

Review

European Digital Innovation Hubs and the Agri-Food Sector: A Scoping Review of Current Knowledge and Sectoral Gaps

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Abstract

The European Digital Innovation Hub (EDIH) network represents the EU’s first program for accelerating digital technology adoption by SMEs and public organizations. However, academic literature on EDIHs remains fragmented with notable sectoral imbalances—particularly underrepresentation of the agri-food sector. This scoping review systematically examines existing EDIH publications to identify knowledge gaps and propose a research agenda. Searches were conducted in Web of Science, Google Scholar, and MDPI databases (Jan–May 2025), complemented by snowballing techniques, identifying 84 publications categorized by methodology, interaction levels, and sectoral relevance. Results reveal uneven distribution across four EDIH interaction levels, with ecosystem-level research dominating while internal dynamics and European network-level coordination remain understudied. Only 1.7% of EDIH beneficiaries receiving services by September 2024 originate from agriculture, confirming the sector’s marginal participation. Most contributions lack empirical validation, relying on theoretical frameworks or isolated case studies with limited geographic scope. As the first comprehensive review addressing EDIHs in agri-food contexts, this study provides timely insights at the end of the first EDIH implementation cycle and outlines priorities for future research to support equitable and evidence-based digital transformation.



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1. Introduction

At the global level, the penetration of digitalization across all economic sectors is driving significant increases in competitiveness, efficiency, and productivity, which in turn intensifies the global race among economies to digitalize as rapidly as possible. In this context of the urgent need to accelerate the digital transformation of the European economy, the European Commission (EC), through the Directorate-General for Communications Networks, Content and Technology (DG CNNECT), launched the first Digital Europe Programme (DEP) for the 2021–2027 programming period. One of the five strategic priorities of this programme is to support the digital transformation of European economies and societies—alongside their key economic sectors—through the establishment of a European Network of Digital Innovation Hubs (ENDIHs).

The agri-food sector in Europe (encompassing agriculture, food processing, distribution, and retail) is a major pillar of the EU economy, generating significant value added and export revenues. Although primary agriculture accounts for only ~3–5% of the EU

workforce, the broader agri-food value chain supports many more jobs beyond the farm gate (up to 15% of the total workforce) (see Table 1 below). While the services sector employs the largest share of the EU workforce, the agri-food sector's strategic importance is disproportionately high—due to its role in food security, rural vitality, and sustainable development [1,2].

Table 1. The European agri-food sector (number of firms, number of employees expressed in millions of euros and as a percentage of total EU employees [197.6 million, 2024], and value added per stage of the value chain, expressed in EUR) [3].

	Agriculture	Processing of Agri-Food Products and Beverages	Marketing of Agri-Food Products and Beverages (Wholesale and Retail)	Food and Beverage Service Activities
No. of companies (mil)	9.1	0.3	1.1	1.6
Employees	8.7 mil (~4.4%)	4.7 mil (~2.3%)	8.5 mil (~4.3%)	8.4 mil (~4.2%)
Value Added (billions of euros)	218.1	265.9	326.5	180.7

From the outset, DG CNNECT emphasized the importance of ensuring a critical mass of EDIHs dedicated to supporting the digitalization of the agri-food sector. The initial call for proposals explicitly required that at least one EDIH per MS be specialized in this domain.

Following the first two calls for proposals launched between 2021 and 2022—coordinated jointly by the MS and DG CNNECT—a total of 168 EDIHs were selected across the EU 27 and DEP Associated Countries to collaborate in achieving this objective. These hubs receive 50% of their funding from the DEP and 50% from the respective national governments. In addition to these, another 86 hubs were accepted into the network on the basis of the Seal of Excellence, which recognized their high-quality proposals, but are fully financed at the national level. Thus, as of May 2025, the ENDIH comprised 254 EDIHs, operating for an initial period of three years, with most scheduled to conclude activities by early 2026—after which new calls for continuation will be launched.

According to the official EDIH catalog (January 2025), there are 93 EDIHs across Europe that serve the agri-food sector, representing approximately 36% of all EDIHs active during the 2023–2025 period. However, only 12 of these hubs (roughly 5%) are exclusively dedicated to the agri-food sector, while the remaining 81 operate in multiple economic sectors, including agri-food.

Despite the sector's recognized strategic importance, intermediary implementation data (up until the 20 of September 2024), provided by the Joint Research Centre (JRC) based on data from the compulsory Digital Maturity Assessment (DMA) audits that SMEs fill in in order to measure their progress on the digitalization scale [4], reveal that the agricultural sub-segment of the agri-food sector remains underrepresented among EDIH beneficiaries. Specifically, only 1.7% of all EDIH service beneficiaries at the time came from agriculture (NACE codes 01), while just 1% originated from the restaurant and food service industries (NACE codes 55 and 56) (See Figure 1 below). Furthermore, beneficiaries from the agricultural segment had the lowest digital maturity level out of all the economic sectors. While no disaggregated data is available regarding SMEs from the manufacturing of food products (NACE code 10), which fall under the Manufacturing sector (with the highest percentage of beneficiary SMEs receiving EDIH services, 28%), these interim results from the first implementation cycle of the EDIH program suggest a tangible risk that

the overall agri-food sector may fall behind in leveraging digitalization as a driver for enhanced competitiveness.

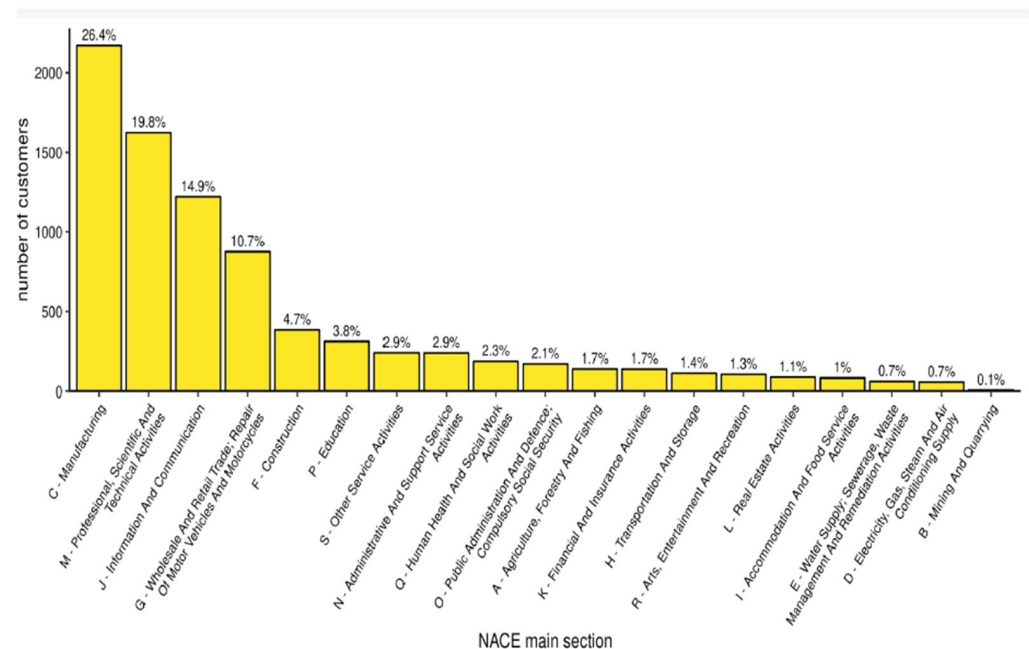


Figure 1. Number of beneficiaries per economic sector—taken from Carpentier et al. [4], with permission for re-use granted by a Creative Commons Attribution 4.0 International (CC BY 4.0) license (<https://creativecommons.org/licenses/by/4.0/>).

Furthermore, despite the breadth of ENDIH and the ambitions of the DEP, the academic literature on the topic remains relatively limited. The thorough bibliographic review conducted through the current paper by mid-2025 identified just around 84 academic articles, scientific communications, and reports published on EDIHs to date.

It is also apparent that existing literature on EDIHs originates primarily from the fields of manufacturing and production, frequently referring to case studies involving EDIHs operating in robotics or Industry 4.0. According to Serrano-Ruiz et al. [5], this reflects real structural imbalances within the ENDIH, notably the visible underrepresentation of the agri-food sector, with certain industries being significantly more advanced in their digital transformation than others.

1.1. Short History of the Development of the ENDIH

The EDIHs have evolved as a concept over the last two programming periods of the European Commission, developing from a simple idea within the strategic documents presented in 2015 to a large ENDIH operating in around 60% of EU regions in 2025, with the help of several European programs [6].

The premises of the DIH concept were set by the EC, in the context of the Digital Single Market strategy, which was launched in 2015, within the programming period 2014–2021. Moreover, during the period 2014–2020, the EC invested EUR 500 million in projects under the Horizon 2020 program dedicated to the development of DIHs. These investments helped to develop the concept through pilot projects of DIH services together with beneficiaries through “cascade funding”, mentoring between DIHs of different maturity, the development of thematic networks, and the publication of the first scientific articles on the subject.

In 2017, at the Open Innovation 2.0 Conference organized by the European Commission, DG CNECT in Cluj-Napoca, Romania, the initial plans for the creation and

development of an ENDIH were presented. In the summer of the same year, two processes were launched by the European Commission to identify potential DIHs: one “bottom-up” through the Futurium project, and the other “top-down” by contracting a consulting firm to undertake desk research. Thus, in the fall of 2017, simultaneously with the launch of the first JRC report on the DIH concept, the first version of the JRC catalog of DIHs was published. Although data from that version of the catalog is no longer available, Gavkalova [7] mentions that an investigation of the S3 platform in 2022 revealed 656 DIHs, of which 572 were fully operational or in preparation. DIHs at this stage were meta-organizations (mere associations of partners) conducting pilot projects or voluntary work aligned with the overall concept.

In the 2021–2027 programming period, DIHs became a public policy instrument, and the development of an ENDIH became a key priority of DEP—the first program exclusively dedicated to digitalization developed by the EC. Thus, in 2020, the first calls for selection of DIHs for the ENDIH were organized at the level of the MS. Then, in January 2021, the first concept paper offered by the DG CNECT of the EC on EDIHs was published (but in draft format). It provides the best descriptions to date of the main concrete elements that define the work of the EDIHs. The final version of the funding guide and the strategic documents of DEP (2021–2027), published with the launch of the second round of EDIH selection in November 2021, provides clarifications on the conditions for accessing European funding. The results of the first two rounds of selection of the DIHs that would be part of ENDIH were announced in June 2022, and the first round of 254 EDIH projects was approved for a period of 3 years up until the beginning of 2026. After this first implementation period, consortia can reapply through another round of calls for a second implementation period of 3 years. Support for the ENDIH and its networking and capacity-building activities is provided by the Digital Transformation Accelerator (DTA).

Overall, the concept of a DIH has evolved over the past two programming periods, but around the same concept of a one-stop-shop hub supporting the digital transformation of SMEs across Europe with four main categories of services (Test before Invest, Access to Finance, Access to Skills, and Innovation Ecosystem Support). DIHs have been conceived to have a strong territorial component, responding to regional needs, but at the same time, they were envisaged to also collaborate at a European level in various forms (through service exchange, mentoring, networking, corridors, and other mechanisms). While in the first programming period, when many informal DIHs were created and participated in service piloting and other support activities, the concept was more fluid and still open to experimentation (for example, leaving room for discussion about other services than the core four services presented above), with the second programming period and the coining of the term EDIH, the concept becomes more formal, depicting a DIH that has passed the evaluation process of the EC, follows EC rules, and is now part of the select ENDIH network actually implementing the program mission.

In spite of these distinctions, many actors to date still use the terms DIH and EDIH interchangeably, even when referring to EDIHs. For the purposes of the current review, the authors will generally refer to EDIHs, as these reflect the current situation, but within the literature review, the term used within each of the academic works cited will be used to maintain consistency with the original work.

1.2. Research Aim and Contribution to the Literature

In a context marked by a limited number of publications on the topic of EDIHs, a clear underrepresentation of the literature focused on the agri-food sector, as well as preliminary data indicating that beneficiaries from the agri-food sector are similarly underrepresented among those who have accessed EDIH services by autumn 2024, this study aims to produce

a thorough scoping review of all existing publications related to EDIHs and the agri-food sector, with the objective of mapping existing gaps in the literature and proposing a research agenda to address them.

This study brings novelty to the field, as there is currently no thorough review of publications focused on EDIHs operating in the agri-food sector within the framework of the European Commission's most important digitalization program. Moreover, a deeper understanding of the existing knowledge and gaps in the implementation of this program in the agri-food sector may contribute to improving its effectiveness and, ultimately, to achieving its ambition of increasing the adoption of digital technologies across all economic sectors [8,9].

