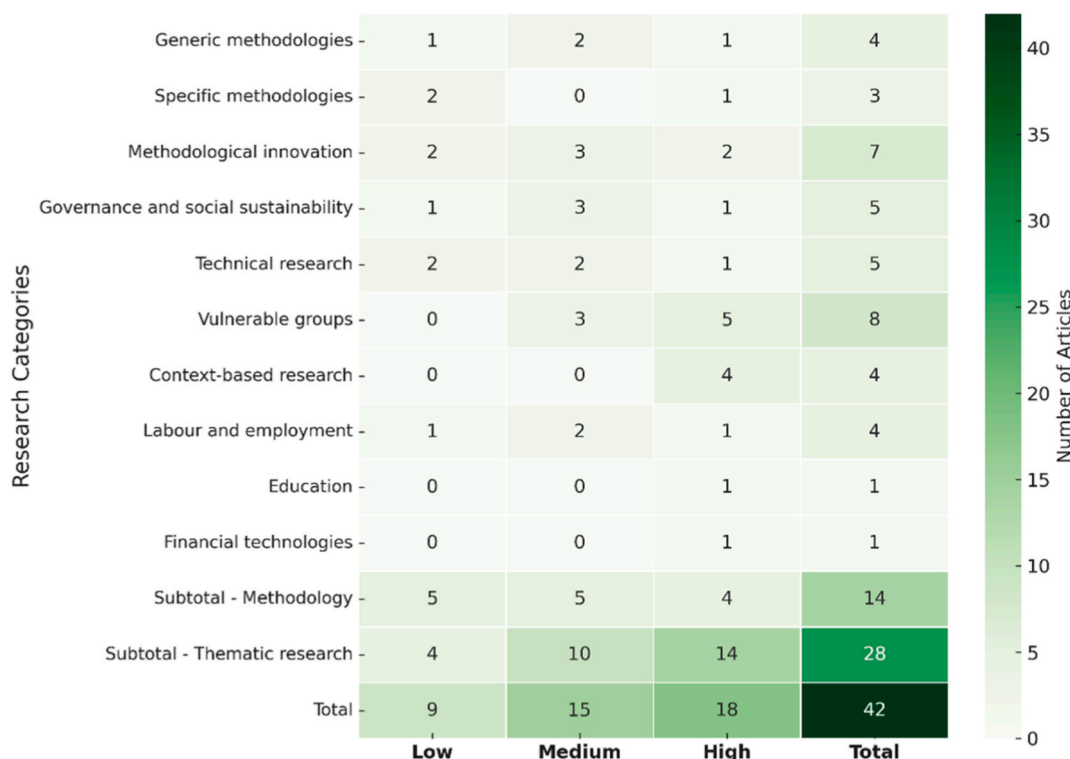


Fig. 8. Updated coverage levels of research gaps based on the gap-oriented systematic mapping.

Nussbaum, 2003).

As regards RQ2 (Which research gaps related to social and spatial inequalities have been identified by existing reviews on digitalisation in agriculture and rural contexts?), however, the gap-oriented mapping shows measurable progress in some areas but persistent fragilities in others.

Where evidence has expanded. Empirical research has increasingly engaged with vulnerable groups and context-based dynamics. Studies focusing on women, smallholders, and rural youth have grown, especially in emerging economies, contributing to a more diversified evidence base. However, the mapping also shows that inclusion gains are often conditional: benefits tend to concentrate among better-resourced and more educated actors, consistent with “Matthew effects” dynamics whereby early advantages compound over time (Perc, 2014; Gómez-Bengochea and Jung, 2024; Tewathia et al., 2020; Khan et al., 2024). This pattern supports the interpretation that digitalisation can reproduce pre-existing structural inequalities even when access improves.

