Social Network Analysis in Industrial Symbiosis focusing on Communication Perspective

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Abstract

Industrial Symbiosis (IS) networks rely heavily on effective communication between firms to realize the exchange of resources and facilitate collaborative sustainability initiatives. While many publications focus on material and energy flows, they give less consideration to the communication processes involved in such collaboration. Social Network Analysis (SNA) provides a powerful approach to mapping and evaluating these interactions. This research uses a systematic literature review (SLR) and SNA to explore how communication is conceptualized within IS networks. The literature review highlights significant variation influenced by industrial contexts, geographic regions, actor roles, and methodological approaches.

Applying these insights, a practical SNA case study of the Twente Hub project reveals a centralized network structure where a single industrial stakeholder plays a central role, acting as a communication broker that links to various groups of research, community, and regulatory actors. Centralization, despite being efficient, creates a likely network vulnerability, such as information bottlenecks, which would compromise resilience. By combining theoretical deduction and empirical analysis, this research adds depth to the understanding of IS communication and demonstrates the practical application of SNA in identifying the major structural features and roles of actors that enable cooperation and network persistence.

Keywords

Industrial Symbiosis, Social Network Analysis, Communication, Stakeholder Coordination, Sustainability

1 Introduction

In the context of sustainable development and the circular economy business model, industrial symbiosis (IS) has emerged as an essential practice to enhance resource efficiency and mitigate environmental impacts. Through cooperation between several industrial organisations, IS allows the reuse and exchange of waste, water, and by-products, turning waste streams into valuable resources [18]. This approach aims to reduce waste and materials within the industrial ecosystem [8].

Communication is essential for successful resource exchange between industrial actors to maintain the cooperation, coordination, and trust [1]. However, understanding and optimising communication within the IS network remains challenging, as it involves various stakeholders, including firms, governments, research institutions, and non-governmental organisations (NGOs). It also requires the development of coordinated links and institutional capacity to manage formal and informal collaborations [5]. IS networks depend on effective information sharing, mutual understanding, and coordinated actions among participants. Successful communication practices can significantly reduce uncertainty, build mutual trust, and strengthen commitment among firms involved in resource exchanges [29].

Social Network Analysis (SNA) has become one of the methodological approaches to correlate the communication structure and a systematic map of IS [1];[2] . SNA enables researchers to visualise and quantify relationships within IS networks, providing insight into how information flows, collaboration strengths exist, and examines the organisation of different relationships [1]. Through SNA, communication dynamics can be depicted as networks where actors (nodes) and their communication ties (edges) are measured and analysed. This transition allows researchers to describe and evaluate the effectiveness and resilience of communication within IS networks.

This study builds on existing literature (e.g. [25]; [28]) that demonstrates the potential of SNA in IS research. Therefore, the existing IS demonstration has already been implemented in several countries (Germany, Türkiye, the Basque Country, and the Netherlands) as a "hubs for circularity (H4C)" for the project called IS2H4C [14]. The project focuses on systemic IS to develop sustainable technologies and infrastructure integration [14]. However, this thesis aims to go beyond general structural analysis by focusing on communication dynamics in the IS4HC project, specifically in the Dutch/Twente hub. A systematic literature review is needed to understand the context of communication dynamics in IS. These insights will lay the conceptual foundation for a future application of SNA in the Twente hub, enabling a more nuanced and contextually grounded understanding of the social processes underlying the implementation of IS.

1.1 Definition

To ensure conceptual clarity and terminology, this section presents definitions related to the circular economy(CE) and IS initiatives frequently referenced in the literature [26], as shown in Table 1. These definitions help distinguish between overlapping terms such as eco-industrial park', 'urban symbiosis', and 'hubs for circularity', which are often used interchangeably in the literature but vary in scale, location, and actor participation. Understanding the setting in which communication dynamics occur and analysing the literature discussed in this study. The terminology in Table 1 also supports the search syntax used throughout the systematic literature review, as shown in Table 2.