Finally, this article aims to provide timely insights at a pivotal moment—coinciding with the conclusion of the initial three-year cycle of the first cohort of EDIHs. By offering a structured overview of the current state of knowledge, it supports researchers and policy-makers in more closely tracking the implementation of the program and in formulating evidence-based recommendations for its continuous improvement in future phases.

2. Materials and Methods

A qualitative bibliographic research method was selected over a bibliometric approach due to the emergent nature of the research topic of EDIHs, which has only recently begun to gain academic attention, with publications dating back to 2018 and around 84 publications available as of mid-May 2025. Furthermore, this method presents several advantages: it allows for the development of new conceptual frameworks, enables in-depth analysis of the research questions, and supports the nuanced examination of related sub-concepts. Furthermore, although this review followed systematic search and screening procedures, its scope and objectives align more closely with the *scoping review* methodology, as it aims to map the breadth of available knowledge on EDIHs and identify research gaps rather than evaluate intervention effects [10].

2.1. Study Selection

The PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) Extension Protocol for Scoping Reviews [11] was used retroactively to provide more clarity and structure on the work conducted. The complementary checklist is available in Supplementary Material. A review protocol was created and registered with the Protocols.io (<https://www.protocols.io/view/european-digital-innovation-hubs-and-the-agri-food-5jyl88xq8l2w> (accessed on 10 October 2025)). Please see the PRISMA-ScR diagrams in Appendix C for article counts per database and literature review phase. These reflect, by and large, the proportional contribution of each database, but may be prone to a degree of error due to the reconstruction of the distribution of articles per database in October 2025 using the same keywords and filters. In spite of maintaining rigor, the exact count may differ upon a re-run of the search (especially with Google Scholar), as search engines might render different results due to other technical factors (e.g., Cookies).

The four distinct stages accurately describe the thorough process employed in order to thoroughly investigate all literature relevant to the research questions (to identify both agricultural and non-agricultural EDIH knowledge).

Phase 1: Identification. The scoping review was conducted in parallel across several interconnected academic databases (information sources), following a consistent methodology. Searches were conducted in the period of January–May 2025 across the MDPI database, the Web of Science indexing database, and the Google Scholar search engine. In a few isolated cases, the full text of the articles was obtained from the researchers' profiles on Research Gate. The search terms were chosen broadly yet clearly, in order to enable producing

a thorough scoping review of all existing publications related to EDIHs and the agri-food sector. The Boolean strings used were “DIGITAL INNOVATION HUB” or “DIGITAL INNOVATION HUB”, AND “AGRICULTURE”. These were applied in stages for each database, in order to identify both the agri-food and non-agri-food literature related to EDIHs. First, the title and abstracts of works were scanned for the relevant keywords, and when the keywords were identified, the full article was downloaded and read as well if it was available.

In spite of institutional constraints regarding access to other databases, the process was complemented by a snowballing technique, implying both forward and backward citation tracking on all included studies, with saturation-based stopping in order to provide assurance of comprehensive coverage in spite of our institutional constraints. This systematically identified additional sources across multiple databases and repositories, including papers indexed in Scopus and IEEE Xplore that were cited in or citing our initial results.

Phase 2: Screening: The eligibility criteria employed were chosen broadly, in order to enable producing a thorough scoping review of all existing publications related to EDIHs and the agri-food sector. Publications addressing the DIH and EDIH concepts—whether explicitly referenced in abstracts or substantively developed within the body of the work—were included, employing the European Commission’s definitions established since the term’s introduction in 2015. Publications mentioning the DIH concept in the title but with abstract content that referred exclusively to other topics and where topic relevance could not be verified through a full-text article were not included. Most types of published academic works were included within the scope of the study (meaning academic articles, conference papers, book chapters, and Ph.D. theses—see Appendix A), with the exception of master theses, letters, conference presentations, working papers, and editorials. Other non-academic but official data sources included were reports of the EC’s JRC on EDIHs, as these included case studies, theoretical frameworks for EDIHs, notes of enabling conditions, and implementation data that were offered as examples of good practices by EC officials and provided additional insights relevant to the scope of the review. No other reports were included within the scope of the study. At times, DOI numbers were not available; therefore, website links were provided when possible.

Phase 3: Eligibility: Published works referring to “digital innovation hubs” from regions other than the European Union were excluded from the research (e.g., digital innovation hubs from South Africa, Africa, New Zealand, Latin America, Asia, etc.). Although the EC launched or is intending to launch some calls for EDIHs in other Associated Countries of the DEP (e.g., Moldova, Balkans, Ukraine), the few publications identified on these topics were not considered as part of the study as the conditions for those calls differed. Furthermore, even within the European context, publications about any other type of innovation or digital hubs, clusters, associations, or groups other than the DIHs supported by the EC through all its programs (DEP, Horizon 2020, or in one instance even Interreg) were excluded from the current study. It is noteworthy to mention that publications dealing with digital innovation in the context of the Smart Villages concept were not included, even if similar in goal to EDIHs. Articles on other topics that only mentioned the EDIHs in very isolated instances (as one of many examples within broader literature research on another topic or as references) were also excluded. No limitations were placed on the disciplines of the selected articles, and no exclusion criteria were formulated for the research quality of the papers.

Phase 4: Inclusion: As a result of this process, 84 papers met the criteria for inclusion in the final selection of articles for both abstract and in-depth analysis. These included publications explicitly referring to the concepts of DIH or EDIH (as defined by the EC since 2015) in the title, abstract, or main text, published in peer-reviewed journals, conference

papers, book chapters, and doctoral theses, as well as reports on the topic published by the JRC. No restrictions were applied regarding disciplinary field, methodological approach, or publication year.

2.2. Data Extraction

Full texts were downloaded when available, while abstracts were used for non-open access articles in the analysis. A total of 84 academic papers were collected during this stage and processed by the leading authors in the period between mid-May 2025 and the end of August 2025. A full master list of all sources included in the synthesis, including publication year, authors, source type, and sectoral relevance, is provided in Appendix A (Table A1). This list ensures traceability of the literature base underpinning the synthesis. For referencing, Zotero was used.

For coding, a table was created including all the works, including data such as title, authors, publishing year and type of academic work, and abstract of the paper,

Data were extracted into a table and charted according to the main analytical themes identified in literature author, year, level of EDIH interaction (according to Serrano-Ruiz [5] framework), method, sector, and main topic (see below more details). Due to the exploratory nature of the review, the charting process focused on identifying major conceptual and methodological trends rather than exhaustive quantitative coding. Information was summarized narratively across major themes (e.g., governance, funding, digital maturity) (see Appendix C—Table A6). Below a detailed account of the coding process followed:

- **Chronologically organized** in order to assess alignment between their publication date and key stages in the development of EDIHs. Articles from the period 2018–2023 when DIHs were developed through the Horizon research and innovation program, when the concept and EDIH approaches were piloted, and methodologies for EDIH development and services were discussed for their contributions to the testing of theories, frameworks, methodologies, ontologies, and case studies, with the note that conclusions were often conceptual, optimistic, lacking extensive empirical grounding and needing revalidation (see Section 4). However, empirical articles based on the S3P database of DIHs and surveys of DIHs existing at the time were marked as outdated, as they relied on the original DIH concepts and flexibility in terms of service definitions, dating back to a period before the first official DEP financing call when many more DIHs existed and did not necessarily respect the rigors set by the EDIH financing calls. Articles published between 2024 and 2025 were considered most relevant in terms of their empirical results, as they coincided with the first implementation phase of the EDIH initiative and could draw on Digital Europe Programme implementation results.
- **Categorized and coded** based on their methodological orientation (e.g., methodological contributions, formal instruments and ontologies, case studies, large-scale surveys or empirical studies, and policy analyses), their sources (whether they were clearly produced as part of a Horizon 2020 or Horizon Europe project) and the levels of interaction of the EDIH that represented the scope of their empirical analysis, following a categorization taken from Serrano-Ruiz et al. [5] (e.g., internal EDIH level, EDIH ecosystem, supra-national, or pan-European ecosystems) in order to enable a more structured discussion (see Appendix B—Coding Manual). When the information provided in the abstract was not sufficient to extract clearer conclusions about the results or methods used, the full article was analyzed. This was, however, not possible for all identified articles (see published works in *italics* from Appendix A).
- **Filtered by sectoral relevance**, such that studies focusing on technical or sector-specific aspects of EDIH implementation within the manufacturing sector were briefly discussed, particularly regarding cross-sectoral insights that could be applicable to

EDIHs as a whole or even to the agri-food domain, and articles related to EDIHs and the agri-food sector were coded and analyzed separately.

After Section 3 on results was finalized, Artificial Intelligence Large Language Model (LLM) Claude Sonnet 4.0 was used for summarizing the main results in the Section 4, with the exception of Section 4.3, a discussion regarding the main themes of the agri-food literature, which was written entirely by the researcher. This was done in order to aid in extracting the main emerging patterns from the large body of results and in order to summarize the research agenda presented in Section 4 based on the research gaps identified. Details of the prompting strategy used, as well as an appraisal of the approach's strengths and weaknesses, are presented in detail in Appendix D.

In spite of the general tendency of LLMs to sometimes conflate similar themes and oversimplify nuanced distinctions, the high-quality results, indicated by the sharp discussion sections that resulted, show that LLMs such as Claude Sonnet 4.0 can serve as safe and useful tools for synthesizing extensive results from literature reviews, particularly when the underlying data has been carefully coded and organized by the researcher. LLMs excel at identifying patterns, generating thematic summaries, and drawing cross-cutting conclusions from structured qualitative data without introducing novel interpretations beyond what the source material contains. When these verification procedures are systematically applied, LLM-assisted synthesis becomes a transparent and auditable component of the analytical process, enhancing efficiency while maintaining research rigor and integrity.

3. Results

Despite the scale of the European EDIH network and the ambitions of DEP, the academic literature contains relatively few contributions dedicated to the study of EDIHs, but with perspectives for future development, as 2024 marked the year with the greatest number of publications to date (see Figure 2 below). This gap has also been noted by Serrano-Ruiz et al. [5], who conducted the most extensive bibliographic study to date on this topic. Their analysis reveals that a search in the Scopus database identified only 17 relevant articles published between 2018 and 2022.

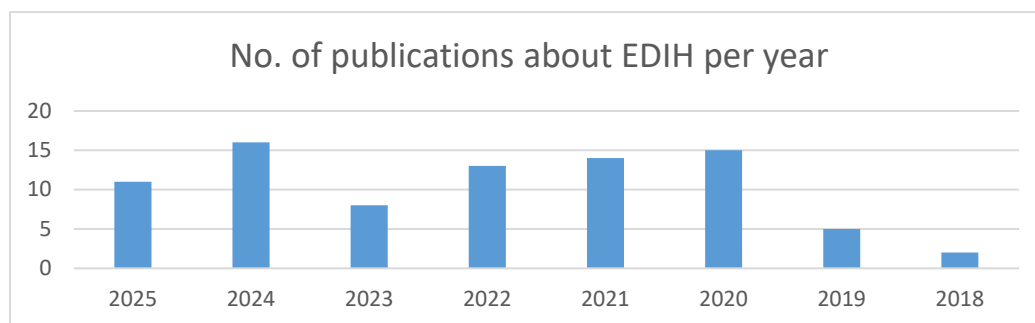


Figure 2. Publication timelines—No. of publications about EDIH (author's own elaboration based on identified literature).

At a general level, the academic literature on EDIHs is rapidly evolving, with a thematically diverse structure and the potential for transversal applicability of research conclusions across multiple sectors. The articles published to date provide a useful foundation for further research and can be broadly categorized into four main types: methodological contributions, conceptual framework development, case studies, and policy analyses. Among these, case studies are by far the most frequent, often closely linked to the development of theoretical and conceptual understandings of the different levels at which EDIHs operate and collaborate.

In this regard, the work of Serrano-Ruiz et al. [5] offers the most comprehensive synthesis of academic contributions related to collaboration among DIHs. Their study presents a concise and structured overview of four distinct levels of interaction within the relational network of DIHs as developed within the geographic context of the European Union (see Figure 3 below):

1. The **DIH level**, which refers to the internal dynamics among consortium members of a single DIH, who typically collaborate at the regional level;
2. The **DIH ecosystem level**, which encompasses external actors interacting with the hub at the regional scale—namely, beneficiaries, technology providers, and other stakeholders active in innovation, knowledge, and technology ecosystems;
3. The **EDIH level**, which includes sets of DIHs engaged in European networking or service-exchange activities, enabling inter-hub collaboration across broader ecosystems that extend beyond national borders (e.g., thematic EU EDIH ecosystems or involving several MSs);
4. The **EDIH network level (ENDI)**, comprising the entire network and facilitating interactions among multiple informal groups of EDIHs, while also representing their collective interests in administrative and societal spheres.

