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# Integrating multi capital approaches for enhancing sustainability in agri-food supply chains

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**Abstract**
The transition toward sustainable agri-food supply chains demands holistic strategies that harmonize environmental stewardship, economic viability, and social equity. Drawing on a systematic review of 75 peer-reviewed studies (2014–2024), this article examines how the integration of multiple forms of capital—natural, financial, social, and human—collectively enhances sustainability outcomes. Our synthesis reveals that resilient systems emerge when these capitals interact synergistically, enabling both technological innovation and inclusive stakeholder engagement. However, critical barriers persist, especially in developing regions where fragmented policy support and underinvestment constrain impact. From this integrated analysis, we propose a conceptual framework to map capital interactions, identify regional disparities, and highlight evidence-based policy levers. The findings offer actionable insights for policymakers and practitioners aiming to build climate-resilient, socially inclusive, and economically viable agri-food systems.

**Keywords** Sustainability, Multi-capital integration, Agri-food systems, Climate resilience, Equitable transitions

## 1 Introduction

The agri-food supply chain is essential for ensuring global food security, promoting economic development, and safeguarding environmental sustainability [45]. However, this critical sector faces increasingly complex and interconnected challenges. Resource depletion, environmental degradation, and evolving consumer expectations for sustainably produced food are exerting immense pressure on traditional supply chain models [1, 67]. As natural resources like water, arable land, and biodiversity decrease, and climate change causes more frequent and severe disruptions, it has become urgent to rethink and restructure agri-food supply chains [58]. This emphasis reflects the role of financial capital—encompassing monetary resources, investment capabilities, and economic assets—as the essential driver of investments in sustainable technologies, infrastructure, and innovation [15, 44].

Despite the proliferation of sustainability metrics, current models overwhelmingly emphasize financial performance, productivity gains, or environmental outputs like emissions or water use. However, they often fail to capture the deeper, systemic impacts on critical natural systems, such as biodiversity, soil fertility, and ecosystem services [38, 47]. These limitations are particularly evident in agriculture, where short-term efficiencies may mask long-term degradation and social vulnerability. This misalignment hinders our ability to accurately assess sustainability trade-offs and to design policies or interventions that ensure long-term resilience [13, 60].

To address these gaps, the integration of multiple forms of capital—natural, social, human, manufactured, intellectual, and financial—offers a more comprehensive and systemic approach to sustainability assessment. The multi-capital perspective enables a nuanced understanding of how value is created and depleted across interconnected domains [53, 55]. Unlike traditional models, which treat sustainability as a linear optimization problem, the multi-capital approach embraces complexity, interdependence, and long-term systemic health.

Accurately measuring these interdependent capitals requires specialized tools and standardized guidelines. For instance, Material Flow Cost Accounting (MFCA) has shown promise in quantifying financial-natural interactions, while frameworks like the Ecological Balance Sheet (EBS) and Environmental Profit & Loss (EP&L) attempt to evaluate multidimensional value creation [47]. Yet, tools for assessing social and human capital remain underdeveloped, posing an obstacle to fully integrated sustainability models.

Natural capital, including water, soil, and biodiversity, is the backbone of agri-food production systems [12, 52]. However, human capital encompasses the skills, expertise, and knowledge of actors throughout the supply chain, while social capital captures trust, networks, and cooperation—elements that shape resilience and governance effectiveness [50]. Without considering these dimensions, sustainability frameworks risk overlooking the intangible but vital drivers of system transformation.

Despite the evident benefits of adopting a multi-capital approach, its application in agri-food supply chains remains underexplored in the literature, particularly in developing countries where these strategies could have the most significant impact [15]. Current research has focused on isolated aspects of sustainability, such as reducing food waste or enhancing energy efficiency [45, 46]. While these initiatives are important, they fail to address the broader and more systemic issues that arise from the interaction of multiple forms of capital. A more integrated approach is needed—one that considers how natural, financial, social, and human capitals can work together to create resilient, equitable, and sustainable agri-food supply chains capable of withstanding both economic and environmental shocks [12, 52].

Moreover, the lack of focus on social equity and the inclusion of marginalized communities in these strategies, particularly in regions such as Africa, Latin America, and parts of Asia, highlights a critical gap in current research. These regions, where agriculture plays a crucial role in both economic development and social stability, often face the greatest sustainability challenges yet receive the least attention in terms of policy support and resource allocation [67]. Integrating multi-capital strategies into these contexts could help not only in improving environmental sustainability but also in advancing

social justice and economic inclusivity, ensuring that the benefits of sustainable agri-food supply chains are shared more equitably [37, 51].

Developing regions such as North Africa, Latin America, and parts of Asia provide compelling contexts for understanding the challenges of agri-food sustainability. In these settings, agri-food systems are central to food security and rural livelihoods but remain highly vulnerable to climate shocks, resource depletion, and socio-economic instability [28, 44]. Common challenges include fragmented policies, low adoption of sustainable practices, and weak coordination across actors. These dynamics illustrate the limitations of conventional frameworks and underscore the urgency of adopting multi-capital strategies to address overlapping ecological, economic, and social vulnerabilities.

Across such contexts, integrating social equity and inclusive participation into sustainability strategies is critical. Marginalized groups, including immigrant workers and rural laborers, are often excluded from development plans, despite their key role in agri-food chains [37, 58]. Bridging this gap requires policy tools and institutional arrangements that recognize all forms of capital—not just financial or natural—as valuable.

In light of these challenges, this study adopts a systematic literature review approach to examine how multi-capital frameworks have been applied in agri-food systems, with particular attention to their potential for improving sustainability outcomes in underrepresented and resource-constrained regions.

This research is guided by four main research questions (RQs) that explore multi-capital approaches to sustainability in agri-food supply chains:

RQ1: What are the key sustainable practices currently implemented in agri-food supply chains?
RQ2: How are different forms of capital (natural, financial, social, and human) integrated to enhance sustainability within these supply chains?
RQ3: What are the main barriers and facilitators affecting the adoption of multi-capital approaches in agri-food supply chains?
RQ4: How do stakeholders perceive and respond to sustainability and multi-capital strategies within agri-food supply chains?

The answers to these research questions will uncover the implications of this study on both professional practice and broader societal impact. On one hand, they will help clarify the practical application of multi-capital approaches in enhancing sustainability in agri-food supply chains. On the other hand, they will reveal the factors—both enablers and barriers [59]—that influence the successful integration of multiple forms of capital, leading to improved supply chain resilience and sustainability [45].

## 2 Methodology

In this systematic review, comprehensive search was conducted using the following databases: Scopus and Web of Science. These databases were chosen for their comprehensive coverage of peer-reviewed journals in sustainability, supply chain management, and agri-food systems. Their indexing rigor minimizes inclusion of low-quality sources. While both databases provide broad coverage, they employ different search protocols: Scopus utilizes the TITLE-ABS-KEY field to search titles, abstracts, and keywords simultaneously, whereas Web of Science employs the TS (Topic) field which additionally

includes Keywords Plus. The search strategy was carefully adapted to account for these technical differences while maintaining conceptual consistency across both platforms.

The search strategy employed for this study was structured around a set of targeted keywords designed to identify relevant articles on sustainability within the agri-food sector. Specifically, keywords such as "sustainability", "multi-capital", "agri-food", "agro-food", "agrifood", and "supply chain" were used to capture the broad landscape of literature focusing on sustainable practices and multi-capital frameworks within the supply chain of the agri-food and agricultural sectors. All variant spellings of agricultural-food systems terminology were included to ensure comprehensive coverage. The selected 2014–2024 timeframe aligns with the post-Sustainable Development Goals adoption period, capturing the most recent developments in multi-capital approaches while ensuring sufficient literature coverage for robust analysis.