Where evidence remains uneven. Several gaps persist in a way that limits cumulative understanding. First, methodological standardisation remains weak: comparable indicators and shared protocols are rare, constraining synthesis across contexts. Second, field-based validation of AI in complex farming environments remains limited and unevenly documented, which is particularly relevant when claims about automation and decision support are translated into policy expectations. These limitations also have implications for inclusion, as the uneven validation of digital tools may reinforce disparities in farmers’ ability to access reliable decision-support technologies. Third, “data-intensive research challenges” remain largely implicit; despite widespread discussion of big data and platforms, empirical work rarely addresses research design implications such as data quality, transparency, and replicability in a systematic way.

Governance, labour, and education: partial consolidation, still fragmented. Recent empirical work increasingly engages with issues of governance and social sustainability, particularly around data ownership, platformisation, trust, transparency, and accountability (Bronson,

2019; Carolan, 2020; Klerkx and Rose, 2020). However, most contributions remain conceptual or case-specific, and systematic empirical analyses of governance arrangements in digital agriculture remain relatively limited. Yet the evidence remains uneven and often context-bound, supporting the conclusion that governance is recognised as important but still under-operationalised as an empirical domain. Research on labour transformation and automation has expanded in recent years, particularly in relation to changing skill requirements, new professional roles, and managerial control in digitally mediated farming systems. Nevertheless, the empirical evidence remains uneven across regions and production systems, leaving significant gaps in understanding the long-term implications for rural labour markets (Carolan, 2020; Prause, 2021). Education and capacity-building appear frequently, but many contributions remain generic; fewer studies examine how advisory systems, peer learning, and facilitation shape distributive outcomes in ways central to rural development practice.

Taken together, the evidence indicates that the literature is moving beyond purely technical framings, but not yet toward a coherent, cumulative understanding of inequality as a redistributive process.

Finally, on RQ3 (To what extent do original empirical studies address these gaps, and which dimensions of social and spatial inequality remain partially explored or largely neglected in rural contexts?) the synthesis points to three unresolved “frontier gaps” with direct implications for rural studies and policy.

The first gap concerns unequal access to digital outcomes, particularly in relation to data ownership, analytical capacity, and algorithmic transparency. While a growing body of literature has begun to address these issues, the available evidence remains fragmented and context-specific, indicating that the transition from traditional digital divides to emerging “data divides” is still only partially understood. This resonates with political economy accounts emphasising that digital transitions are redistributive processes that reshape who controls resources, knowledge, and decision-making (Bronson, 2019; Carolan, 2020). Future research needs to evaluate governance arrangements that can redistribute benefits e.g., data stewardship models, participatory rule-setting, and accountability mechanisms rather than treating

governance as a normative add-on.

The second gap can be identified in capabilities and learning infrastructures. A capabilities lens highlights that digital tools enhance well-being only when farmers can convert access into empowerment through education, advisory support, institutional trust, and collective learning environments (Sen, 1999; Nussbaum, 2003). This directly connects to rural development debates on extension, facilitation, and innovation systems, suggesting that research should better measure how learning infrastructures mediate distributive outcomes.

The third gap focuses on comparability without erasing context. The review reveals a productive tension: methodological gaps call for comparative and longitudinal approaches, while thematic gaps demand contextual specificity. Future research should therefore develop designs that enable comparison (shared indicators, transparent protocols) while preserving context (mixed methods, participatory inquiry). This is particularly important for just-transition debates in rural studies, where “what works” depends on institutional and territorial conditions.

Overall, the discussion suggests that digital agriculture should be analysed not only as technological innovation but as a socio-technical governance regime. This reframing is consistent with rural studies debates on inequality and just transitions and provides an interpretive bridge from fragmented evidence to a research agenda centred on redistribution, accountability, and capabilities.

## 5. Conclusion: main findings, limitations, and future research directions

More broadly, these findings suggest that digitalisation in agriculture should be understood not only as a process of technological innovation but as a socio-technical transformation that reshapes power relations, capabilities, and development opportunities across rural territories.

This review set out to identify and structure research gaps on the relationship between digital technologies and social inequality in agriculture, and to assess the extent to which recent empirical work addresses those gaps. By combining descriptive bibliographic mapping, a meta-review of existing reviews, and a gap-oriented mapping of primary studies, the paper provides an integrated and transparent overview of an expanding but uneven literature.