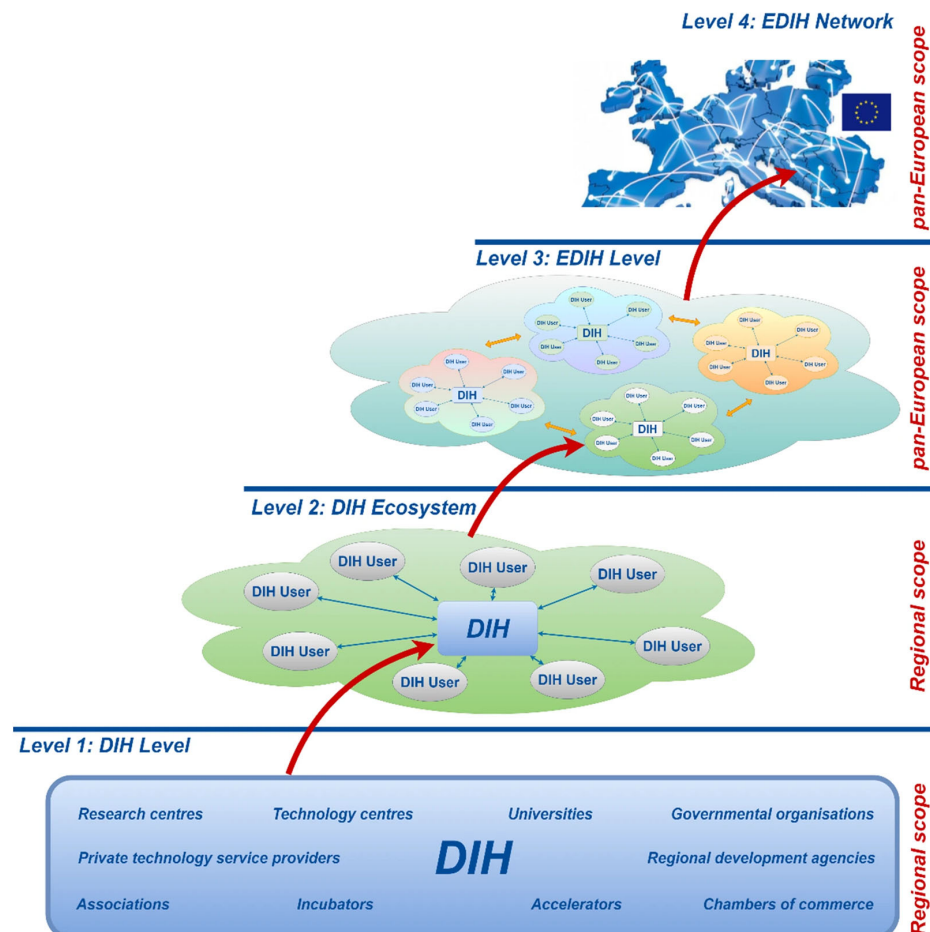


Figure 3. Relationship levels within the pan-European space of DIHs action—taken from Serrano-Ruiz [5], used with permission from the authors. Available online <https://link.springer.com/article/10.1007/s10845-024-02322-5/figures/1> (accessed on 1 September 2025).

Interactions across this multi-level network are shaped by a wide array of factors, including the interests, strategies, and willingness of actors to engage in collaboration, as well as institutional variables such as funding availability, relevant legislation, and

governmental or administrative support influencing the implementation of the Digital Europe Programme.

Although the framework of Serrano-Ruiz et al. [5] builds a complex conceptual framework grounded the levels described above, which is in turn further supported by the Data-based Business–Ecosystem–Skills–Technology (D-BEST) model introduced by Sassanelli and Terzi [12] (developed through the Horizon 2020 project HUBCAP; see Section 3.1.3 below), which is the most fully developed and most cited frameworks for understanding EDIH cooperation, the current scoping review will not be using any other elements of the mentioned conceptual models. For the purposes of the present bibliographic study, we will apply the four levels of interaction synthesized by Serrano-Ruiz et al. [5] as an analytical framework to assess the level at which each academic contribution to the EDIH literature is situated, as well as to explore the thematic focus and limitations of the existing body of research. To operationalize the four-level conceptual framework from Serrano-Ruiz et al. [5], we developed explicit coding rules defining objective criteria for assigning each source (Appendix B).

The following literature review is divided into two parts—the first reviews articles regarding sectors other than agriculture, while the second reviews those about agriculture.

3.1. Literature Review of Papers Not Related to Agri-Food

3.1.1. The DIH Level (Internal)

Research on EDIH internal dynamics remains limited, addressing methodological frameworks, organizational structures, and collaborative mechanisms. The foundational work by Kalpaka et al. [13] offers the most comprehensive internal guidance, outlining a seven-step DIH development methodology that spans regional needs assessment, business model design, partnerships, and impact evaluation. This JRC report serves as an operational blueprint, emphasizing the importance of understanding local contexts and regional assets before establishing DIH structures.

A significant share of research originates from Georgescu’s contributions, which explore associative and organizational dimensions of DIHs [14]. Their bibliographic analysis [15] identified a persistent gap in the literature concerning digital ecosystems and innovation hubs, while a subsequent multivariate empirical study [16] revealed an underrepresentation of marketing services within DIH portfolios based on S3P data. Georgescu and Avasilcai [17] provide updated insights into Romanian EDIH structures and actor relationships, highlighting national-level coordination challenges. Complementary perspectives include Hadjimitsis et al. [18], who describe the development of the EcoE DIH in Cyprus as an extension of a regional center of excellence, leveraging existing capacities to establish a world-class hub across five application areas. Maurer [19] contributes an ontology of innovation actors from Vorarlberg, Austria, illustrating DIHs as service systems that co-create value among consortium partners, though this study predates the current EDIH network. Olszewski and Pawlewski [20] offer a critical analysis of the advantages and drawbacks of positioning research entities at the core of DIH ecosystems and the need for transversal stakeholder involvement in R&D projects.

Regarding open innovation and co-creation strategies, Sotirofski and Kraja [21] discuss the positive effects of EDIHs on business and marketing collaboration, an idea echoed by Georgescu et al. [22] and Maurer [18]. Jovanovic et al. [23] present ten healthcare robotics case studies developed through the DIH-HERO project’s COVID-19 response, demonstrating the flexibility of DIH service portfolios. Recent examples include Myllymäki and Hakala [24] on the activities of Robocoast EDIH, and Sassanelli et al. [25] on Ce-DIH’s innovation ecosystem, which applies a systemic, circular-economy perspective to digitalization through diverse consortium competences.

Collectively, these works emphasize three recurring themes: the need for methodological guidance in EDIH establishment, the centrality of associative structures for digital transformation, and the underexplored potential of collaborative and marketing-oriented services.

3.1.2. The DIH Ecosystem Level (External)

This is the most studied level of interaction of EDIHs, with the most articles, perhaps because the regional ecosystem represents the fundamental operating embedding of EDIHs. Research on EDIH ecosystem development reveals several interconnected streams that manifest at a regional level: ecosystem design principles, beneficiary analysis, theoretical models, ontologies and practice-led methodologies, sustainability factors, policy environment, and an EDIH's role as knowledge broker and intermediary.

For ecosystem building and understanding, Doyle and Cosgrove [26] study the interaction of an SME with a DIH by looking at the introduction of a digital technology by the manufacturing SME through an EU experiment. Lanz et al. [27,28] offer sector-specific perspectives through their TRINITY project analysis in robotics, demonstrating practical ecosystem-building approaches within specialized technological domains. Vakirayi and Belle [29] explore DIHs in various socio-economic contexts and spark a debate about ways of measuring their actual impact on their ecosystem.

Beneficiary-focused research represents a particularly active area, reflecting practitioners' recognition that understanding user needs is critical for EDIH success. The following studies, emerging primarily during the first EDIH implementation period (2023–2025), provide comprehensive insights across multiple dimensions. Haukipuro et al. [30] provide foundational insights through Finnish case studies that identify good practices for research and innovation hub development within the regional ecosystem. Ogorean et al. [31] deliver the most detailed cross-sectoral analysis, examining Romanian SMEs and public organizations to reveal how sector-specific characteristics create diverse digitalization challenges, from internal resistance to fragmented implementation efforts. Meanwhile, Khan et al. [32] and Khanelloupoulou et al. [33] focus specifically on AI adoption maturity, with Finnish and Greek case studies, respectively, showing that most SMEs remain in early adoption stages, struggling with technical knowledge gaps and strategic development challenges. The multi-country perspective provided by Tanhua et al. [34] broadens this understanding, surveying six EU countries to confirm that digitalization is progressing, though unevenly, with only 20–26% of companies achieving “analytics as business vision” status. Overall, we note diversity in the scale, geographical areas, types of ecosystems, and beneficiary profiles captured by each article, ranging from collaboration processes, to needs and composition of the ecosystem, to the level of digital maturity and barriers to adopting specific technologies.

Specific service and sector methodologies, formal tools and ontologies, and practitioner methodological contributions constitute the dominant category of articles, developed through both Horizon 2020 project case studies during EDIH preparation phases and practical implementation within operating EDIHs.

Sector-specific approaches and service-specific tools also feature prominently, with Cotrino et al. [35] developing a manufacturing-focused Industry 4.0 platform featuring four integrated modules (hub, strategy, community, and collaboration) for SME technology transfer. In contrast, the work of Sarippa et al. [36] stands out as the only contribution addressing EDIH service delivery specifically, proposing a flexible learning framework for skills development and technology transfer that acknowledges the notorious digital skills deficit in agri-food and other sectors. Nazarenko et al. [37] showcase a brief case study of a DIH that developed three comprehensive AI training programs for industry growth. In terms of service benchmarking approaches, Rudawska [38] conducts a bench-

marking of the services of a DIH case study (DIH4Industry) in order to assess whether these meet the one-stop-shop model, while Babo et al. [39] conduct a benchmarking of several tools for measuring the digital maturity of companies, including the DMA service of the EDIHs. Recent developments include Carolis et al.'s [40] DREAMY model for multidimensional digital maturity assessment, representing an evolution toward more sophisticated evaluation frameworks.

The formal tools and ontological development literature focuses on standardization and interoperability frameworks for EDIH networks. The DIH4CPS project anchors this theoretical stream, with Semerano et al. [41] developing ontological models for measuring EDIH and partner network maturity levels, emphasizing collaboration as the fundamental success factor. Feltus et al. [42] advance this approach through multidimensional models that integrate networks, skills, and partnerships, providing standardization foundations for knowledge management and enabling interoperability across the broader EDIH ecosystem.

Practitioner methodological contributions emerge from operational EDIHs documenting real-world implementation experiences and methodologies. The Greek ahead DIH leads this empirical stream through Khanelloupoulou et al.'s [43] comprehensive work, presenting the “APSS” methodology (Awareness, Piloting, Scaling, Sustainability) as a practical four-phase framework for AI-driven organizational transformations, while listing key success factors for the sustainability of AI adoption, mentioning that Smart Attica EDIH's methodologies were adopted by the Greek government itself [44]. Rajkovic [45] contributes marine sector perspectives from InnovaMare EDIH, identifying cross-sectoral collaboration within an innovation ecosystem as essential for sustainable ecosystem development. Gaiani and Ala-Karvia [46] provide a Finnish perspective through their analysis of the Arctic Development Environments Cluster, though their findings remain limited to ecosystem animation efforts without concrete measurable outcomes.

The conceptualization of EDIHs as “knowledge brokers” represents a significant theoretical advancement in understanding their role beyond mere technical facilitation. Crupi et al. [47] pioneered this perspective through empirical research with Italian DIHs, demonstrating that these organizations not only disseminate existing digital transformation knowledge but also actively generate new insights through their intermediary activities. Zamiri et al. [48] complement this understanding by examining how dynamic research and collaboration networks enhance knowledge creation and management, highlighting the specific contributions of living labs and DIHs in establishing new research domains and project initiatives. A further study by Zamiri et al. [49] proposes DIHs as enhancers of mass collaborative learning communities through their services and facilities, based on a study of four EU projects. Marinelli et al. [50] conduct an exploratory research design and action research methodology in order to uncover the dimensions of a regional knowledge ecosystem guided by a DIH supporting SMEs towards the adoption of the “Digital Artisan platform” deriving from an Industry 4.0 project.