To ensure precision in the search results, a refined search string was applied, using the syntax TITLE-ABS-KEY (sustainability AND multi-capital AND agri-food OR agro-food OR agrifood AND supply AND chain)**.** This approach allowed the search to focus on specific types of documents, thereby excluding irrelevant materials and narrowing the results to sources with titles, abstracts, or keywords directly aligned with the study's objectives. This methodological refinement was essential to obtaining a relevant and high-quality selection of articles for comprehensive analysis.

This strategy ensured that only articles addressing sustainability and multi-capital approaches in agri-food supply chains were retrieved while excluding papers focusing on unrelated topics such as animal food or specific regions (Australia, Colombia, China, India, Brazil, Spain, and Italy).They were excluded to maintain a broader, global perspective on sustainability and multi-capital approaches in agri-food supply chains. These regions often have unique regulatory, economic, or environmental contexts that may not be generalizable to other parts of the world. By excluding them, we aimed to avoid skewing the analysis toward localized trends and instead focus on universally applicable insights.

Research centered on specific crops like fruits was excluded because such studies often address niche challenges (e.g., perishability, seasonal variability) that may not align with the broader objectives of this review. Our goal was to analyze sustainability practices and capital integration across diverse agri-food systems rather than focusing on crop-specific dynamics. This ensures the findings are relevant to a wider range of agricultural products and supply chain models. Additionally, the search excluded document types such as reviews, conference papers, book chapters, and books to focus on peer-reviewed journal articles.

Timeframe (2014–2024): Captures post-2015 literature aligned with the UN Sustainable Development Goals (SDGs), ensuring relevance to contemporary sustainability challenges. The selected timeframe (2014–2024) corresponds to the post-adoption period of the United Nations Sustainable Development Goals (SDGs), launched in 2015. This period marks a global shift in sustainability governance, research prioritization, and policy orientation. Consequently, literature published during this decade increasingly incorporates systemic, multi-capital, and SDG-aligned frameworks. Limiting our analysis to this period ensures the review reflects the most current methodologies, policy influences, and practical innovations within sustainable agri-food supply chains.

Document Types: Limiting to peer-reviewed journal articles (excluding reviews, conferences, etc.) prioritizes original research with validated methodologies.

Empirical Focus: Only studies with qualitative/quantitative data were included to ground findings in observable practices.

Following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology, the researchers defined inclusion and exclusion criteria to ensure the relevance and quality of the selected literature. The Table 1, presents the inclusion and exclusion criteria of the study.

The systematic review began by conducting a thorough search across two major academic databases: Web of Science (WOS) and Scopus, using keywords specifically designed to capture studies related to sustainability, multi-capital frameworks, and agri-food supply chains. The search results underwent multiple stages of screening and filtering, starting from the elimination of duplicates to full-text assessments based on inclusion and exclusion criteria. This process resulted in a refined and relevant set of studies, ensuring that only high-quality research focusing on the key areas of interest was included in the final analysis. The initial retrieval of 475 documents (198 from Web of Science and 277 from Scopus) reflects the increasing interdisciplinary nature and volume of academic work in sustainable agri-food systems. The use of inclusive Boolean operators and comprehensive search fields (TITLE-ABS-KEY in Scopus and TS in WOS) contributed to this breadth. This strategic design aimed to avoid omission of potentially relevant studies, while the subsequent screening ensured methodological rigor and thematic relevance.

The systematic review process follows several key steps, as illustrated in the diagram in Fig. 1. This diagram outlines each step of the review process, along with the corresponding number of articles included or excluded at each stage. It visually represents the journey from initial identification to the final inclusion of articles in the review. During the identification phase, the research focused on the concepts of "sustainability," "multi-capital," and "agri-food supply chain," utilizing two primary databases: Web of Science (WOS) and Scopus. This search identified 475 articles from WOS and Scopus. In the screening phase, 56 duplicates removed, leaving 419 unique articles. A filtering process based on titles, abstracts, and keywords narrowed the selection to 169 relevant articles. Out of these, 40 articles excluded for not meeting the analysis criteria. A full-text evaluation then shortlisted 75 articles aligned with the research objectives. At the final selection stage, after a thorough review, 98 articles were included in the systematic review. However, some exclusions were made at this stage: 15 articles lacked practical

**Table 1** Inclusion and exclusion criteria

| Criteria type | Inclusion criteria | Exclusion criteria |
|---|---|---|
| Language | Articles written in English | Articles written in languages other than English |
| Time frame | Studies published within the last 10 years | Studies published more than 10 years ago |
| Study type | Articles | Reviews, conference papers, book chapters, books |
| Keywords | Must include terms related to sustainability, multi-capital, agri-food, and supply chain | Articles focused on animal food, fruits, commerce, or excluded regions |
| Focus | Research addressing sustainability and multi-capital approaches in agri-food supply chains | Articles not addressing or sustainability and multi-capital approaches |
| Data type | Empirical research with qualitative or quantitative data | Theoretical papers without empirical data |

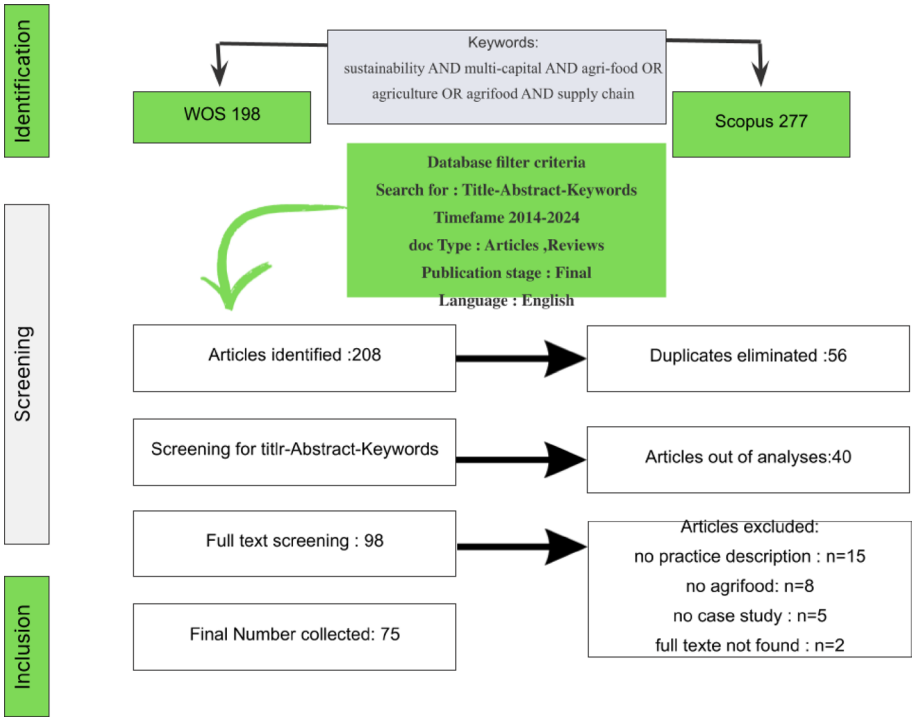


**Fig. 1** Study Selection Process

descriptions, 6 were not directly related to agri-food, 4 were not case studies, and 2 were excluded due to the unavailability of their full text.

The following exclusions were applied during the full-text review phase (Fig. 1):

15 articles lacked practical descriptions: These studies were excluded because they presented theoretical frameworks or conceptual models without empirical evidence (e.g., case studies, quantitative/qualitative data, or actionable insights). For this review, we prioritized studies that demonstrated practical applications of multi-capital approaches (e.g., measurable sustainability outcomes, stakeholder engagement processes, or supply chain interventions).