Three conclusions emerge. First, the evidence base is expanding and diversifying, but inequality remains structurally patterned. Empirical work increasingly addresses vulnerable groups and context-based dynamics, especially in emerging economies. However, across contexts, benefits frequently accrue to better-resourced and more educated actors, indicating persistent capability differentials and cumulative advantage dynamics. Inclusion in terms of access and adoption does not automatically translate into equitable outcomes.

Second, progress is visible in governance and socio-technical perspectives, yet key methodological and technical gaps remain unresolved. The literature shows growing attention to data governance, platformisation, labour transformation, and ethical concerns, supporting the view that digitalisation is embedded in power relations rather than being a neutral productivity transition. At the same time, methodological standardisation, longitudinal and cross-regional designs, and field-based validation of AI applications remain limited, constraining cumulative learning and evidence-based policy claims.

Third, the most policy-relevant unresolved issues concern redistribution and capabilities rather than technology per se. The review suggests that the digital divide is increasingly expressed through unequal capacities to capture value from data, analytics, and algorithmic systems. A capabilities-oriented reading underscores that empowerment depends on education, advisory systems, and institutional support. A technology justice perspective highlights the need for participatory governance and accountability mechanisms that can shape technological trajectories and distribute benefits more fairly.

This review has limitations. It relies on peer-reviewed literature indexed in Scopus and Web of Science and may under-represent grey

literature and practitioner knowledge. Keyword-driven searches may miss influential social science contributions that examine digital agriculture through advisory systems, skills, or innovation networks without using inequality-related terminology, despite mitigation through snowballing. Finally, systematic mapping describes the distribution of evidence and gaps but does not estimate causal effects of digitalisation in practice; the conclusions therefore reflect patterns in the academic literature rather than direct measurement of real-world impacts.

Building on the mapped gaps, future work should prioritise.

- Longitudinal and comparative designs to assess how digitalisation reshapes inequalities and governance over time and across regions.
- Mixed-method and participatory approaches linking technical performance to distributive outcomes, lived experience, and local institutions.
- Governance-focused empirical research on data ownership, stewardship, transparency, and mechanisms for fair benefit-sharing.
- Capabilities and learning infrastructures, including extension services, peer-to-peer networks, facilitation, and digital literacy as determinants of distributive outcomes.
- Under-studied regions and rural contexts, expanding evidence beyond dominant geographic clusters and strengthening research in Africa, Latin America, and small-island or remote rural settings.

In conclusion, digitalisation in agriculture should not be treated as an automatic driver of modernisation nor as an inevitable source of exclusion. These findings reinforce growing arguments in rural studies and political economy analyses of digital agriculture that technological change cannot be understood independently from the institutional and governance arrangements shaping access, control, and value distribution. Digitalisation is a socio-technical and governance process shaped by institutions, power relations, and the distribution of capabilities. Advancing toward just and inclusive rural digital futures therefore requires not only technological innovation but also governance arrangements and learning systems that expand farmers’ capabilities, ensure accountability, and support fairer redistribution of benefits.

These findings also contribute to ongoing debates in rural studies by highlighting how digitalisation interacts with territorial inequalities, institutional capacities, and governance arrangements that shape development trajectories in rural areas.

Ultimately, whether digitalisation in agriculture reinforces existing inequalities or contributes to more just and resilient rural futures depends less on the technologies themselves than on the social, institutional, and political choices that govern their design, deployment, and use.

## CRedit authorship contribution statement

**Sara Calzolari:** Conceptualization, Data curation, Methodology, Writing – original draft, Writing – review & editing. **Giuseppe Timpanaro:** Funding acquisition, Investigation, Supervision, Writing – original draft, Writing – review & editing. **Alessandro Grasso:** Software, Writing – review & editing. **Gabriella Vindigni:** Funding acquisition, Investigation, Supervision, Writing – review & editing.

## Declaration of competing interest

The authors declare that they have no conflict of interest.

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views and opinions; neither the European Union nor the European Commission can be considered responsible for them.

## Data availability

Data will be made available on request.

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