The intermediation function receives more sophisticated treatment in recent contributions. Jurčić and Strahonja [51] advance the field by modeling EDIHs as strategic value delivery intermediaries between research and industry, based on an earlier conceptual analysis of DIHs as value delivery systems [52], emphasizing how contextual factors including public policies, geographic proximity, and regional digitalization levels influence their effectiveness. Their value delivery system concept positions EDIHs as strategic regional innovation actors rather than passive technical facilitators. Lepore et al. [53] validate the finding that DIHs are innovation intermediaries and apply this lens to the development of inclusive smart city ecosystems by conducting desk research on 48 DIHs specialized in this topic. The paper suggests a framework for boosting their functions as transformation leaders, knowledge brokers, and technical mediators to facilitate the use of

Industry 4.0 technologies for building inclusive smart cities. Through a multiple-case-study approach, research by Spiegarelli et al. [54] investigates how innovation intermediaries such as DIHs are able to unlock the collaborative potential of blockchain technologies for SMEs so as to enhance their environmental sustainability. The authors also propose a roadmap aimed at improving collaboration within a DIH's ecosystem, one outlining three essential functions: enabling, core, and facilitating effective partnerships and innovation processes. Colovic et al. [55] provide a comprehensive analysis through their study of 18 French digital innovation intermediaries, identifying three core institutional activities: disrupting existing symbolic systems, creating new relational systems and artifacts, and establishing and maintaining operational routines across different intermediation levels.

Research on EDIH sustainability factors emphasizes the critical importance of value proposition clarity and stakeholder engagement. Sassanelli and Terzi [56] and Sarippa et al. [33] converge on the premise that sustainable EDIH networks require clear value propositions and effective private sector partner attraction and retention, proposing adapted tools like the Value Proposition Canvas and Business Environment Canvas for innovation networks. Zamiri [57] contributes a five-dimensional conceptual framework for establishing sustainable DIHs based on comprehensive needs and goals analysis, while Dalmarco et al. [58] challenge one-size-fits-all approaches through their analysis of over 300 DIHs across three initiatives, demonstrating that regional characteristics fundamentally determine value creation, provision, and capture mechanisms. Anzivino et al. [59] conduct a qualitative study based on interviews with meta-organizations such as DIHs in order to investigate how four orchestration mechanisms (collaboration platform set-up, resource management, process enablement, and scale-up) can support sustainability-oriented innovation leveraged by digital innovation, highlighting how the sequentiality of mechanisms helps achieve their purposes.

The geographical dimension receives particular attention from Asplund et al. [60], who emphasize that SMEs inherently require regionally based supporting entities for effective digitalization, drawing on FED4SAE and HUBCAP project experiences to highlight how funding and institutional support quality directly influence EDIH service delivery effectiveness. This validates to some extent the territorial perspective promoted by Rissola and Sorvik [61], who provide the earliest works regarding DIHs and their embeddedness in regional Smart Specialization Strategies.

Policy environment research reveals both opportunities and challenges for EDIH sustainability. Hervás-Oliver et al. [62] demonstrate through Spanish DIH interviews that these structures effectively function as multi-actor collaborative platforms facilitating Industry 4.0 transitions. However, in another study, Hervás-Oliver and Artes-Artes [63] suggest that although DIHs can promote the most innovative EU policies on Open Innovation and Industry 4.0, they are not coordinated with national and regional initiatives, nor do they fully support SMEs, marking an uneven digitalization in Europe. To this point, Orazi and Sofritti's [64] Italian analysis also exposes critical discontinuities between regional and national digital innovation initiatives, highlighting coordination failures that undermine EDIH effectiveness. Lacova et al. [65] further define foreseen challenges of DEP in the Slovak environment based on a comparative case study analysis of existing and candidate DIHs from the country.

3.1.3. The EDIH Ecosystem Level (Supra-National)

The supra-national level of EDIH interaction refers to supra-national cooperation, but in smaller clusters such as international thematic clusters or several countries, and does not involve the whole EDIH network (as is the case with the ENDIH level (see Section 3.1.4)). This level emerged as a recognized necessity by 2020, when Butter [66] identified the

imperative for coordination and efficiency optimization across regional, national, and EU levels, given the proliferation and diverse focus of DIHs within an increasingly complex multi-layered innovation ecosystem. This recognition catalyzed significant theoretical development aimed at understanding and optimizing inter-EDIH collaboration.

The theoretical landscape is dominated by a cohesive body of methodological frameworks centered on the D-BEST model. Sassanelli and Terzi [12] provide the foundational contribution through their extended D-BEST model, developed on the basis of the Ecosystem–Technology–Business–Skills–Data (ETBSD) reference model for configuring the service portfolio of DIHs [67–69] and enabling inter-EDIH collaboration. The D-BEST model was validated within the HUBCAP cyber-physical technologies project, establishing conceptual foundations for analyzing horizontal and vertical EDIH interactions with emphasis on interoperability and sustainability. The D-BEST framework currently represents the most fully developed model for understanding EDIHs, offering a clear and well-structured basis for configuring an EDIH’s service portfolio with a view toward transactional collaboration between EDIHs. It relies on five service masterclasses (Ecosystem, Technology, Business, Skills, and Data), as well as sub-service types and sub-classes, in order to conceptualize the exact assets being transferred within the collaboration, but also provides guidance on how to measure this collaboration. While originally oriented towards cyber-physical systems, the D-BEST methodology offers potential for transferability to EDIHs operating in other sectors, including agri-food, by enabling EDIHs working within this sector to collaborate with a view to service provision of SMEs. Nevertheless, to date, it has only been applied in the manufacturing sector, with a limited territorial focus and without a comprehensive investigation into the specific causes or network configurations of DIHs [7].

This work spawned **complementary methodological developments of the original D-BEST framework**: Sassanelli et al. [70] further developed a D-BEST-based DIH customer journey method, able to configure a DIH’s unique value proposition and further illustrate this application through pilot case studies [68]. The same authors conduct a comparative analysis of the main platforms grounded on the D-BEST reference model developed by different DIH networks at the time [71]. Razetti et al. [72], based on work from the DIH4AI project, switched the taxonomy of the D-BEST model to transform it into a tool for legal and ethical issues in order to enable DIHs to provide much-needed support for softer aspects of AI adoption. Haidar et al. [73] extend the D-BEST framework by integrating the ECOGRAI method to create standardized collaboration assessment methodologies applicable across all sectors, while Serrano-Ruiz et al. [5] develop comprehensive frameworks for understanding multi-level collaboration from local to pan-European networks, introducing the IOATM methodology for quantifying collaborative activities. Serrano-Ruiz et al. [5] complete this theoretical cluster by analyzing innovation ecosystems generated by DIHs, emphasizing collaboration and networks as fundamental innovation drivers. Quadrini et al. [74] conduct an empirical study of Italian and Polish DIHs (based on Smart Specialization Platform data) using the D-BEST reference model in order to understand affinities and differences between the DIHs of the two countries. Overall, Sassanelli et al. [67–69], Sassanelli and Terzi [12,70], Haidar et al. [73], Serrano-Ruiz et al. [5], and Razetti et al. [72] form a common body of work with detailed methodologies for formalizing and understanding collaboration as the main activity of EDIHs, but in a manner specific to the methodologies of the manufacturing sector and cyber-physical systems.

Cross-border collaboration also emerges as a prominent theme, with Voros [75] proposing a “Marketplace-as-a-Service” platform through SMART4ALL to fund pilot experiments across digitalized agriculture, transport, and environment sectors, while Queiroz et al. [76] demonstrate practical cross-border implementation through the Portugal–Spain DISRUPTIVE consortium, exploring the quality of innovation in a cross-border

context. They address agri-food through their Hub4AGRI component using the quadruple helix model. Volpe et al. [77] complement this with preliminary results from DigiFed's cross-border collaboration tools.

The **empirical contribution** from Dyba et al. [78] provides a comparative analysis of regional Industry 4.0 policies across Germany, Italy, and Poland, reinforcing the critical importance of adapting interventions to regional socio-economic conditions for successful technology adoption. Another empirical study is that of Ujwary-Gil and Godlewska-Dzioboń [79], who conducted a social network analysis using data from the Smart Specialization Platform in order to measure the network cohesion, centrality, and specialty of Polish DIHs. Their results both validate this method of research for various levels of DIH ecosystems and offer insights into network structure and the most influential DIHs.

3.1.4. The ENDIH Level (Pan-European)

Pan-European EDIH research has evolved toward macro-regional analyses that increasingly connect DIH development with broader European policy frameworks, particularly the Artificial Intelligence Strategy and Digital Europe Programme. This research stream demonstrates growing sophistication in understanding EDIHs within larger socio-economic and policy contexts.

The **econometric research** strand, led by Georgescu et al. [80], establishes quantitative foundations for understanding EDIH–economic development relationships. Their study correlates DIH numbers on the S3 platform with GDP per capita and EU Digital Society Index indicators, revealing that businesses increasing digital technology uptake contribute to GDP growth, while high-DESI countries both accelerate GDP growth and host more candidate DIHs. Their complementary Visegrad Group analysis [81] reinforces these findings across the Czech Republic, Hungary, Poland, and Slovenia, demonstrating that technology investments drive GDP per capita growth and highlighting DIHs' competitive advantages across the EU. These studies suggest that regional macroeconomic disparities significantly influence digital technology adoption rates across member states.

Typological and clustering research provides structural insights into EDIH diversity and distribution patterns. Wintjes and Vargas [6] develop comprehensive DIH typologies based on organizational characteristics, identifying four hub types (Private for Service, Private for Manufacturing, Universities for Service, Universities for Manufacturing) while revealing common cross-sectoral challenges. Gavkalova et al. [7] extend this approach through empirical analysis of 38 countries using the D-BEST reference model, producing four country clusters with similar service portfolio characteristics that correlate with socio-economic development levels. However, both studies suffer from temporal limitations, representing pre-EDIH network snapshots that reduce their contemporary relevance.

Policy-focused research examines EDIHs as implementation tools for European digital strategies. Czyżewska-Misztal [82] positions EDIHs as essential instruments for regional AI regulation and promotion, noting their role in addressing implementation gaps in European Commission regional technology approaches. Ruohonen and Timmers [83] provide an early Digital Europe Programme evaluation, demonstrating strong alignment between funded projects and strategic priorities including cybersecurity, AI, high-performance computing, and SME support.

3.2. Literature Review of Papers Related to the Agri-Food Sector

It is also noted from the previous section that the literature related to EDIHs comes mainly from the field of production and the processing industry (manufacturing), referring to case studies represented by EDIHs in areas such as robotics or Industry 4.0. According to Serrano-Ruiz et al. [5], this reflects real imbalances existing in the European

EDIH network, in particular, a visible underrepresentation of the agri-food sector, with some sectors being much more advanced in terms of digitalization than others.

As Serrano-Ruiz et al. [5] also note, **the only notable bibliographical exception is the contribution of Lombardo et al. [84] in the field of precision agriculture**, which states that in order to accelerate the adoption of technology in marginal areas of the EU, such as deeply rural, mountainous, or economically disadvantaged areas, the classic ‘top-down’ approach, based on the transfer of knowledge and technology from research centers and universities, should be replaced by a ‘bottom-up’ approach, based on open innovation. This would lead to regional co-generation of agri-food technology for the creation of products and services. The authors believe that the application of the technology transfer model based exclusively on research within universities, research centers, and companies has major limitations in marginal territories that are characterized by a lack of education (91% of farmers have only basic education, and only 6% are specialists) and low innovation rates. For this reason, the authors consider it more appropriate that in these areas, and especially the EDIHs—which align with these innovation principles through their statute—there should be greater use of technology co-generation techniques in agriculture that promote collaboration between the actors involved, including the end users of the innovation. Although the proposal is valid, the paper is a scientific communication, largely theoretical, and not based on concrete empirical studies related to EDIHs.

Other marginally important articles on the in-depth understanding of EDIHs in the field present the concept of EDIHs, the challenges, or isolated case studies of good practices. Gernego et al. [85] conduct a conceptual analysis of the impact of digitalization on rural business development and the challenges encountered in this process, with the aim of formulating implications for the provision of support services by DIHs. They mention the challenges related to the existence of digital infrastructure in rural areas, as well as the positive effects that these hubs can have on increasing competitiveness in these areas if they are financially supported through EU programs. A limitation of this article is its theoretical nature, based on a small number of scientific references.