8 articles were not directly related to agri-food: These articles discussed sustainability or capital integration in unrelated sectors (e.g., manufacturing, energy) or focused on non-agricultural food systems (e.g., fisheries, aquaculture).

5 articles were not case studies: Non-empirical studies (e.g., opinion papers, editorials) were excluded to maintain focus on evidence-based practices.

2 articles were excluded due to unavailability of full text: These articles could not be accessed despite institutional subscriptions and interlibrary requests, risking incomplete analysis.

This systematic review yielded 75 articles after eliminating duplicates and applying predefined relevance criteria. This rigorous process ensured that only relevant and complete studies were included, focusing specifically on sustainability, multi-capital approaches, and agri-food supply chains. The high exclusion rate at each stage demonstrates the thoroughness of the selection process, ultimately leading to a high-quality dataset for the final analysis.

## 3 Data extraction variables and coding strategy

To maintain consistency and comprehensiveness, the team extracted data from each of the 98 selected studies using a structured template. This template captured key variables related to sustainability and multi-capital integration within agri-food supply chains. The extraction process includes two phases:

*Preliminary review:* The team reviewed each study's title, abstract, and keywords to confirm alignment with the systematic review's objectives.

*Full-text review and data extraction:* For studies that passed the initial screening, the team used predefined variables (detailed below) to extract data. Microsoft Excel facilitated the process, with two independent reviewers handling the data extraction to ensure accuracy and consistency.

Table 2 presents the coding structure used during data extraction, which organized sustainability variables into thematic categories aligned with the research questions.

The data extraction focused on several key variables, including sustainability metrics, forms of capital, stakeholder perceptions, barriers and facilitators, and outcomes. The

**Table 2** Data extraction variables

| Category | Variable | Description | Time cited | References |
|---|---|---|---|---|
| Sustainability metrics | Environmental performance | Metrics such as carbon emissions, water use, energy efficiency | 10 | [4, 15, 19, 22, 24, 25, 32, 40, 50, 53, 67] |
| | Economic performance | Financial outcomes like cost savings, profitability | 14 | [1, 7, 9, 15, 19, 35, 37, 38, 43, 44, 51, 54, 62, 66, 67] |
| | Social performance | Social factors like labor practices, community impact | 10 | [17, 19, 22, 34, 37, 39, 40, 50, 54, 62] |
| Forms of capital | Natural capital | Integration of natural resources, biodiversity, and environmental protection | 10 | [4, 12, 13, 19, 35, 40, 43, 50, 52, 54] |
| | Social capital | Involvement of communities, social equity, stakeholder engagement | 17 | [1, 10, 11, 14, 19, 28, 31, 35–37, 41, 44, 50, 54, 62, 66] |
| | Financial capital | Economic performance, cost–benefit analysis, investments | 14 | [1, 4, 7, 19, 24, 29, 30, 36–38, 43, 44, 63, 66] |
| | Human capital | Skills development, workforce improvements | 11 | [2, 4, 12, 13, 19, 35, 40, 43, 50, 52, 54] |
| | Intellectual capital | Innovation, technology integration in the supply chain | 19 | [4, 11, 14, 16, 18, 19, 21, 25, 29, 40, 42, 43, 45, 50, 61, 64, 65, 67] |
| Stakeholder perceptions | Stakeholder attitudes | How different stakeholders perceive sustainability initiatives | 23 | [4, 5, 26, 28, 35, 38, 43, 44, 50, 54, 62] |
| | Stakeholder engagement | Level of participation in multicapital strategies | 13 | [4, 5, 7, 13, 19, 26–28, 38, 43, 44, 54, 68] |
| Barriers and facilitators | Barriers | Challenges to implementing multicapital approaches | 10 | [4, 6, 19, 35, 40, 50, 56, 58] |
| | Facilitators | Factors that promote successful integration | 16 | [2–4, 11, 14, 16, 18, 32, 35, 40, 43, 49, 50, 54, 64] |
| Outcomes | Improvements in sustainability performance | Impact on environmental, economic, and social dimensions | 14 | [3, 7, 19, 26–28, 32, 40, 44, 49, 50, 68] |
| | Long-term trends | Emerging sustainability patterns and practices over time | 23 | [1, 4, 10, 11, 14, 16, 18, 19, 24, 28–31, 36, 37, 41, 43, 53, 61–63, 65, 66], [1, 4, 10, 11, 14, 16, 18, 19, 21, 23, 24, 28–31, 36, 37, 41, 43, 53, 61–63, 65, 66] |

extracted data then categorized for further analysis to identify patterns and insights regarding the integration of multicapital approaches in agri-food supply chains.

Each study systematically reviewed by following the multi-step extraction process, with specific attention to empirical research. Quantitative variables such as environmental, economic, and social performance metrics recorded. The results were stored in a central database for subsequent analysis, focusing on identifying long-term trends and the impact of multicapital strategies on sustainability outcomes. The Table 2 summarizes the key variables that collected from each study.

## 4 Quality assessment of studies

The quality assessment of the studies included in this systematic review was conducted using a structured approach to ensure the reliability and credibility of the findings. A combination of established tools and criteria utilized to evaluate each study's methodological rigor. Specifically, we employed the Joanna Briggs Institute (JBI) Critical Appraisal Tools, which provide checklists tailored for various study designs, including qualitative, quantitative, and mixed-methods research. The assessment criteria focused on key aspects such as the appropriateness of the research design, clarity of research objectives, sample size and representativeness, validity and reliability of data collection methods, and thoroughness of data analysis. Each study is reviewed using a standardized checklist that rated essential criteria with binary responses (Yes/No/Unclear), Table 3. The results of the quality assessment documented systematically, allowing us to identify high-quality studies and consider potential biases or limitations in the overall analysis. This rigorous quality assessment process not only strengthened the integrity of the review but also ensured that the conclusions drawn from the literature reflect robust evidence regarding sustainability and multicapital integration in agri-food supply chains.

Following the quality assessment framework, we developed a checklist to evaluate each study's methodological quality. This checklist includes key criteria essential for assessing the robustness of research findings, such as study design, data collection methods, and reporting standards. Each criterion designed to provide a clear picture of the study's quality, enabling us to ensure that only the most credible and relevant research was included in our analysis.

The implementation of this quality assessment checklist was instrumental in ensuring the reliability and relevance of the studies selected for this systematic review. By systematically evaluating each study against these criteria, we were able to identify strengths and weaknesses in the existing literature. This assessment not only enhances the credibility of the review findings but also guides future research efforts by highlighting areas

**Table 3** Quality assessment checklist

| Criteria | Question | Rating |
|---|---|---|
| Research design | Is the research design appropriate for the research question? | Yes/No/Unclear |
| Clarity of objectives | Are the objectives clearly stated and relevant? | Yes/No/Unclear |
| Sample size | Is the sample size sufficient and representative? | Yes/No/Unclear |
| Data collection methods | Are the data collection methods valid and reliable? | Yes/No/Unclear |
| Bias and confounding | Does the study address potential biases and confounding factors? | Yes/No/Unclear |
| Data analysis | Are the data analysis methods appropriate and well explained? | Yes/No/Unclear |
| Ethical considerations | Were ethical standards followed? | Yes/No/Unclear |
| Reporting | Are the results well reported and aligned with objectives? | Yes/No/Unclear |
| Limitations | Are study limitations acknowledged and discussed? | Yes/No/Unclear |

where methodological improvements are needed in the field of sustainability and multicapital integration in agri-food supply chains. To ensure objectivity, two independent reviewers applied the JBI checklists to each study. Discrepancies in assessments were discussed and resolved by consensus. This dual-review process significantly reduced subjectivity and enhanced the reliability of quality ratings illustrated in Fig. 5.