2 Problem Statement

Opacity in communication, trust, and organised communication hampers the effectiveness of IS. Although the physical transactions are well-documented, the social and communicative transactions

are not transparent. Mapping and analysing these communication patterns through the SNA approach can be used to identify how companies communicate, who holds the power, and where bottlenecks or gaps are present.

3 Research Questions

To address this research, the paper aims to answer the following two research questions: *"How have scholars conceptualised "communication" within industrial symbiosis networks?"* and *"How can Social Network Analysis be used to map and analyze communication patterns among stakeholders within the Twente Hub industrial symbiosis network?"*.

The first research question is to acknowledge that "communication" in IS has already been researched using the SLR method, and the second is to understand the implementation of the communication in IS using the SNA method with a case study of IS2H4C in the Twente hub.

In order to answer the research questions, the first research question (RQ) is divided into three sub-questions to gain a deeper understanding of the perspective that already involves "communication" in IS.

(1) In what industrial contexts and geographic regions has SNA of IS communication been applied?
(2) What roles do intermediary actors play in influencing/reshaping network communication according to existing studies?
(3) What limitations are identified in applying SNA to study communication in IS?

4 Methodology

This section discusses how to answer the research question. A systematic literature review (SLR) was adopted based on Denyer and Tranfield [27] as a guideline. A SLR is a structured and rigorous research methodology used to identify, evaluate, and synthesise all relevant studies on a specific topic. There are three steps, namely: (i) Planning the review, (ii.) Conducting the review, and (iii) Reporting the review [13].

4.1 Planning the Review

The author decided to use two databases, such as SCOPUS [9] and Web of Science [7], to gather literature reviews. Several keywords previously mentioned in Table 1 can be used to refine the search and focus on the specific topic of IS, as shown in the search syntax of Table 2. First in Scopus is TITLE-ABS-KEY, which matches the search terms within the title, abstract, and keywords. Second, the Boolean operators, such as the AND operator, were used to ensure that all specific keywords appeared in the search results simultaneously, and the OR operator was applied to include synonyms or related terms, thus broadening the search to capture variations in terminology related to IS and communication. Third, the search term of LANGUAGE was restricted to documents written in English to maintain linguistic consistency. Finally, the document type filter LIMIT-TO(DOCTYPE) was used to include only specific types of scholars work, namely review articles ("re") and journal articles ("ar"). Nevertheless, the search syntax in Web of Science is simpler than Scopus. The syntax includes TS (the same as TITLE-ABS-KEY), boolean operators (AND, OR), language, and document types [13].

4.2 Conducting the Review

The query across the two databases resulted in 39 articles with potential correlation to the study, comprising 17 and 22 from Web of Science and Scopus, respectively. The papers curated with a specific assessment and criteria for inclusion and exclusion have been designed to ensure the relevance and quality of the studies. The following inclusion and exclusion criteria were applied:

Inclusion Criteria

(1) The study must discuss IS within the communication using the SNA method
(2) The study must be of an Articles or Review document type to ensure academic standards
(3) The study must be published in English

Exclusion Criteria

(1) The study is incomplete, or restricted.
(2) The study focuses not on IS in communication
(3) The study is a duplicate, which can appear on both databases.

As a result, the step-by-step data selection process is illustrated in Figure 1.