In terms of **case studies**, the first published on DIHs in the agri-food sector comes from the report prepared for JRC by Mörner et al. [86], which analyses six European DIHs, including Andalusia Agrotech, specialized in agriculture. The case study highlights the importance of anchoring DIHs in regional smart specialization strategies (RIS3), as well as their connectivity at European level. In the same year, Alonso et al. [87] and Miranda et al. [88] present case studies such as the HUB4AGRI initiative and the SmartDairyTracer solution in Portugal in their scientific communications, noting that their success validates the idea that DIHs have evolved from a concept to an operational study, through which they can deliver tangible results to actors in the agricultural sector, solving both the technical problems and the need for specialized solutions that characterize efficient AKIS actors. Aragonés et al. [89] provide a dual case study of two DIHs in Andalusia and South-East Ireland, providing two examples of their positive role in finding solutions for biomass valorization through digitalization, based on consultations with over 100 stakeholders from the respective ecosystems. The lessons learned from the two EDIHs are that (i) stakeholders’ needs must be understood, (ii) the greatest impact on the beneficiaries of EDIH services is the presentation of technologies coming from other companies in the industry that have implemented the technologies, and (iii) communication plans and a good definition of services are very important for the success of EDIHs. Stojanova et al. [90] present a DIH (non-EDIH, funded by an Interreg project but still considered relevant) that supported the digitalization of the wine sector in a certain region of Slovenia and note the positive effects on the local ecosystem, while Simek et al. [91] present the design of the PoliRural DIH centered around an online platform, created as part of the PoliRural Horizon 2020 project,

providing access to several assets for rural policy development. O’Gorman et al. [92] present a rare and atypical case study that offers a model of collaboration between artists, companies, and EDIHs applied to the agri-food industry. This article explores a creative and atypical interdisciplinary collaboration, but it is not very representative of the most pressing issues facing the sector.

4. Discussion

4.1. Discussion Regarding the Volume of Publications at Each Level of EDIH Interaction

The analysis of the literature topics related to EDIHs according to the interaction levels proposed by Serrano-Ruiz et al. [5] reveals an uneven distribution of academic contributions across the four interaction levels, with articles dedicated to the internal level of the EDIH and ENEDIH levels being most underrepresented. The uneven distribution of the literature at the different levels of interaction of EDIHs suggests that the literature is in a phase of consolidation, with a pronounced focus on regional relations, highlighting the relative maturity of this field through the development of specific methodologies, formal ontologies for interoperability, and the conceptualization of EDIHs as “knowledge brokers”. This richness reflects the crucial importance of regional relations for the efficient functioning of EDIHs. Notable is the body of work surrounding the D-BEST model of Sassanelli and Terzi [12], which shows interest in facilitating cross-border cooperation between EDIHs.

4.2. Discussion Regarding Main Themes of EDIH Non-Agri-Food Literature for Each Level of EDIH Interaction

Regarding the main themes of the literature at each level,

1. **Research on the internal dynamics of DIHs** reveals three fundamental themes that collectively shape organizational effectiveness within these innovation intermediaries. The literature emphasizes the critical importance of methodological guidance for EDIH establishment, highlighting how structured development frameworks provide essential operational foundations for successful hub creation and management. Equally significant is the centrality of associative structures in enabling digital transformation, where collaborative organizational forms and consortium mechanisms prove instrumental in facilitating innovation and knowledge transfer processes. Finally, there exists considerable untapped potential in collaborative and marketing-oriented services, with evidence suggesting that current service portfolios significantly underrepresent these high-impact areas despite their demonstrated value for SME engagement and ecosystem development. However, this emerging field suffers from a fundamental limitation: the absence of comprehensive empirical validation for these theoretical frameworks and methodological recommendations, leaving critical questions about practical implementation effectiveness across diverse regional and sectoral contexts largely unanswered.
2. **Research on the regional ecosystem level of EDIHs** reveals a complex landscape characterized by several interconnected challenges and opportunities that collectively define the current state of EDIH implementation and effectiveness. The most prominent theme emerging across multiple research streams is the fundamental tension between standardization requirements and contextual adaptation needs, which manifests in various forms throughout the EDIH ecosystem. While there is a critical need for standardization frameworks to enable interoperability and coherent service delivery across the European network, the evidence consistently demonstrates that regional characteristics, local innovation systems, and sector-specific requirements demand highly contextualized approaches. This tension is further complicated by the predominant early-stage digital maturity of European SMEs regardless of ge-

ography, creating a situation where EDIHs must simultaneously address universal capacity-building needs while tailoring their services to diverse regional contexts and sectoral particularities.

The research also highlights a significant evolution in understanding EDIHs' role within regional innovation ecosystems, moving from conceptualizing them as passive technical facilitators to recognizing them as strategic knowledge brokers and active intermediaries in regional innovation systems. This transformation is accompanied by the development of sophisticated institutional frameworks and the prevalence of cross-border collaboration models that reflect EDIH's transnational mission, yet these advances are undermined by persistent implementation challenges. Critical gaps emerge between theoretical frameworks and practical application, between available services and actual beneficiary capabilities, and between EDIH ambitions and coordinated policy implementation at regional and national levels. The research consistently points to the need for broader empirical validation across diverse European contexts, as current contributions suffer from limited geographic scope and remain largely case-study-based. Despite promising methodological developments and the emergence of sector-specific yet transferable platforms, the field requires extensive replication studies and more rigorous evaluation of effectiveness to bridge the gap between formal standardization efforts and practical implementation realities, ultimately ensuring that EDIHs can fulfill their potential as drivers of regional digital transformation.

3. **Research on the supra-national level of EDIH interaction** demonstrates significant progress in developing standardized collaboration frameworks that address the inherent complexity of multi-level coordination across regional, national, and European dimensions. The theoretical landscape has matured around comprehensive methodological approaches that enable systematic analysis of inter-EDIH cooperation, with particular emphasis on interoperability, sustainability, and quantifiable collaboration metrics. However, these advances reveal a pronounced sectoral bias, with manufacturing and cyber-physical systems dominating the development of collaboration methodologies and conceptual frameworks. This sectoral concentration limits the broader applicability of proposed frameworks and highlights a critical gap in understanding how inter-EDIH collaboration functions across diverse operational environments, particularly in sectors like agri-food, services, or creative industries. The field urgently requires empirical validation and adaptation of these theoretical frameworks beyond manufacturing contexts to ensure that standardized collaboration approaches can effectively support the heterogeneous EDIH landscape envisioned by European digital transformation policies.
4. **Research on the European EDIH network level** demonstrates the emergence of quantitative evidence linking EDIH presence to economic development outcomes, with studies revealing positive correlations between DIH density, GDP growth, and national digitalization indices. This macro-level analysis has established EDIHs as integral policy implementation instruments within broader European digital strategies, particularly the AI Strategy and Digital Europe Programme, positioning them as essential tools for regional technology promotion and regulatory compliance. However, the research faces significant challenges in maintaining contemporary relevance due to the rapid evolution of the EDIH network, with many foundational studies becoming outdated as the official EDIH framework superseded earlier DIH configurations. The evidence collectively suggests that while EDIHs possess demonstrable economic impact potential and align well with European strategic priorities, their effectiveness varies considerably across regional socio-economic contexts, necessitating continued

empirical monitoring and adaptive research approaches as the network matures and evolves beyond its initial implementation phase.

4.3. Discussion Regarding Main Themes of Agri-Food Literature

The academic literature on EDIHs in the agri-food sector reveals significant underrepresentation that aligns with Serrano-Ruiz et al.'s [5] observations regarding structural imbalances within the European EDIH network, where certain sectors demonstrate considerably more advanced digitalization than others. Implementation data from the first EDIH cycle corroborates these findings, showing agri-food's underrepresentation among beneficiaries despite the sector's strategic European importance, creating substantial risks for agricultural competitiveness through digitalization.

The thematic content of agri-food EDIH articles demonstrates researcher optimism regarding positive digitalization effects [85,86,89–92], particularly during the pre-implementation period (2019–2023). However, these contributions consistently emphasize the necessity of anchoring EDIHs in local contexts, including beneficiary needs [89], regional smart specialization strategies [86], rural infrastructure prerequisites [78,85], and bottom-up approaches based on open innovation and technology co-generation specific to agricultural requirements [84]. A critical limitation characterizes these contributions: most remain theoretical or rely on isolated case studies without comprehensive empirical validation of proposed hypotheses.

The conceptualization of EDIHs as “knowledge brokers” [47] gains particular significance through subsequent work by Jurčić and Strahonja [51] and Colovic et al. [55], which, combined with insights from Alonso et al. [87] and Miranda et al. [88], establishes EDIHs as de facto new Agricultural Knowledge and Innovation System (AKIS) actors. This positioning necessitates sector-specific understanding and adapted practices to effectively serve agri-food stakeholders, highlighting the need for specialized competencies beyond generic digital transformation approaches.

4.4. Discussion of Methodological Limitations of EDIH Literature

The methodological landscape of EDIH research reveals significant limitations that consistently emerge across all four levels of analysis, highlighting fundamental challenges in establishing a robust evidence base for this emerging field. The most pervasive methodological constraint is the absence of comprehensive empirical validation, with research heavily skewed toward theoretical contributions, isolated case studies, and limited geographic scope rather than rigorous, large-scale empirical investigations. This pattern manifests across internal dynamics research, where theoretical frameworks lack practical implementation validation; ecosystem-level studies, which remain predominantly case-study-based despite calls for broader replication; supra-national collaboration research, confined largely to manufacturing contexts; and network-level analysis, where rapid EDIH evolution renders foundational studies quickly outdated.

A critical temporal validity challenge compounds these limitations, as the rapid transformation from early DIH configurations to the official EDIH network has created a significant disconnect between existing research and contemporary realities. Many foundational studies reflect pre-EDIH network snapshots that no longer accurately represent current operational contexts, necessitating substantial methodological adaptation and updated empirical investigation.

Furthermore, the research demonstrates pronounced sectoral and geographic bias, with manufacturing and cyber-physical systems dominating theoretical development while other sectors, particularly agri-food, remain severely underrepresented. This bias limits the transferability and generalizability of findings across the heterogeneous EDIH landscape.

The field urgently requires a methodological paradigm shift toward longitudinal studies, standardized evaluation frameworks, multi-sector comparative analyses, and continent-wide empirical validation to bridge the persistent gaps between theoretical ambitions and practical implementation realities, ultimately enabling evidence-based policy refinement and program optimization as the EDIH network matures.

4.5. Research Agenda for Further Research

Based on the analysis presented, we can identify the following underrepresented research directions that require further investigation (see Table 2 below).

Building on the proposed research agenda, several priority topics emerge for advancing an evidence-based approach to agri-food digitalization within the EDIH network:

1. **Testing and validating the D-BEST model for the agri-food sector.** Given the popularity of the framework and its broad usage to enable analyses, future research should validate an “Agri-D-BEST” framework.
2. **Strengthening the EDIH knowledge-broker and intermediation roles within AKISs.** EDIHs should formally integrate into AKISs by establishing feedback loops among farmers, researchers, and policymakers—ensuring that local needs inform European digital policy and the overall approach of EDIH with regard to the agri-food sector.
3. **Conducting a barrier analysis for digitalization in agri-food through EDIH.** At the moment, the barriers preventing more agri-food beneficiaries from accessing EDIH services are poorly understood. A thorough analysis is needed, taking into account both needed adaptations to EDIH services or other program characteristics and external factors such as infrastructure limitations in rural areas, cost–benefit analysis of rural-specific digitalization interventions, development of rural-adapted digital transformation models, and local anchoring strategies in rural realities.

Policymakers can enable the research community to contribute to distilling evidence-based best practices, digitalization patterns of SMEs, and other valuable insights by deciding to share anonymized data of SME beneficiaries’ DMA scores, as well as further data on EDIH results following the end of the first 3-year implementation cycle. If enabled by appropriate data, the research agenda and priority steps outlined above can render the agri-food digitalization process more measurable and inclusive, guiding both DEP implementation and future Horizon Europe initiatives.

Table 2. Research agenda—topics for further investigation.

Topics	Specific Aspects
Internal Level of EDIHs	• Empirical Validation of Theoretical Frameworks—large-scale validation studies of existing methodological guidance frameworks, comparative effectiveness analysis of different EDIH establishment approaches, cross-regional validation of organizational structure recommendations • Internal Organizational Dynamics—how the internal structures of EDIHs actually work, governance mechanisms and decision-making processes at the internal level, resource management, learning, and optimization of internal capabilities • Service Portfolio Development—systematic evaluation of collaborative and marketing-oriented services’ potential, gap analysis between current offerings and high-impact service categories, development of evidence-based service expansion strategies • Developing skills and training teams within EDIHs

Table 2. Cont.