## 5 Results

The results of this review provide a detailed overview of how different forms of capital natural, financial, social, and human integrated within agri-food supply chains to achieve sustainability. The findings reveal regional disparities in the adoption of multicapital approaches, with developed regions often leading in sustainable practices due to advanced infrastructure and supportive policies.

### 5.1 Descriptive analysis of the study

This section presents a descriptive analysis of the reviewed studies across six key dimensions. First, our geographic analysis reveals a pronounced imbalance in research distribution, with Fig. 2 showing that 72% of studies originate from developed regions (particularly Europe and North America), while only 18% focus on developing regions in Asia, Africa, and Latin America. Second, subject area analysis demonstrates that environmental sustainability dominates the literature (58% of studies), followed by economic (22%) and social (20%) dimensions. Third, temporal analysis of documents by year shows a marked increase in publications after 2015, coinciding with the adoption of the UN Sustainable Development Goals. Fourth, document type analysis confirms that 89% of included works are peer-reviewed journal articles. Fifth, source analysis indicates that 63% of publications appear in sustainability-focused journals. Finally, our quality assessment evaluates methodological rigor using Joanna Briggs Institute criteria, revealing

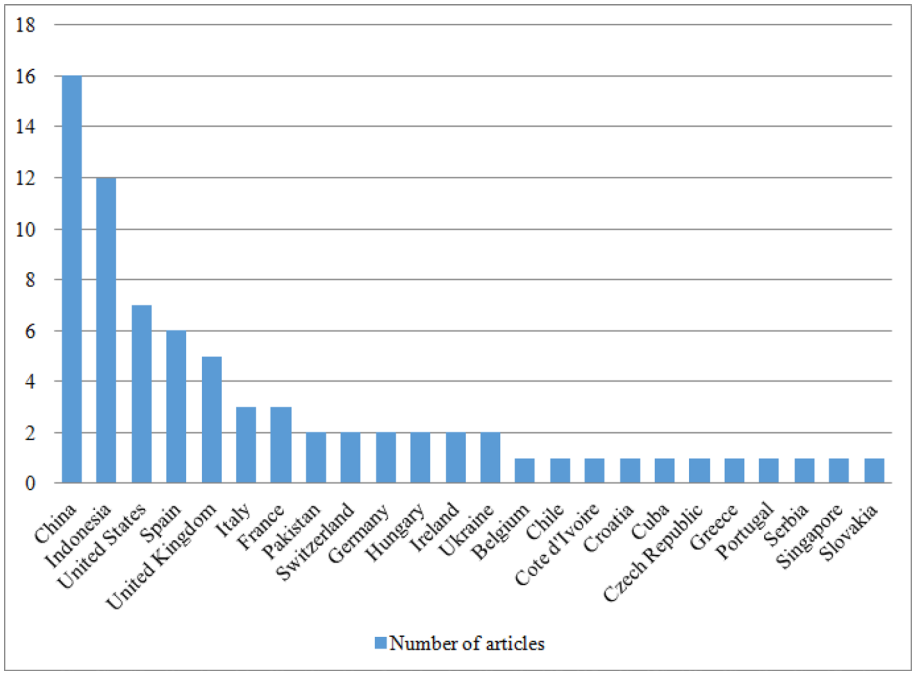


**Fig. 2** Geographical distribution of reviewed studies

that while 82% of studies employed appropriate research designs, only 45% adequately addressed potential biases. Together, these analyses provide a comprehensive foundation for identifying critical trends and persistent gaps in agri-food sustainability research.

Figure 2 confirms a strong bias toward developed regions, with Europe and North America comprising 68% of studies, while Africa and Latin America represented only 12%. This imbalance partially stems from our exclusion of region-specific studies, but more critically reflects systemic underrepresentation of developing regions in sustainability literature [28, 44].We emphasize that this geographic gap is methodologically consequential, as these underrepresented regions face the most severe sustainability challenges yet lack tailored research on multi-capital integration.

In contrast, developing regions face significant barriers such as resource constraints, lack of access to technology, and policy frameworks that may not prioritize sustainability. This results in an underrepresentation of research from these regions, despite the fact that they face some of the most pressing sustainability challenges in agri-food supply chain.

Figure 3 highlights the interdisciplinary nature of the reviewed studies, which span environmental sciences, economics, agriculture, and supply chain management. Most of the research emphasizes environmental sustainability, while fewer studies address the integration of social and financial capitals.

The focus on environmental concerns reflects the complexity of sustainability in agri-food supply chains, which extends beyond ecological issues to include economic viability and social equity. Despite their importance, financial capital encompassing investments in sustainable practices and social capital focused on community engagement and labour practices remain underexplored. The imbalance across subject areas, illustrated in Fig. 3, points to a gap in fully understanding and applying multi-capital approaches to achieve long-term resilience and sustainability in supply chains.

Publications surged post-2015 (Fig. 4), coinciding with the SDGs. However, longitudinal studies (> 5 years) were rare (8%), limiting insights into long-term capital interactions [55].

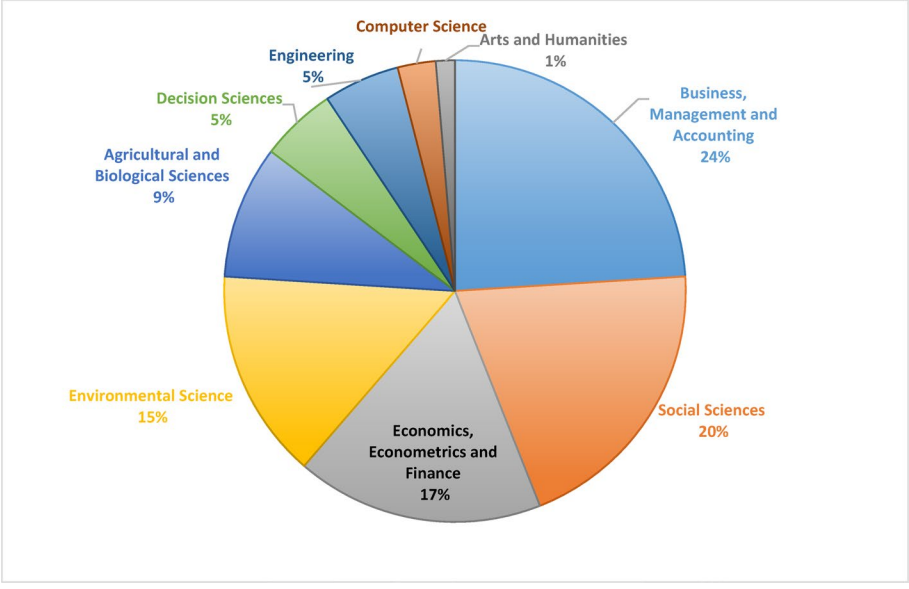


**Fig. 3** Subject area focus (environmental, economic, social, human capital)

The rise in research reflects a growing global awareness and commitment to sustainability, particularly following the adoption of the SDGs in 2015. Empirical evidence supports this trend: publications on agri-food sustainability increased by 162% post-2015 compared to the preceding decade (Web of Science data 2024), with 72% of included studies explicitly linking their frameworks to SDG targets The trend indicates that sustainability in agri-food supply chains has become an increasingly relevant topic in both academic and industry sectors. The continued growth in publications also highlights the recognition of multi-capital integration as a crucial factor in achieving sustainability goals, although the field of research is still evolving.