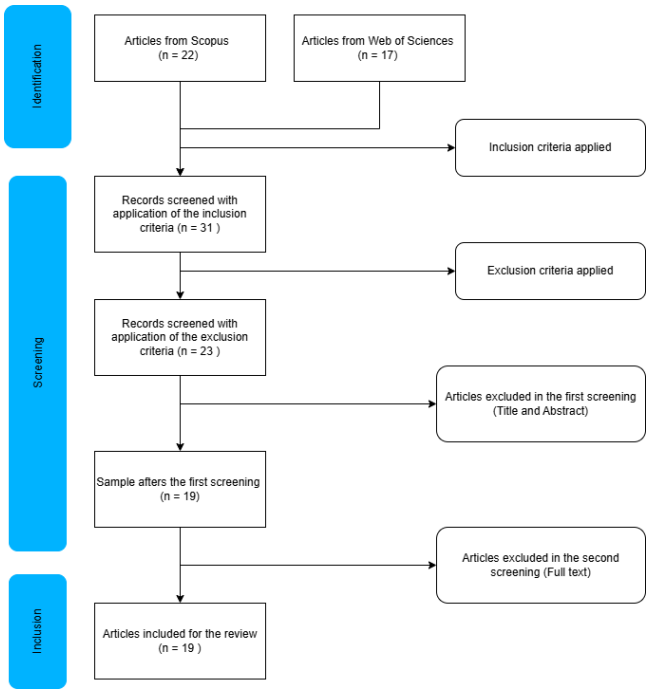

Figure 1: Selection Process

4.3 Reporting the review

After applying the inclusion and exclusion criteria, the number of documents was reduced to 23, and further reduced to 19 after the second screening. In this SLR, there is no restriction on years because the topic is still considered new to be discussed, as you can see in the search results in databases, which have only 39 results without any screening or filtering. From the 23 papers, 16 were

Table 1: CE industrial initiatives: definitions (Sources: Tleuken et al., 2025 [26])

Concept	Definition
Hubs for Circularity	Integrated ecosystems that apply circular economy (CE) principles to maximize resource use and reduce waste through sharing, reusing, and recycling.
Industrial Symbiosis	A mutually advantageous collaboration among industries where waste, by-products, and resources are exchanged to enhance efficiency and sustainability.
Eco-Industrial Park	A purposely designed industrial area that aims to reduce environmental impacts by promoting resource reuse, waste minimization, and energy efficiency through collaboration among businesses.
Urban Symbiosis	An adaptation of industrial symbiosis in urban areas focused on sustainable resource use, waste reduction, and stakeholder cooperation.
Sustainable Production Network	A network of interlinked organizations and businesses working collaboratively to optimize production, reduce costs, and improve environmental performance.
By-Product Synergy	The identification and exchange of one firm's waste or by-products as inputs for another,enhancing resource efficiency and minimizing waste.
Islands of Sustainability	Designated areas that exemplify high sustainability standards and serve as reference models for wider-scale sustainable development.
Positive Energy Districts	Districts that generate more renewable energy than they consume, supporting sustainability through strategic energy use and technology.
Zero-Waste Hubs	Communities or areas aimed at achieving zero waste by implementing practices like recycling, reuse, and waste minimization to avoid landfilling or incineration.
Industrial Recycling Network	A system of interconnected industries working together to recycle and reuse waste, materials, and by-products to reduce environmental harm within industrial sectors.

Table 2: Search Syntax on Digital Databases

Data Sources	Search Syntax
Scopus Database	TITLE-ABS-KEY("industrial symbiosis" OR "hubs for circularity" OR "eco industrial park*" OR "eco-industrial park" OR "urban symbiosis" OR "production network" OR "industrial cluster" OR "circular* hub*" OR "circular* ecosystem" OR " by-product-synergy" OR "island* of sustainability" OR " positive energy district*" OR "zero waste hub*" OR "industrial recycling network*") AND TITLE-ABS-KEY("social network analysis") AND TITLE-ABS-KEY("communication" OR "information exchange" OR "knowledge sharing" OR "collaboration" OR "trust") AND (LIMIT-TO (LANGUAGE,"English")) AND (LIMIT-TO (DOCTYPE,"re") OR LIMIT-TO (DOCTYPE,"ar"))
Web of Science	TS=("industrial symbiosis" OR "hubs for circularity" OR "eco industrial park*" OR "eco-industrial park" OR "urban symbiosis" OR "production network" OR "industrial cluster" OR "circular* hub*" OR "circular* ecosystem" OR "by-product-synergy" OR "island* of sustainability" OR "positive energy district*" OR "zero waste hub*" OR "industrial recycling network*") AND TS=("social network analysis") AND TS=("communication" OR "information exchange" OR "knowledge sharing" OR "collaboration" OR "trust") Refined by: LANGUAGES: (ENGLISH) AND DOCUMENT TYPES: (ARTICLES or REVIEW ARTICLE)

listed in Scopus and 7 were showcased on Web of Science. There are duplicate works listed on the Web of Science and Scopus, such as [26] and [25]. After 23 papers being reviewed, three papers were excluded due they were irrelevant to this review study. The details of 19 papers can be seen in Appendix B

5 Systematic Literature Review

This section provides a structured analysis of the findings derived from the SLR. There is both descriptive analysis and thematic content analysis, with a more specific focus on how communication is addressed in the IS setting. These findings are intended to identify patterns, define key concepts, and highlight gaps in the existing body of research.