Topics	Specific Aspects
Regional-Ecosystem-Level Research Priorities	• Standardization vs. Contextualization Balance—framework development for optimal balance between standardization and local adaptation, comparative analysis of regional customization strategies and outcomes, impact assessment of local innovation systems on EDIH effectiveness • Knowledge Brokerage Function Validation—empirical validation of EDIHs transition from passive facilitators to strategic intermediaries, quantitative measurement of knowledge creation vs. knowledge transfer activities, longitudinal analysis of EDIH impact on regional innovation ecosystems • SME Digital Maturity Progression—multi-year longitudinal studies of SME digital transformation trajectories, cross-European comparative analysis of digital maturity patterns, effectiveness evaluation of capacity-building interventions • Service–Capability Gap Analysis—systematic assessment of gaps between available services and beneficiary capabilities, regional comparative studies of service uptake and effectiveness, development of adaptive service delivery models
Supra-National-Level Research Priorities	• Multi-Sector Framework Adaptation—extension and validation of D-BEST model beyond manufacturing contexts, development of sector-specific collaboration frameworks for agri-food, services, creative industries, cross-sector comparative analysis of collaboration patterns and effectiveness • Inter-EDIH—Empirical analysis of multi-level coordination across regional, national, and EU dimensions, effectiveness evaluation of existing coordination instruments and policies, development of improved inter-EDIH collaboration assessment methodologies • Policy Coherence Assessment—analysis of policy alignment between different governance levels, evaluation of coordination mechanisms’ effectiveness, development of coherent multi-level governance frameworks
European Network-Level Research Priorities	• Updated Economic Impact Assessment—comprehensive analysis using current EDIH network data (post-2023), multi-country longitudinal studies of EDIH–economic development correlations, regional comparative analysis of economic impact across diverse socio-economic contexts • Policy Implementation—integration with EU policies (AI strategy, DEP), analysis of alignment between EDIH activities and European strategic priorities • Network Evolution Monitoring and Learning—development of adaptive research frameworks for dynamic network environments • Cross-Regional Comparative Analysis—systematic comparison of EDIH effectiveness across different regional contexts, analysis of success factors in diverse socio-economic environments

Table 2. Cont.

Topics	Specific Aspects
Agri-Food Sector—Specialized Research	• AKIS Integration Framework Development—comprehensive analysis of EDIHs as new Agricultural Knowledge and Innovation System actors, impact assessment of EDIH integration on existing AKIS structures, development of sector-specific competency frameworks for agri-food EDIHs, the role of EDIHs in farmers’ decision-making strategies regarding technology adoption (including investigating complex farmer–researcher–market interactions) • Barrier Analysis for Digitalization in Agri-Food through EDIHs—systematic empirical investigation of infrastructure limitations in rural areas, cost-benefit analysis of rural-specific digitalization interventions, development of rural-adapted digital transformation models, and local anchoring strategies in rural realities, as well as general adaptation of EDIH services to the needs of agri-food beneficiaries • Bottom-Up Innovation Validation—empirical validation of open innovation and technology co-generation approaches in agriculture within EDIHs, comparative analysis of traditional vs. participatory technology transfer effectiveness in EDIH services, analysis of farmer participation patterns in digital innovation processes • Adapting Services to the Particularities of the Agricultural Sector—development and testing of agriculture-specific EDIH service portfolios, analysis of seasonal and cyclical factors in agricultural digitalization, integration strategies with precision agriculture and smart farming initiatives, and particularities related to various agri-food sub-sectors (e.g., horticulture, animal rearing, etc.) • Agricultural Competitiveness Analysis—long-term impact assessment of agricultural digitalization on (regional) sectoral competitiveness, comparative analysis with other sectors’ digitalization progress or between agri-food sub-sectors (e.g., horticulture, animal rearing), development of agriculture-specific digital transformation metrics • The social impact of digitalization on sector polarization and strategies to mitigate structural inequalities.
Cross-Cutting Methodological Priorities	• Comprehensive Empirical Validation—extensive empirical research instead of one-off case studies; large-scale, multi-country longitudinal studies across all EDIH levels; development of standardized evaluation frameworks and key performance indicators; rigorous replication studies of existing case study findings • Geographic and Sectoral Representation—systematic inclusion of underrepresented sectors and regions in research, development of stratified sampling frameworks ensuring representative coverage, cross-sector comparative studies using harmonized methodologies • Temporal Validity Enhancement—regular updating and validation of research findings to reflect network evolution since the implementation of the DEP program and ENDIH • Theory–Practice Integration—bridging gaps between theoretical frameworks and practical implementation, participatory research approaches involving EDIH practitioners and beneficiaries, development of evidence-based policy recommendation frameworks • Methodological Innovation—development of new research methods appropriate for dynamic innovation ecosystems, integration of mixed-methods approaches for comprehensive EDIH assessment, creation of real-time data collection and analysis capabilities

5. Conclusions

The current study aimed to produce a thorough scoping review of all existing publications related to EDIHs and the agri-food sector, with the objective of mapping existing gaps in the literature and proposing a research agenda to address them.

Regarding the first objective of the current paper, of mapping existing gaps in the literature, we can conclude that the research landscape of EDIH publications to date demonstrates significant imbalances. The academic literature is heavily concentrated on ecosystem-level interactions, while critical areas such as internal organizational dynamics and European-level coordination mechanisms remain severely understudied. Perhaps most concerning is the double disadvantage facing the agri-food sector, which suffers from both academic neglect and practical underrepresentation, with only 1.7% of EDIH beneficiaries coming from agriculture (by September 2024) despite the sector's strategic importance to European food security and rural development. This disparity creates a tangible risk that agricultural digitalization will lag behind other sectors, potentially exacerbating existing competitiveness gaps and undermining the program's goal of comprehensive digital transformation across all economic domains. The predominance of theoretical contributions and isolated case studies over rigorous empirical research represents a critical weakness in the current knowledge base. While these studies provide valuable conceptual frameworks and preliminary insights, the lack of longitudinal studies measuring real impact, standardized evaluation methodologies, and comprehensive validation of proposed models limits our understanding of EDIH effectiveness and optimal implementation strategies.

The resulting research agenda meets the second objective of the current paper, representing a uniquely valuable and timely contribution to current literature, providing the first systematic mapping of research priorities specifically addressing the intersection of European digital innovation policy and agricultural transformation. By offering structured guidance for researchers and policymakers to address the most pressing knowledge gaps, this research agenda has the potential to catalyze the empirical research necessary to ensure truly inclusive and effective digital transformation across all sectors of the European economy, preventing the agri-food sector from falling behind in an increasingly digitalized global landscape.

The evidence suggests that DEP policymakers should consider integrating the research priorities identified in this study into the future work program agendas of research and innovation programs such as Horizon Europe or future frameworks in this field in order to enable a much more systematic understanding of the ENDIH and to provide this network with appropriate tools that answer outstanding needs. In the short term, some of the knowledge gaps can be addressed by empowering the DTA with the agenda resulting from this study and by directing it to address outstanding questions within ENDIH, in particular through thematic working groups, or other structures aimed at reflection, learning, and knowledge generation based on communities of practice. Last but not least, the academic community could contribute to these outcomes if provided with more (anonymized) data about the results of the first 3-year implementation cycle, which could lead to a better understanding of the effectiveness of certain DIH strategies, digitalization pathways of various SMEs, and sectoral patterns and evidence-based solutions for an evolving network.

The study's novel insights come at a pivotal time for the ENDIH, at the end of the initial three-year cycle of the first cohort of EDIHs. By offering a structured overview of the current state of knowledge, it supports researchers and policymakers in contributing to the overall mission of the program of supporting the digital transformation of European economies and societies—alongside their key economic sectors, among which agri-food is critical.

In spite of its ambition of becoming one of the most thorough scoping reviews regarding the EDIH literature and in particular about the body of work regarding EDIHs in the agri-food sector, some limitations of the current study are the lack of access to all databases which would have increased the reach of the searches, the retroactive application of the PRISMA ScR protocols which could have lead to some errors, and the lack of double-coding of the 84 articles identified within the scope of the current study.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/agriculture15212305/s1>, PRISMA-ScR-Fillable-Checklist_ITC_EDIH Agri 1.

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Data Availability Statement: The data used for the current study is publicly available and is listed in Appendix A.

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Abbreviations

The following abbreviations are used in this manuscript:

AI	Artificial Intelligence
DG CNNECT	Directorate-General for Communications Networks, Content and Technology
DIH	Digital Innovation Hub
DMA	Digital Maturity Assessment
DTA	Digital Transformation Accelerator
EDIH	European Digital Innovation Hub
ENDIH	European Network of Digital Innovation Hubs
EC	European Commission
EU	European Union
DESI	EU Digital Society Index
DEP	Digital Europe Programme
JRC	Joint Research Center
LLM	Large Language Model
MDPI	Multidisciplinary Digital Publishing Institute
MS	Member State
S3P	European Commission's Smart Specialization Platform

Appendix A

Table A1. Master list of publications included in the scoping review (n = 84). (Notes: 1. Where papers are listed in *italics* font, this indicates that only the abstract could be consulted. 2. In the Type field, the following annotations were used: J—Journal Article; CP—Conference Paper; B—Book Chapter; R—Report; PhD—Ph.D. Thesis; A—Non-Peer-Reviewed Article.)

No.	Authors and Publication Year	Type	Title
2025 (until May 2025)			
1	Anzivino et al. [59]	J	Orchestration Mechanisms in Sustainability-Oriented Innovation: A Meta-Organization Perspective.
2	Carolis et al. [40]	J	The Digital REadiness Assessment MaturitY (DREAMY) framework to guidemanufacturing companies towards a digitalisation roadmap
3	Colovic et al. [55]	J	Institutionalising the digital transition: The role of digital innovation intermediaries
4	Georgescu and Avasilcai [17]	B	<i>Transforming SMEs’ Digital Potential Through Associative Cooperation: The Analyses of Romanian Digital Innovation Hubs.</i>
5	Khan, et al. [32]	CP	<i>AI Adoption in Finnish SMEs: Key Findings from AI Consultancy at a European Digital Innovation Hub</i>
6	Khanelloupoulou et al. [43]	J	Accelerating AI-powered digital innovation through “APSS”: A novel methodology for sustainable business AI transformation
7	Khanelloupoulou et al. [33]	J	Embarking the AI journey: insights from ahedd DIH on Greece’s (potential) AI adopters
8	Khanelloupoulou et al. [44]	B	<i>Smart Attica EDIH: A Paradigm for DIH Governance and a Novel Methodology for AI-Powered One-Stop-Shop Projects Design</i>
9	Rajkovic [45]	PhD	The process of establishing an innovation ecosystem as a result of knowledge exchange among various stakeholders in the blue economy—the example of the strategic project InnovaMare
10	Rouhonen and Timmers [83]	J	Early Perspectives on the Digital Europe Programme
11	Spigarelli et al. [54]	J	Unlocking Collaborative Opportunities for Environmental Sustainability through Innovation Intermediaries
2024			
12	Babo et al. [39]	CP	Study of Digital Maturity Models Considering the European Digital Innovation Hubs Guidelines: A Critical Overview.
13	Czyżewska-Misztal, D. [82]	J	The European Union’s Approach to Artificial Intelligence from a Territorial Perspective: The Case of DIHs and EDIHs Programmes.
14	Gavkalova, et al. [7]	J	Digital Innovation Hubs and portfolio of their services across European economies.
15	O’Gorman et al. [90]	J	MUSAE: Fusion of art and technology to address challenges in food and health.
16	Haidar. et al. [73]	B	<i>Developing Performance Indicators to Measure DIH Collaboration: Applying ECOGRAI Method on the D-BEST Reference Model</i>

Table A1. Cont.