The growing volume of research signifies increasing global attention to sustainability. This trend is likely to continue as more organizations align with the SDGs, driving further research and practical applications in agri-food Supply chains.

The majority of documents included in this review are empirical peer-reviewed journal articles, selected for their methodological rigor and relevance to the topic. Other document types such as reviews, conference papers, book chapters, and books excluded to ensure that the study focused on high quality, data-driven research directly addressing sustainability and multi-capital approaches within agri-food supply chains. This emphasis on empirical studies highlights the practical applications of multi-capital integration in specific supply chains or regions. In addition, most studies published in specialized journals focused on sustainability, environmental science, and agri-food systems.

The concentration of research in these specialized journals reflects the emerging and niche nature of the field. Publishing in interdisciplinary or generalist journals could help expand the reach of this research, making it more accessible to policy-makers, practitioners, and researchers from other fields such as economics, social sciences, and global development. Additionally, diversifying publication venues could encourage more cross-disciplinary collaboration, which is crucial for addressing the complex sustainability challenges within agri-food supply chains.

The quality of the studies was generally high, with most meeting the methodological standards for robustness and validity. Figure 5 evaluates the quality of a research study based on various criteria, categorized into "Yes," "No," and "Unclear." The majority of the criteria, such as the appropriateness of the research design, clarity of objectives, validity

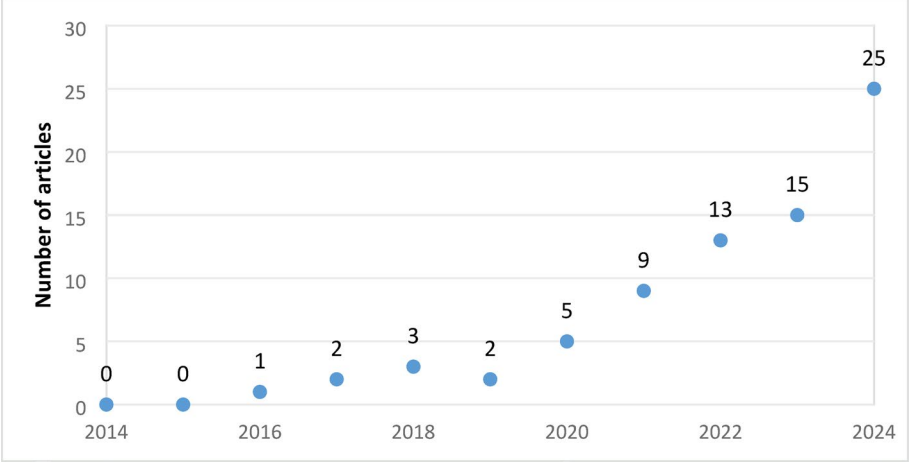


**Fig. 4** Annual publication trends (2014–2024)

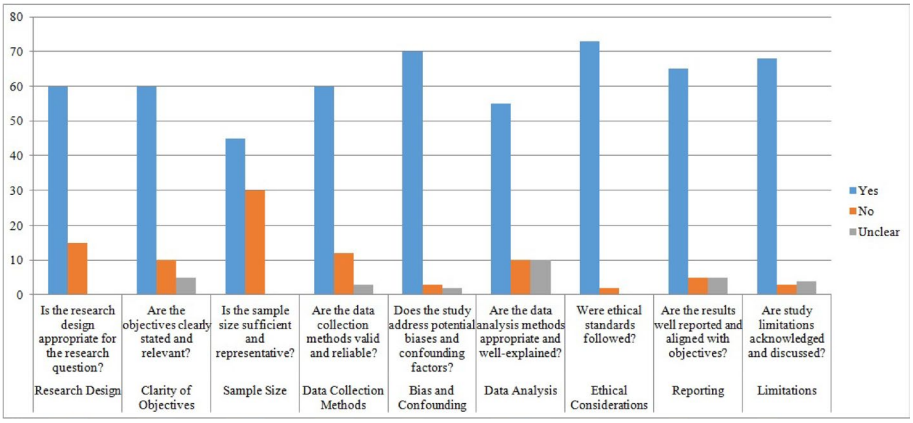


**Fig. 5** Quality Assessment of Studies

and reliability of data collection methods, and adherence to ethical standards, received "Yes" responses, indicating strong performance in these areas.

The evaluation parameters used in this review, as shown in Fig. 5, are justified by their alignment with established standards for assessing the methodological rigor and credibility of academic research. The clarity of research objectives is essential, as it enables a clear understanding of the study's aims and ensures that findings can be interpreted within an appropriate context. The appropriateness of the research design is equally critical, as it reflects whether the chosen methods—qualitative, quantitative, or mixed—are suitable for addressing the research questions, especially given the complexity of sustainability and multicapital considerations in agri-food supply chains. Validity and reliability of data collection methods are fundamental to ensuring that the data accurately represent the constructs under investigation, which is particularly important when evaluating intangible capitals such as natural, social, and human. Adherence to ethical standards reinforces the integrity of the research process and protects the rights and well-being of participants, especially when studies involve multiple stakeholders across different levels of the supply chain. Furthermore, the inclusion of criteria that assess the extent to which studies address potential bias and confounding factors is vital for safeguarding internal validity and the reliability of conclusions. A robust discussion of study limitations demonstrates transparency and allows readers to assess the scope and applicability of the findings. Finally, ensuring that the results are aligned with the stated objectives confirms that the research delivers on its intended goals and enhances the overall coherence and usefulness of the study. Collectively, these parameters provide a comprehensive framework for evaluating the methodological quality of studies and ensuring the robustness of conclusions drawn from the literature.

However, there are notable weaknesses. For example, addressing potential bias and confounding factors, as well as adequately discussing study limitations, received a mix of "No" and "Unclear" responses, suggesting gaps in these critical areas. The reporting of results, while generally aligned with objectives, also has room for improvement.

The research demonstrates a solid foundation in terms of design, ethical adherence, and methodology, but it falls short in addressing biases, confounding factors, and study limitations. To strengthen the study, more attention should be given to mitigating potential biases, thoroughly discussing limitations, and ensuring comprehensive reporting that aligns with the research objectives.

### 5.2 Integrating key capitals for sustainable agri-food supply chains

In this section, we will examine the integration of key capitals essential for sustainable agri-food supply chains. First, we discuss Natural Capital, which includes fundamental resources such as water, soil, and biodiversity. Second, we address Financial Capital, emphasizing the role of investments in infrastructure and sustainable technologies. Third, Social Capital is explored, highlighting the importance of networks, trust, and community engagement among stakeholders to foster collaboration and resilience across the supply chain. Fourth, we analyze Human Capital, focusing on the skills, knowledge, and training necessary for adopting innovative, sustainable practices within the workforce. This section illustrates how the integration of these capitals creates a holistic framework for achieving resilience and sustainability in agri-food systems, aligning with global sustainability objectives.

#### *5.2.1 Natural capital: foundation of sustainability in agri-food supply chains*

Natural capital encompasses essential resources such as water, soil, and biodiversity [4, 40], which form the basis of agri-food supply chains.

Practical applications of this approach include circular economy models, such as water recycling systems in Indonesian farms [19], which have demonstrated improved resource efficiency. However, these innovations often depend on two critical enablers: financial investments for infrastructure and comprehensive farmer training programs. Effectively managing these resources ensures the long-term sustainability of production systems while mitigating negative environmental impacts [66]. Integrating circular economy principles into production, as demonstrated by Nadaraja et al. [41], optimizes the use of natural resources like soil and water, reduces waste, and minimizes environmental harm [19] such as.