5.1 Descriptive analysis

This section provides a quantitative analysis of the 19 selected studies in the SLR.

Table 3: Distribution Document Type

Type	2025-2020	2019-2015	2014-2010	2010-2000	Total
Journal Paper/ Article	8	4	2	3	17
Review	1	0	1	0	2
Total	9	4	3	3	19

Table 4: Distribution of Articles by Journal

Journal	Articles
Journal of Environmental Management	2
Competitiveness Review	1
Ecosystem Services	1
Sustainability (Switzerland)	1
Management Research	1
Journal of Cleaner Production	2
Regional Science Policy and Practice	1
Journal of Industrial Ecology	2
Business Strategy and the Environment	1
Chinese Geographical Science	1
Economic Development Quarterly	1
Journal of Material Cycles and Waste Management	1
Journal of the Textile Institute	1
BRQ - Business Research Quarterly	1
Journal of Management Studies	1
Journal of Construction Engineering and Management	1

Table 3 presents the distribution of the selected documents by type and publication period. The majority of the sources are journal articles (85%), with the highest concentration between 2020 and 2025. Review papers account for a smaller portion of the literature and are infrequently distributed across earlier years.
Table 4 shows the number of articles published in different journals included in the review. Although most journals contributed a single article, a few journals appeared more than once, indicating recurring interest in the topic within certain academic outlets. This suggests that research on IS and communication is gaining attention in various scholarly publications.

5.2 Content analysis

This section presents the perspective on communication in the industrial context, geographic region, actors, and limitations of the IS to address the research and sub-research questions stated in Chapter 3. Consequently, the findings suggest that communication within the IS network facilitates collaboration. Still, it can also become a source of conflict due to differences in interest and perspectives between actors.

5.2.1 Industrial Context This section addresses sub-RQ1 and examines how various sectors have already utilised IS upon realisation. In the *chemical and pharmaceutical industries*, good communication promotes critical resource sharing and managing environmental risks. Ashton [1] conceptualises communication as informal, relational interactions among managers, characterised by trust-building, knowledge spillovers, and interpersonal knowledge sharing, which maintain collaborative and resilient industrial ecosystems. He mentioned that informal relations are no contract between firms, which depend only on trust among managers. Similarly, Song et al. [24] expressly represent communication as direct processes involving direct advisory interaction, governance mechanisms, information exchange, formally negotiated accords, and nations. Communication becomes multidimensional, essential to organising stakeholder responsibilities, abilities, and handling hazardous waste within China's chemical industrial parks [24].

Clear communication within the *waste management and recycling sectors* is vital to changing waste streams into sustainable resources, ensuring precise information flow, and coordinating stakeholder resources and engagement. Song et al. [25] define communication as operational cooperation among anchor companies with scheduled exchanges as essential linkages for resource integration in China's coal and mining eco-industrial complexes. They claim that corporations implicitly communicate through established resource flows, with the quality of communication directly reflected in the efficiency and efficacy of resource sharing procedures. Yao et al. [30] further conceptualise communication through formal urban-industrial interactions, which are critical to integrating resource flows, governance frameworks, collaborative agreements, and waste management practices within the Yangtze River Delta. Moreover, Chammout and Eladaway[6] define communication as structured stakeholder dialogue in construction waste management to overcome decision-making barriers and promote the adoption of CE practices.