No.	Authors and Publication Year	Type	Title
17	Haukipuroet al. [30]	J	Key aspects of establishing research, knowledge, and innovation-based hubs as part of the local innovation ecosystem.
18	Jurčić and Strahonja [51].	A	Factors Influencing European Digital Innovation Hubs as Intermediaries in Processes of Value Delivery from Research Community to Industry and Vice Versa.
19	Lacová et al. [65]	J	Digital Innovation Hubs as Examples of Cooperation to Foster the Digital Skills of Employees in SMEs
20	Marinelli et al. [50]	J	Unveiling Knowledge Ecosystem Dimensions for MSMEs' Digital Transformation, toward a Location-Based Brokerage
21	Myllymäki & Hakala [24]	CP	Robocoast Digital Innovation Hub to Promote Digitalization of Businesses in Finland
22	Nazarenko et al. [37]	J	<i>Integration of AI Use Cases in Training to Support Industry 4.0.</i>
23	Ogrean et al. [31]	J	Exploring Digital Needs in the Centru Region, Romania: A Comparative Cross-Sectoral Study
24	Orazi & Sofritti. [64]	J	Innovation 4.0 Policies in Italy: Strengths and Weaknesses of the Innovation Ecosystem of the "Transition 4.0" Plan from an International Perspective.
25	Serrano-Ruiz et al. [5]	J	Relational network of innovation ecosystems generated by digital innovation hubs: a conceptual framework for the interaction processes of DIHs from the perspective of collaboration within and between their relationship levels.
26	Sotirofski, & Kraja [21]	J	Digital Innovation Hubs Transforming Business and Marketing Collaboration
27	Tanhua et al. [34]	J	Digital Maturity of Companies in Smart Industry Era
2023			
28	Feltus. et al. [42]	J	Towards a Multidimensional Ontology Model for DIH-Based Organisations.
29	Gaiani and Ala-Karvia [46]	B	Digital innovation hubs as drivers for digital transition and economic recovery: The case of the Arctic Development Environments Cluster in Lapland
30	Georgescu et al. [16]	B	<i>Digital Innovation Hubs: SMEs' Facilitators for Digital Innovation Projects, Marketing Communication Strategies and Business Internationalization</i>
31	Lepore et al. [53]	J	Building Inclusive Smart Cities through Innovation Intermediaries
32	Sarraipa et al. [36]	J	A Learning Framework for Supporting Digital Innovation Hubs.
33	Sassanelli et al. [25]	CP	Coalescing Circular and Digital Servitization Transitions of Manufacturing Companies: The Circular Economy Digital Innovation Hub
34	Zamiri et al. [49]	CP	Supporting Mass Collaborative Learning Communities Through Digital Innovation Hubs
35	Wintjes and Vargas [6]	J	Digital Innovation Hubs: Insights from European Experience in Supporting Business Digitalization.

Table A1. Cont.

No.	Authors and Publication Year	Type	Title
2022			
36	Dyba et al. [78]	J	Actions fostering the adoption of Industry 4.0 technologies in manufacturing companies in European regions.
37	Georgescu, et al. [15]	B	<i>Associative and Non-associative Business Structures: A Literature Review for the Identification of Business Development Opportunities for SME in the Digital Age.</i>
38	Georgescu et al. [80]	CP	Digital Transition, Digital Innovation Hubs and Economic Development—An EU Case Study
39	Georgescu et al. [81]	J	DIHs and the Impact of Digital Technology on Macroeconomic Outcomes
40	Georgescu et al. [14]	J	A business ecosystem framework for SME development through associative and non-associative business structures in the digital age
41	Quadrini et al. [74]	J	Using the D-BEST Reference Model to Compare Italian and Polish Digital Innovation Hubs
42	Razzetti et al. [72]	CP	L-BEST: Adding Legal and Ethical Services to Manage Digital Innovation Hubs Portfolios in the Artificial Intelligence Domain
43	Rudawska [38]	J	The One Stop Shop Model—A Case Study of a Digital Innovation Shop
44	Sassanelli and Terzi [56]	J	Building the Value Proposition of a Digital Innovation Hub Network to Support Ecosystem Sustainability.
45	Sassanelli and Terzi [12]	J	The D-BEST Reference Model: A Flexible and Sustainable Support for the Digital Transformation of Small and Medium Enterprises
46	Sassanelli and Terzi [70]	CP	The D-BEST Based Digital Innovation Hub Customer Journey Analysis Method: Configuring DIHs Unique Value Proposition
47	Sassanelli et al. [71]	CP	Digital Innovation Hubs Proposing Digital Platforms to Lead the SMEs Digital Transition
48	Stojanova, S. et al. [90]	J	Rural Digital Innovation Hubs as a Paradigm for Sustainable Business Models in Europe’s Rural Areas.
49	Ujwary-Gil and Godlewska-Dzioboń [79]	CP	Digital Innovation Hubs: Two-Mode and Network-Based View on Technology and Services Provided
2021			
50	Asplund et al. [60]	CP	<i>Problematizing the Service Portfolio of Digital Innovation Hubs</i>
51	Cotrino et al. [35]	J	Industry 4.0 HUB: A collaborative knowledge transfer platform for small and medium-sized enterprises.
52	Dalmarco. et al. [58]	CP	<i>Digital Innovation Hubs: One Business Model Fits All?</i>
53	Gernego, et al. [85]	J	Challenges and opportunities for digital innovative hubs development in Europe.
54	Georgescu et al. [22]	B	Digital Innovation Hubs—The Present Future of Collaborative Research, Business and Marketing Development Opportunities

Table A1. Cont.

No.	Authors and Publication Year	Type	Title
55	Hervas-Oliver et al. [62]	J	Emerging regional innovation policies for industry 4.0: analyzing the digital innovation hub program in European regions
56	Hervás-Oliver and Artes Artes [63]	J	The Digitization of European Business: The Digital Innovation Hubs, What Is Next?
57	Jovanovic et al. [23]	J	Digital Innovation Hubs in Health-Care Robotics Fighting COVID-19: Novel Support for Patients and Health-Care Workers across Europe.
58	Maurer [19]	B	<i>Business Intelligence and Innovation: A Digital Innovation Hub as Intermediate for Service Interaction and System Innovation for Small and Medium-Sized Enterprises</i>
59	Sassanelli et al. [69]	CP	<i>Digital Innovation Hubs Supporting SMEs Digital Transformation.</i>
60	Sassanelli et al. [68]	CP	<i>The D-BEST Based Digital Innovation Hub Customer Journeys Analysis Method: A Pilot Case.</i>
61	Semeraro [41]	CP	<i>Interoperability Maturity Assessment of the Digital Innovation Hubs</i>
62	Volpe et al. [77]	CP	<i>Experimentation of Cross-Border Digital Innovation Hubs (DIHs) Cooperation and Impact on SME Services.</i>
63	Zamiri et al. [57]	CP	<i>Towards A Conceptual Framework for Developing Sustainable Digital Innovation Hubs</i>
2020			
64	Aragonés et al. [89]	J	Digital innovation hubs as a tool for boosting biomass valorisation in regional bioeconomies: Andalusian and South-East Irish case studies.
65	Butter et al. [66]	B	<i>Digital Innovation Hubs and Their Position in the European, National and Regional Innovation Ecosystems.</i>
66	Crupi et al. [47]	J	<i>The digital transformation of SMEs—a new knowledge broker called the digital innovation hub.</i>
67	Hadjimitsis et al. [18]	CP	<i>The ERATOSTHENES Centre of Excellence (ECoE) as a Digital Innovation Hub for Earth Observation</i>
68	Jurčić and Strahonja [52]	CP	Conceptual Analysis of the Digital Innovation Hub as a Value Delivery System
69	Kalpaka et al. [13]	R	Digital Innovation Hubs as Policy Instruments to Boost Digitalisation of SMEs—A practical handbook & good practices for regional/national policy makers and DIH managers
70	Lanz et al. [27]	CP	Digital innovation hubs for robotics—TRINITY approach for distributing knowledge via modular use case demonstrations
71	Lanz et al. [28]	A	Digital Innovation Hubs for enhancing the technology transfer and digital transformation of the European manufacturing industry
72	Olszewski and Pawlewski [20]	CP	<i>Stakeholder Involvement Added Value Indicators in IT Systems Design for Industry 4.0 Digital Innovation Hubs.</i>

Table A1. Cont.

No.	Authors and Publication Year	Type	Title
73	Queiroz. et al. [76]	J	A Quality Innovation Strategy for an Inter-regional Digital Innovation Hub
74	Razzetti et al. [72]	CP	L-BEST: Adding Legal and Ethical Services to Manage Digital Innovation Hubs Portfolios in the Artificial Intelligence Domain
75	Sassanelli et al. [67]	CP	Towards a Reference Model for Configuring Services Portfolio of Digital Innovation Hubs: The ETBSD Model
76	Šimek et al. [91]	CP	Innovation Hub for Rural Areas and People
77	Vakirayi & Belle. [29]	CP	<i>Exploring the role of digital innovation hubs in socioeconomic development.</i>
78	Voros [75].	CP	SMART4ALL -Technological Challenges and Funding Opportunities in the Areas of Balkans and Eastern Europe.
2019			
79	Alonso et al. [87]	J	An Edge-IoT platform aimed at smart farming and agro-industry scenarios.
80	Doyle and Cosgrove [26]	J	<i>Steps towards digitization of manufacturing in an SME environment</i>
81	Miranda & Medina [88]	J	HUB4AGRI—Digital Innovation Hub for Portuguese agri-food sector.
82	Miörner et al. [86]	R	Exploring heterogeneous Digital Innovation Hubs in their context A comparative case study of six (6) DIHs with links to S3, innovation systems and digitalisation on a regional scale.
83	Zamiri et al. [48]	CP	<i>Knowledge Management in Research Collaboration Networks</i>
2018			
84	Lombardo. et al. [84]	J	Proposal for spaces of agrotechnology co-generation in marginal areas.
85	Rissola and Sorvik [61]	R	Digital Innovation Hubs in Smart Specialisation Strategies

Appendix B

Table A2. Coding manual—coding rules and decision criteria for assigning the identified literature to each of the four levels of Serrano-Ruiz’s (2024) framework.

Level of Interaction	Criteria for Inclusion
Level 1: DIH Internal Dynamics	Primary focus on internal dynamics among consortium members of a single DIH, who typically collaborate and co-create at an internal organizational level to produce unitary DIH services. DIH methodologies, associative behaviors, organizational structures, consortium relationships, and interdisciplinary work resulting in a common output (service provision) or governance within a single DIH - Key indicators: mentions “consortium”, “members”, “internal”, “single hub case study”, “governance”, “organizational structure”, “co-creation strategies”, “structure”, “EDIH Structure”, “actor relationships” - Exclude if study discusses inter-DIH collaboration, relationship with beneficiaries, or regional ecosystems beyond matters exclusively about the single hub

Table A2. Cont.

Level of Interaction	Criteria for Inclusion
Level 2: DIH Ecosystem	Primary focus on all types of interactions between a DIH and its regional ecosystem (which encompasses external actors interacting with the hub at the regional or at most at the national scale—namely, beneficiaries, technology providers, and other stakeholders active in innovation, knowledge, and technology ecosystems, including authorities from the enabling environment). - Key indicators: “beneficiaries”, “regional”, “SMEs”, “technology providers”, “stakeholder engagement”, “local ecosystem”, “ecosystem building”, “methodologies”, “tools” and “ontologies” (to enable DIHs for sectoral or ecosystem service provision, technology transfer), “network maturity”, “implementation”, “cross-sectoral ecosystem animation/collaboration”, “knowledge brokerage”, “intermediation”, “learning communities”, “knowledge ecosystem” - As opposed to the Internal DIH level, where DIH service provision was discussed as a result of internal dynamics (e.g., associative structures, consortium composition), the DIH Ecosystem level discusses service provision with a view to the external ecosystem (i.e., relationship to beneficiaries) and its demands - Exclude if study primarily addresses DIH-to-DIH networking at binary or group level, or European-level coordination
Level 3: EDIH Inter-Hub Collaboration	Primary focus on DIHs engaged in cross-border collaboration or European networking or service-exchange activities between multiple EDIHs, enabling inter-hub collaboration across broader ecosystems across regions and reaching the national and international level (e.g., thematic EU EDIH ecosystems or regional initiatives involving several EDIHs within a national context or within several MS) - Key indicators: “inter-EDIH”, “networks”, “networking”, “collaboration between hubs”, “transactional collaboration”, “cross-border collaboration”, “service exchange”, “hub coordination”, “interoperability”, “asset transfer”, “national”, “(comparative) national case studies”, “thematic working group” - Exclude if study focuses on single hub operations or study aspects focusing on the whole European network-level governance
Level 4: European EDIH Network (REHID)	Primary focus on studies comprising the entire network as a system, pan-European coordination, typologies for DIHs based on network-level analyses, network-wide policies, and/or DEP-level EDIH policy implications Key indicators: “European network”, “ENDIH”, “network-level”, “collective”, “pan-European”, “DEP”, “typologies of DIHs” Exclude if study addresses only regional or more limited inter-hub dynamics other than the entire ENDIH.