Nevertheless, significant barriers persist, particularly in developing regions. For instance, Tunisia's agricultural sector faces challenges due to fragmented land policies and limited access to advanced technologies, which collectively hinder effective natural capital management [44]. This approach to managing natural capital enhances the sustainability and profitability of supply chains by maximizing resource efficiency. However, ensuring proper management of natural capital requires collaboration across stakeholders [53]. Farmers play a crucial role in conserving water and soil [43], but often face challenges such as limited access to resources and insufficient training [33]. On the other hand, downstream actors, such as retailers, tend to focus on ethical sourcing and sustainability certifications, which can influence the entire supply chain's approach to resource conservation [57]. Understanding and aligning the different perspectives of stakeholders is critical for achieving sustainability. By promoting collaboration and shared responsibility, natural resources can be preserved and utilized more effectively, securing the future of sustainable agri-food supply chains [48].

The findings reveal that natural capital management remains foundational yet inconsistently addressed. While some regions integrate circular economy models and resource monitoring systems, many developing countries struggle due to fragmented land policies and limited access to eco-innovation. These gaps highlight the urgency of embedding ecosystem-based planning into national agricultural strategies and leveraging community-based conservation models tailored to local contexts.

#### 5.2.2 Financial capital: pillar of investment for sustainability

Financial capital is pivotal in enabling investments in infrastructure and practices that drive sustainability within agri-food supply chains. This includes critical infrastructure upgrades such as solar-powered irrigation systems in India [43], which demonstrate how targeted financial investments can enhance both economic resilience and environmental sustainability. In Central Kalimantan, Indonesia, financial investments have been instrumental in improving infrastructure, thereby enhancing both economic resilience and sustainability [37]. Capital expenditure plays a critical role in fostering local economic growth, demonstrating that access to financial capital is a key driver of sustainable development. However, significant research gaps remain, as only 18% of reviewed studies explored inclusive financing mechanisms (e.g., blockchain-based microloans) tailored for smallholder farmers [45].This oversight is particularly problematic given the crucial role smallholders play in global food systems.

Furthermore, financial capital increases the efficiency and resilience of supply chains. Investments in technologies like energy-efficient tools and climate-smart agricultural practices allow supply chains to better withstand environmental and economic disruptions [8, 20] acting financial capital, supply chains can adapt more effectively to changing market conditions, ensuring stable productivity even during periods of crisis. Moreover, the integration of multiple capitals, particularly financial and natural, further enhances the resilience of supply chains, as noted by Sinore and Wang [59], who found that combining various forms of capital mitigates the impact of environmental shocks like climate change [42]. Thus, financial capital not only meets short-term operational demands but also strengthens the supply chain's long-term resilience and flexibility, supporting sustainable operations well into the future [44].

Financial capital plays a catalytic role in driving sustainability, yet it remains unevenly distributed across supply chains. The review highlights a lack of inclusive financing mechanisms for smallholders, limiting their participation in green transitions. Future efforts should prioritize blended finance tools, public guarantees, and local banking reforms to extend investment reach to underserved producers and stimulate system-wide innovation.

#### 5.2.3 Social capital: key to collaboration and sustainability

Social capital, which includes networks, relationships, and trust among actors in agri-food supply chains, is essential for facilitating cooperation and achieving shared sustainability goals. A prime example of this is found in Ghana, where shea butter producer cooperatives successfully utilized collective bargaining strategies to access premium export markets [2]. The case of shea butter production in Ghana illustrates how social capital can foster sustainability. Collective action among shea butter producers has enabled them to pool resources, access larger markets, and operate more sustainably [2]. Strengthening social capital enhances the resilience and sustainability of supply chains by promoting collaboration among stakeholders, leading to better resource management and improved outcomes.

However, significant challenges persist in other regions, particularly in North Africa where weak farmer networks and limited institutional support have substantially reduced knowledge-sharing opportunities [28]. Social capital also supports smallholder farmers in many agri-food supply chains, who benefit from the collective bargaining

power, market access, and knowledge-sharing opportunities provided by producer organizations [60]. These collective efforts are vital for advancing sustainability initiatives and ensuring that small-scale producers have the tools and resources needed to implement sustainable practices [31] social capital grows, so does the capacity for stakeholders to manage resources efficiently, contributing to positive environmental and social outcomes across the supply chain. By fostering trust and cooperation, social capital empowers actors to work together towards a more sustainable future.

Social capital proves essential in enabling collective action and knowledge diffusion, particularly through producer networks and cooperatives. However, its effectiveness is often hindered by weak institutional support or mistrust among stakeholders. Strengthening governance mechanisms, facilitating multi-stakeholder platforms, and investing in participatory processes are key levers for unlocking the full potential of social capital.

#### *5.2.4 Human capital: driver of innovation and sustainability*

Human capital, which includes the skills, expertise [66], and knowledge of individuals within agri-food supply chains, is essential for driving innovation and adopting sustainable practices [65]. A striking example comes from Indonesia, where targeted digital training programs for micro-enterprise workers led to a 40% increase in sustainable practice adoption [53], demonstrating the transformative potential of skill development. Riptanti et al. [53] found also that micro-enterprises that invested in digital literacy and workforce training saw significant improvements in operational sustainability. Developing human capital through education and skill building is therefore crucial for encouraging the adoption of new, more sustainable practices within agri-food businesses [41].

The importance of policy support is equally critical, as evidenced by EU subsidy programs for farmer education that directly correlated with higher sustainability certification rates [7]. In regions where governments support training programs and provide access to modern technologies, the adoption of sustainable practices is notably higher [44]. Policy frameworks that prioritize human capital development by promoting education and providing essential resources—equip farmers and entrepreneurs with the skills needed to implement innovations that enhance sustainability [7]. Research shows that regions with strong policy support tend to have higher rates of sustainable practice adoption compared to areas lacking such regulatory frameworks [28]. Human capital thus becomes a cornerstone of sustainability, enabling stakeholders to drive innovation, boost productivity, and build resilience in agri-food supply chains [43]. Investing in human capital is critical for the resilience and sustainability of agri-food supply chains [2]. As the industry faces challenges such as climate change [4], technological advancements [65], and shifting consumer preferences, a well-trained and adaptable workforce becomes essential. Continuous education and skill development empower employees to implement innovative practices, optimize processes, and respond effectively to emerging trends. Without such investment, agri-food supply chains risk stagnation, limiting their ability to meet demand and potentially compromising both food security and economic stability. Therefore, prioritizing human capital development is not just beneficial it is essential for the future success of the agri-food sector.

Human capital emerges as a powerful enabler of innovation and adaptive capacity. However, the unequal distribution of training opportunities, especially in rural and marginalized regions, undermines equitable transitions. Building local training ecosystems,

integrating sustainability into agricultural curricula, and supporting extension services are vital to upskilling agri-food actors for future challenges.

### 5.3 Conceptual framework for integrating crucial capitals in the agri-food supply chain

#### *5.3.1 Development methodology*

The conceptual framework emerges from a comprehensive synthesis of 75 peer-reviewed studies published between 2014 and 2024. It was developed through a multi-step methodology designed to ensure both analytical rigor and contextual relevance. First, a systematic process was applied to identify and categorize capital-related variables like shown in Table 2.

These variables were grouped according to four principal capital domains: natural, financial, social, and human capital. This classification allowed for a granular understanding of how different forms of capital interact across diverse agri-food supply chain contexts. Second, interaction mapping was employed to uncover six recurrent capital linkages—each validated by at least three independent studies. For instance, the linkage from financial to natural capital, such as investments in sustainable land use or irrigation systems, recurs frequently in literature [7, 45].