Appendix C PRISMA-ScR Diagrams

Table A3. PRISMA-ScR diagram (MDPI).

Stage	Details
Identification stage —how many records you found in each database and through other methods (snowballing, grey literature, etc.)	Records identified through database searching – “digital innovation hub” (n = 75) – “digital innovation hub” AND “Agriculture” (n = 28) Total records identified (n = 103)
Screening stage —how many records were screened and excluded at the title/abstract level	Records after duplicates removed (n = 74) Records screened (n = 74) Records excluded (n = 68) Full-text articles assessed for eligibility (n = 6)

Table A3. Cont.

Stage	Details
Eligibility stage —how many full texts were assessed and reasons for exclusion	Full-text articles excluded with reasons (n = 1) Reason “isolated mention of EDIH” (n = 1)
Inclusion stage —final number of included studies with breakdown by source type if relevant	Studies included in qualitative synthesis (n = 7)

Table A4. PRISMA-ScR diagram (Google Scholar).

Stage	Details
Identification stage —how many records you found in each database and through other methods (snowballing, grey literature, etc.)	Records identified through database searching - “digital innovation hub” (n = 797.000, for which the search stopped after 126 items because the exact term was no longer visible in the search results returned) - “digital innovation hub” AND “Agriculture” (n = 105.000, for which the search stopped after 40 items because the exact terms were no longer visible in the search results returned) Total records identified (n = 166)
Screening stage —how many records were screened and excluded at the title/abstract level	Records after duplicates removed (n = 142) Records screened (n = 142) Records excluded (n = 41) Full-text and abstract articles assessed for eligibility (n = 101)
Eligibility stage —how many full texts were assessed and reasons for exclusion	Full-text articles excluded with reasons (n = 52) Reason “no mention of EC’s EDIH concept” (n = 28) Reason “type of paper not relevant” (n = 9) Reason “geographical scope not relevant” (n = 13) Reason “isolated mention of EDIH” (n = 2)
Inclusion stage —final number of included studies with breakdown by source type if relevant	Studies included in qualitative synthesis (n = 49)

Table A5. PRISMA-ScR diagram (Web of Science).

Stage	Details
Identification stage —how many records you found in each database and through other methods (snowballing, grey literature, etc.)	Records identified through database searching - “digital innovation hub”—(n = 147) - “digital innovation hub” AND “agriculture” (n = 101) Additional records through other sources (n = 12) Total records identified (n = 360)
Screening stage —how many records were screened and excluded at the title/abstract level	Records after duplicates removed (n = 339) Records screened (n = 339) Records excluded (n = 297) Abstract articles assessed for eligibility (n = 310) Full-text articles assessed for eligibility (n = 42)
Eligibility stage —how many full texts were assessed and reasons for exclusion	Full-text articles excluded with reasons (n = 14) Reason “no mention of EC’s EDIH concept” (n = 2) Reason “type of paper not relevant” (n = 2) Reason “geographical scope not relevant” (n = 2) Reason “isolated mention of EDIH” (n = 8)
Inclusion stage —final number of included studies with breakdown by source type if relevant	Studies included in qualitative synthesis (n = 28)

Table A6. Charting Table—Prisma ScR compliant.

Theme	No. of Sources	Representative References	Key Insights
1. DIH Internal Dynamics (Level 1)	13	Kalpaka et al. (2020 [13]); Georgescu (2021 [14–16]); Georgescu & Avasilcai (2023 [17]); Hadjimitsis et al. (2021 [18]); Maurer (2019 [19]); Olszewski & Pawlewski (2022 [20]); Sotirofski & Kraja (2022 [21]); Jovanovic et al. (2021 [23]); Myllymäki & Hakala (2023 [24]); Sassanelli et al. (2023 [25])	methodological frameworks for DIH establishment; governance structures and associative models; collaborative mechanisms and co-creation processes; Kalpaka et al.’s seven-step JRC methodology as foundational blueprint; organizational and ecosystem integration gaps; underrepresentation of marketing and communication services; evolution of hubs from research centers to service systems; adaptability of DIH service portfolios to crises and sectoral contexts; need for stronger methodological guidance; need for robust associative governance; need for deeper exploration of collaborative and market-oriented services
2. DIH Ecosystem Level (Level 2)	40	Doyle & Cosgrove (2020 [26]); Lanz et al. (2021 [27,28]); Vakirayi & Belle (2021 [29]); Haukipuro et al. (2022 [30]); Ogorean et al. (2023 [31]); Khan et al. (2023 [32]); Khanelloupoulou et al. (2023 [33,43]); Tanhua et al. (2023 [34]); Cotrino et al. (2021 [35]); Sarippa et al. (2022 [36]); Semerano et al. (2021 [41]); Feltus et al. (2022 [42]); Crupi et al. (2021 [47]); Zamiri et al. (2022 [48,49]); Jurčić & Strahonja (2022 [51]); Hervas-Oliver et al. (2021 [62]); Rissola & Sørvik (2020 [61]); Orazi & Sofritti (2023 [64])	ecosystem design and beneficiary analysis—diversity of contexts, user needs, and digital maturity; service and sector methodologies—practical frameworks for technology transfer, Industry 4.0 platforms, and flexible learning models; formal tools and ontologies—interoperability and standardization frameworks (DIH4CPS); knowledge-broker and intermediary functions—DIHs as active innovation intermediaries beyond technical facilitation; sustainability and value-proposition studies—stakeholder engagement, contextualized value creation, and long-term network sustainability; policy and territorial factors—coordination challenges between EU, national, and regional initiatives; overall characterization—EDIHs as complex, multi-actor regional organisms dependent on ecosystem cohesion, tailored services, and S3 alignment; research gaps—lack of comparative quantitative validation and underrepresentation of cross-sector applications (agri-food, public services)

Table A6. Cont.

Theme	No. of Sources	Representative References	Key Insights
3. EDIH Inter-Hub Collaboration (Supra-National Level 3)	14	Sassanelli & Terzi (2020 [12]); Sassanelli et al. (2021 [67–71]); Razetti et al. (2022 [72]); Haidar et al. (2022 [73]); Serrano-Ruiz et al. (2024 [5]); Voros (2021 [75]); Queiroz et al. (2022 [76]); Volpe et al. (2023 [77]); Dyba et al. (2023 [78]); Ujwary-Gil & Godlewska-Dzioboń (2023 [79])	inter-EDIH collaboration formalized through D-BEST (Ecosystem–Technology–Business–Skills–Data) and ETBSD frameworks; conceptual and operational architecture for configuring service portfolios and measuring collaboration intensity; extensions including DIH Customer Journey, legal-ethical AI modules, and ECOGRAI-based metrics; multi-level interaction frameworks (IOATM) linking local, regional, and EU dynamics; empirical and cross-border cooperation mechanisms via SMART4ALL, DISRUPTIVE, and DigiFed projects; application of the quadruple-helix approach in digitalized agriculture and industry; comparative and social-network analyses showing how regional policies and network cohesion influence innovation diffusion; mature theoretical and applied understanding of supra-national collaboration; sectoral bias toward manufacturing and cyber-physical systems; limited replication and validation in other domains such as agri-food
4. European EDIH Network (Pan-European Level 4)	6	Georgescu et al. (2023 [80]); Georgescu et al. (2023—Visegrad [81]); Wintjes & Vargas (2021 [6]); Gavkalova et al. (2023 [7]); Czyżewska-Misztal (2023 [82]); Ruohonen & Timmers (2024 [83])	shift from descriptive mapping to macro-regional, econometric, and policy-driven analyses; linkages between EDIH development, the EU Digital Europe Programme, and Artificial Intelligence Strategy; econometric evidence of positive correlations between DIH density, GDP per capita, and DESI scores—higher digital adoption drives economic growth; typological and clustering analyses identifying four hub types and country clusters aligned with socio-economic gradients; limitations of pre-EDIH datasets reducing temporal relevance; policy-oriented research framing EDIHs as instruments for AI governance, cybersecurity, and SME support; integration of EDIHs into European digital-strategy implementation; emergence of a maturing macro-analytical perspective on EDIHs; uneven data coverage and lack of post-2023 validation across EU member states

Table A6. *Cont.*

Theme	No. of Sources	Representative References	Key Insights
5. EDIHs and Agrifood sector	9	Lombardo et al. (2023 [84]); Gernego et al. (2023 [85]); Miörner et al. (JRC 2021 [86]); Alonso et al. (2021 [87]); Miranda et al. (2021 [88]); Aragones et al. (2022 [89]); Stojanova et al. (2022 [90]); Simek et al. (2022 [91]); O’Gorman et al. (2023 [92])	scarce and fragmented literature with systemic under-representation of the agri-food sector within the EDIH ecosystem; predominance of conceptual and isolated case analyses; advocacy for bottom-up, co-generative innovation models to address low digital literacy and innovation deficits in marginal EU regions; identification of infrastructure and competitiveness challenges in rural areas; importance of anchoring DIHs in regional RIS3 strategies, stakeholder-driven service design, and effective communication of peer technologies; evidence from Iberian and JRC case studies emphasizing regional embedding and connectivity; sector-specific digitalization potential in sub-sectors such as wine and rural policy; emergence of creative and cross-sector collaboration models (e.g., art–industry partnerships); overall depiction of a nascent, uneven, and largely descriptive research stage; need for systematic, empirical assessment of agri-food EDIH performance and policy integration

Appendix D

As mentioned in Section 2 on materials and methods, after Section 3 on results was finalized, the Artificial Intelligence Large Language Model (LLM) Claude Sonnet 4.0 was used for summarizing

1. The main results in the Discussion Section (with the exception of Section 4.3, a discussion regarding the main themes of the agri-food literature, which was written entirely by the researcher) in order to aid in extracting the main emerging patterns from the large body of results;
2. The research agenda presented in Section 4, in order to summarize it based on the research gaps identified.

For the Discussion Section (with the aforementioned exception of Section 4.3), due to limits in prompt sizes, the discussion sections corresponding to each DIH level of interaction were generated in two phases. Firstly, for each of the four phases, the main paragraphs of results corresponding to each group of articles (i.e., Thematic, including, for example, studies on ecosystem building, or Methodological, including methodologies, ontologies, practitioner literature, etc.) were prompted to the LLM with the instruction to “Rephrase, summarize and discuss the articles in the following text amongst each other, concluding on main themes when possible”. Then, for each of the four phases, the resulting main themes were provided as input, with the following prompt “Write a short, summative paragraph

about the [] level of a DIH based on the following themes, without mentioning the main authors: [input]”.

The research agenda was generated by providing in a document, as text, the Results Section (which was coded and entirely written by the human researcher) and prompting the LLM to “synthesize the underrepresented research directions and which require further research”.

All the results offered by Claude Sonnet 4.0 then underwent line-by-line verification (where the researcher cross-referenced every claim, pattern, or conclusion generated by the LLM against the original coded data and extracted findings, ensuring that synthesized statements accurately represent the underlying evidence) and source verification (by requesting the LLM to indicate which coded themes or source categories informed specific conclusions in the first of the two stages of prompt engineering, allowing the researcher to audit the synthesis process). The research agenda underwent further editing by the human researcher in order to filter and improve the relevance of synthesized points.

In spite of the general tendency of LLMs to sometimes conflate similar themes and oversimplify nuanced distinctions, the high-quality results, indicated by the sharp discussion sections that resulted, show that LLMs such as Claude Sonnet 4.0 can serve as safe and useful tools for synthesizing extensive results from literature reviews, particularly when the underlying data has been carefully coded and organized by the researcher. LLMs excel at identifying patterns, generating thematic summaries, and drawing cross-cutting conclusions from structured qualitative data without introducing novel interpretations beyond what the source material contains. When researchers provide pre-coded thematic categories, extracted findings, and organized excerpts from their scoping review results, LLMs function effectively as sophisticated synthesis engines that help transform granular findings into coherent narrative summaries suitable for discussion sections. This approach is particularly valuable for scoping reviews, which inherently involve large volumes of diverse sources and thematic material—LLMs can efficiently synthesize across these themes while maintaining fidelity to the researcher’s original coding and analytical decisions. Importantly, since the researcher has already conducted the interpretive work through coding and analysis, the LLM’s role becomes largely mechanical: identifying thematic connections, organizing information hierarchically, and articulating conclusions that are directly traceable to the coded data rather than introducing independent interpretation. When these verification procedures are systematically applied, LLM-assisted synthesis becomes a transparent and auditable component of the analytical process, enhancing efficiency while maintaining research rigor and integrity.

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