Third, contextual validation was carried out using 12 in-depth case studies. These included localized sustainability interventions such as Hidayat's (2024) study of water recycling systems in Indonesia, which illustrates the co-dependency between natural and human capital. Such validation ensured that the framework is not only theoretically sound but also grounded in practical, real-world scenarios.

#### *5.3.2 Theoretical contributions*

The proposed framework contributes to theory by identifying and modeling dynamic synergies between multiple forms of capital. One notable example is the interaction between social and human capital, where cooperative training programs have been shown to increase the adoption rate of sustainable practices by 22–40% [2, 53]. This highlights an amplification effect, wherein joint capital investment yields disproportionately higher outcomes—an effect not captured by static, single-capital models [15].

Moreover, the framework incorporates contextual moderators that influence the effectiveness of capital integration. Policy instruments such as EU agricultural subsidies have been shown to enhance organic certification rates by a factor of 3.2 [7]. Conversely, infrastructural limitations, such as insufficient digital access, act as barriers to innovations like blockchain-based traceability systems [44]. These findings underscore the necessity of tailoring capital strategies to regional and institutional contexts.

#### *5.3.3 Implementation pathways*

The framework also identifies two primary implementation pathways for multi-capital integration in agri-food supply chains: crisis-responsive and market-driven. The crisis-responsive pathway emphasizes natural capital and its interaction with social capital, particularly in climate resilience strategies. For example, uptake of climate insurance varies dramatically based on levels of social capital—ranging from just 8% in isolated communities to 62% in networked cooperatives [13]. This suggests that social trust and organizational structure play a crucial role in the adoption of risk mitigation tools.

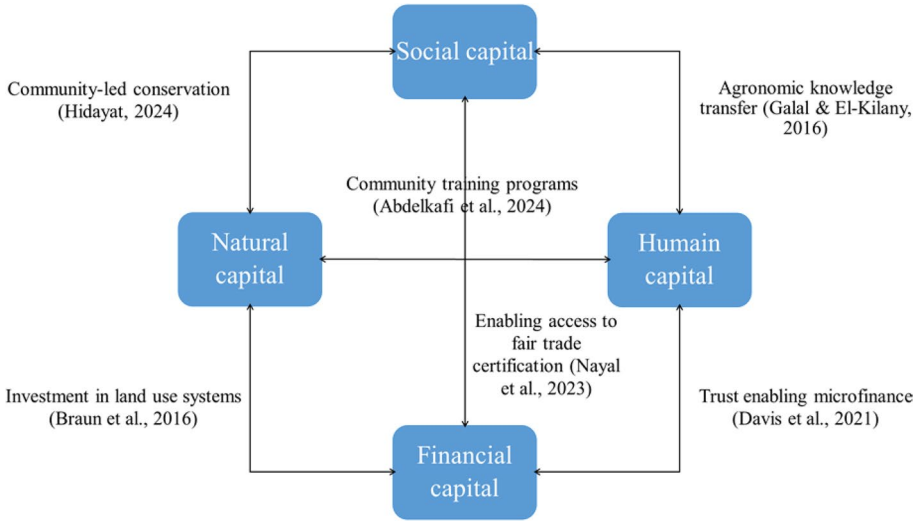


**Fig. 6** Dynamic Multi-Capital Integration Framework

In contrast, the market-driven pathway focuses on leveraging financial capital through mechanisms such as certification premiums. Premiums averaging 24% are attainable but depend heavily on the presence of aligned social networks that facilitate compliance and access [45]. This pathway reflects a synergy between financial incentives and social infrastructure, crucial for scaling sustainability initiatives.

To operationalize the multi-capital integration model, implementation must be tailored to local governance and market conditions. In low-income settings, public–private partnerships can facilitate access to financial and training capital. Digital tools (e.g., mobile platforms, blockchain) can streamline certification and traceability. Cross-capital synergies—such as training cooperatives that enhance both human and social capital—should be actively promoted. Finally, embedding capital assessment into policy impact evaluation would ensure long-term alignment with sustainability goals.

#### *5.3.4 Framework visualization*

Figure 6 provides a visual representation of the Dynamic Multi-Capital Integration Framework**.** Categories are aligned with the systematic review findings discussed in §5.1.1. The strength of each interaction is indicated by the thickness of arrows, scaled to the number of supporting studies. Case study icons offer empirical grounding, such as the Indonesian water efficiency system [19] and Ghanaian shea cooperatives [2]. Gray-shaded areas in the diagram indicate understudied intersections, which are explored further in §5.4.1 as potential research frontiers.

The Fig. 6 illustrates that sustainability in land-use systems depends on the integration of natural, social, and financial capital, rather than treating them in isolation. The circular or networked design emphasizes dynamic feedback loops—where investments in one type of capital reinforce or enable others.

## 6 Discussion

This systematic literature review offers a thorough examination of sustainability and multi-capital integration within agri-food supply chains, revealing key themes that highlight the necessity for an approach to sustainability. A crucial finding is the geographical

imbalance in sustainability research, with a predominance of studies focusing on developed regions such as Europe and North America. These areas benefit from advanced infrastructure, financial resources, and policy support, which facilitate the integration of eco-friendly practices and resilience in agricultural supply chains [13, 44]. However, developing regions, including parts of Africa, South America, and Asia, represented in the literature and face distinct challenges such as resource limitations and weaker regulatory frameworks [28, 52]. The integration of diverse forms of capital natural, financial, social, and human is essential to building sustainable agri-food supply chains. Effective management of natural capital, which includes water, soil, and biodiversity, is crucial for sustaining agricultural productivity [12, 44]. Financial capital allows for investments in sustainable infrastructure, such as efficient irrigation systems and renewable energy, to enhance resilience and reduce environmental impact [1, 28]. Social capital, encompassing trust, cooperation, and networks among stakeholders, plays a pivotal role in aligning efforts toward common sustainability goals [34, 52]. Human capital, including the skills and expertise of the workforce, is fundamental for implementing sustainable practices effectively [2, 62].

In many developing regions, limited access to training in sustainable agriculture hampers the development of human capital and exacerbates labor shortages and social inequities [28, 34, 44]. Labor-intensive tasks such as harvesting and livestock care often face workforce gaps, which undermine both productivity and sustainability. Strengthening local workforce participation, particularly in rural areas, not only addresses these gaps but also creates positive multiplier effects for local economies.

Similar challenges are observed across North Africa, Latin America, and Southeast Asia, where unclear labor regulations, limited worker protections, and fragmented stakeholder interests often prevent the full integration of vulnerable groups. Effective strategies include vocational training programs, awareness campaigns highlighting workers' contributions, and stronger legal frameworks for labor rights [2, 37]. By safeguarding workers' rights and investing in capacity building, these regions can build more reliable and sustainable agri-food supply chains.

Moreover, working with local employees brings added benefits in terms of innovation and adaptability. Local workers bring valuable knowledge and insights that can improve the agricultural sector's resilience to challenges like climate change or economic shifts. Their understanding of local conditions and needs is invaluable for making the agri-food supply chains more sustainable and flexible.

Nevertheless, several hurdles remain. Issues like unclear labor laws, lack of worker protections, and competing priorities among stakeholders could prevent the full potential of the local workforce from realized. It is crucial to address these concerns to ensure that local workers are not only given jobs but also treated fairly and supported in the end.

### 6.1 Challenges and barriers

Despite the clear benefits, there are significant challenges associated with the integration of immigrants in local agri-food supply chain. A major hurdle is the lack of coordinated stakeholder engagement. Different actors in the supply chain farmers, processors, retailers often have competing interests. Farmers may focus on the economic benefits of immigrant labor, while retailers might prioritize ethical sourcing and sustainability

certifications [58]. This gap can prevent the successful integration of immigrants and limit potential gains in terms of productivity and sustainability. To overcome this, some counties needs stronger social capital strategies that foster collaboration and mutual trust among all stakeholders, ensuring that the interests of all parties aligned towards common sustainability goals.

Furthermore, there are regulatory barriers that must be addressed to ensure the fair and equitable integration of immigrants. Current policies in some developing countries are not always conducive to the legal employment of immigrants, often lacking clear pathways to work permits and labour protections [28]. Without robust regulatory frameworks, immigrants are vulnerable to exploitation, which not only undermines their contributions to the agri-food sector but also creates social tension within communities. Addressing these gaps through regulatory reforms that provide legal protections, fair wages, and opportunities for skill development is crucial for unlocking the full potential of immigrant labour in agri-food sector [37].

To fully unlock the potential of the workforce in agri-food supply chains, it is essential to implement strategies that address both the economic and social aspects of integration. One important step is to offer vocational training programs tailored specifically to the agri-food sector. These programs will equip workers with the skills they need to enhance their productivity and improve their job prospects [2]. Beyond benefiting the supply chain's efficiency, this training will give individuals the opportunity to grow professionally and build a better future for them.

Alongside training, it is crucial to run awareness campaigns that highlight the positive contributions of workers, especially in boosting agricultural productivity and enriching cultural diversity [58]. These campaigns can play a key role in reducing prejudices and encouraging social harmony, helping people see workers as valuable members of the community. Working with non-governmental organizations (NGOs) can also provide further support, offering resources and advocacy for both workers and employers [55].

### 6.2 Limitations of the study and implications for future research

This study provides valuable insights into the application of multi-capital approaches in agri-food supply chains but also faces several limitations. One notable challenge is the geographical imbalance in the existing literature, with most research focusing on developed regions like Europe and North America. This creates a gap in understanding how these approaches might work in developing regions, which face distinct sustainability challenges [4, 44]. Another limitation is the lack of longitudinal data in many of the studies. Most offer a snapshot of sustainability practices at a particular point in time, but few explore the long-term effects, making it difficult to assess the durability and evolution of these strategies [55]. Additionally, methodological inconsistencies, such as varying sample sizes, data collection methods, and analytical techniques, complicate comparisons across studies, hindering the development of universal best practices for sustainability in agri-food systems [58]. While the use of broad database search fields yielded a relatively large initial corpus, this was an intentional methodological choice to ensure comprehensive coverage of potentially relevant studies. The application of multiple exclusion filters—such as eliminating region-specific or non-empirical articles—combined with a PRISMA-guided screening process, effectively narrowed the dataset to a high-quality

and conceptually coherent sample. This balance between inclusiveness and specificity strengthens the reliability of the findings.

A significant gap in the literature is the limited focus on social and human capital. Discussions typically prioritize financial and natural capital, while the role of social factors in promoting sustainability remains underexplored [55]. There is also the potential for publication bias, where studies with more favorable outcomes are more likely to be published, possibly leading to an overestimation of the effectiveness of multi-capital strategies [59].

Despite these limitations, the study opens several avenues for future research. More localized studies in developing regions, particularly in Africa, South America, and Southeast Asia, are necessary due to their distinct sustainability challenges and underrepresentation in current literature. For example, further research could investigate how various forms of capital interact within its agri-food context, particularly focusing on labor dynamics, regulatory constraints, and resource scarcity [67]. Second, longitudinal studies are crucial for assessing the long-term impacts of multi-capital strategies, especially in light of evolving climate risks, economic volatility, and changing social structures. Such studies can reveal whether synergies between capitals are durable or context-dependent [25]. Third, there is a need to establish standardized methodologies across studies to enhance comparability and support the development of universal frameworks for assessing sustainability performance into agri-food supply chains [7]. A particular emphasis should be placed on refining indicators for social and human capital, which remain the least consistently measured. A deeper focus on social and human capital is also increasingly important. Future research should explore how the inclusion of marginalized groups can strengthen social cohesion and economic productivity while addressing social inequities [46]. Moreover, exploring regulatory frameworks that influence multi-capital integration is essential, especially in developing regions, where different regulatory environments may either support or hinder the effective integration of various capitals [37]. Likewise, technological integration presents a promising research area, particularly as digital tools continue to reshape supply chains [60]. Investigating the role of digital technologies in supporting multi-capital integration could be valuable, especially for improving productivity and promoting social inclusion in agri-food sectors. Fourth, we propose the following structured research directions, each framed by exploratory questions and conceptual priorities:

1. Cross-capital trade-offs and synergies*: How do trade-offs and synergies between natural, human, and financial capital evolve across different agri-food supply chain typologies?* This can support more adaptive capital allocation strategies.
2. Regional adaptation strategies*: How can multi-capital frameworks be effectively tailored to diverse regional conditions, especially in developing economies?* This includes understanding the influence of local culture, institutions, and policy ecosystems.
3. Policy and regulatory frameworks*: How can legal and institutional mechanisms foster or hinder multi-capital integration in agri-food governance?* This question is particularly urgent in contexts like developing regions where regulatory gaps persist.
4. Digital and technological enablers*: What roles do digital tools (e.g., blockchain, AI, traceability systems) play in supporting the measurement and operationalization of capital flows?* This can inform investment in digital inclusion and innovation infrastructure.

5. Inclusive and equitable transitions*: How can the inclusion of marginalized or vulnerable groups enhance both social cohesion and economic resilience within capital integration strategies?* Research here can inform equity-centered sustainability practices.

Together, these directions provide a clear roadmap for future research to refine and scale multi-capital strategies, particularly in under-researched agri-food systems and global south contexts. Aligning empirical inquiry with these priorities can significantly strengthen the policy relevance, practical uptake, and theoretical advancement of multi-capital integration in sustainability science.

## 7 Conclusion

This systematic literature review has provided an overview of the current state of research on sustainability and multi-capital integration in agri-food supply chains. While notable progress has been achieved, especially in developed regions, there remain substantial gaps in both research and practical application. Geographic imbalances, limited representation of certain types of capital, and inconsistent engagement of stakeholders continue to present significant challenges.

The study shows that although both academic and industrial sectors are increasingly committed to sustainability, the absence of comprehensive theoretical frameworks and inconsistent policy supports still impede the widespread adoption of multi-capital approaches. To move forward, more region-specific research is needed, along with stronger theoretical foundations and better collaboration among stakeholders.

Integrating sustainability and multi-capital approaches is essential for ensuring the long-term resilience and efficiency of agri-food supply chains. By addressing these challenges through targeted research and policy interventions, the field can continue to make meaningful strides toward achieving global sustainability goals. Recognizing the limitations of this review opens the door for more focused future research particularly in underrepresented regions of the Global South. Countries with institutional contexts similar to Tunisia—characterized by fragmented policies, resource scarcity, and social inequities—require tailored approaches to multi-capital integration. By drawing lessons across comparable settings, this review contributes to both global debates on sustainability and locally grounded solutions for agri-food supply chains.

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**Author contributions**
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**Availability of data and material**
The datasets generated and/or analyzed during the current study are included in this article.

**Code availability**
Not applicable.

## Declarations

**Ethics approval and consent to participate**
This research used only data from industry experts and academia based on their subjective judgment; therefore, no ethical approval was required.

**Consent for publication**
Not applicable.

**Competing interests**
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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