In *agro-industrial clusters*, scholars tend to conceptualise communication as strategic interaction aimed at fostering innovation and cooperation. Galaso and Rodriguez [11] view communication as a strategic alliance and interaction that builds a common regional identity and competitive advantage throughout Uruguay's dairy agro-industrial cluster, thereby enhancing regional competitiveness and collaborative innovation. They conceptualise communication as including strategic dialogue on coordinating regional actors with shared objectives. Additionally, Galaso, Miranda, and Picasso [12] also define communication as shaping strategic decisions about whether firms innovate through internal means or external cooperation mechanisms in the rubber and plastic industry. Their research posits strategic dialogues and exchanges underlying choices as communications. Communication is defined as strategic conversations and exchanges underpinning decisions critical to cluster competitiveness. Martinez-Chafer et al. [19] illustrate communication as mediated through brokers, which helps clear knowledge exchanges and directly influences innovation performance and cluster dynamics in agro-industrial clusters.

In *manufacturing and textile industries*, their characteristic is in classifying communication through informal relationship connections or effective structured interactions, which offer significant advantages of their own, especially for sustainable innovation and network strengthening. Communication is facilitated through informal networks based on personal and community ties within manufacturing clusters, informing the evolution of Henan's rural manufacturing clusters in China [17]. These network relationship-based connections facilitate the establishment of trust and informal knowledge sharing, which is vital for cluster resilience. Thus, formal and strategic communication are identified by Belso-Martinez [4] as imperative in driving technological innovation and adaptive competitiveness of textile clusters. Their concept of communication involves formalised interaction, deliberate exchanges(e.g., sharing resources, knowledge, or strategic information), and coordinated activities to foster continued innovation.

Effective communication is especially critical in the *construction industry* due to complex landscapes, diverse stakeholders, and sustainability transitions toward circular practices. Chammout and Eladaway [6] emphasise the importance of communication as a structured and necessary interaction for navigating the complex regulatory and stakeholder landscapes typical of the sector.

In *extractive industries, such as mining and coal*, effective communication networks enhance environmental regulation, operational efficiency, and resource management. Song et al. [25] demonstrate how well-designed and reliable communication channels facilitate the successful exchange and recycling of materials to ensure mining sustainability.

Finally, broader industrial *ecosystems and general sustainability* contexts require sophisticated and nuanced communication plans to be able to effectively deal with a diverse range of stakeholders, facilitate knowledge sharing, and sustain cooperative interaction in the extended period. Ashton and Bain [2] understand communication as lowering " short mental distances", involving trust, openness, and mutual understanding among companies. They contend that such decreases in mental distance directly enhance operating efficiency, facilitating smoother interactions and more efficient information sharing, thereby emphasising communication as central to effective symbiotic relationships. Domenech and Davies [8] quoted communication as implied social mechanisms, such as trust, reciprocity, and cooperation facilitated through effective communication, that are required for the long-term sustainability of IS networks. Barraclough et al. [3] propose communication as structured stakeholder interactions that can be systematically mapped to identify and address collaboration gaps within ecosystem service governance systems.

5.2.2 Geographic Regions This section will address sub-RQ1 and analyse how geographic contexts have significantly influenced the communication dynamics within IS networks through region-specific governance, cultural, and infrastructural characteristics. In Europe, research emphasises diverse industrial settings and highlights the importance of embedded social mechanisms. Domenech and Davies [8] highlight Europe's social institutions, including reciprocity and trust, as foundations of long-term collaboration. Moreover, local and community involvement enable effective communication for technology adoption, reinforcing the importance of regional embeddedness in rural Italy [10]. Thus, Martinez-Chafer et al. [19] and Belso-Martinez et al. [4] stress geographic proximity as the most crucial standard for high-quality communication within European industrial clusters. High-quality communication involves structured, strategic, and timely knowledge exchanges, enabling practical innovation and competitiveness.

In Latin America, regional identities and strategic communication alliances facilitate collaborative innovation. Galaso and Rodriguez [11] underline how communication shapes shared regional goals and enhances innovation capacities in Uruguay's dairy clusters. Furthermore, Galaso, Miranda, and Picasso [12] reinforce this, showing how local communication patterns strategically influence innovation decisions in rubber and plastic clusters.

Asian contexts, particularly in China, communication practices within IS are distinctly shaped by regional governance structures and policy frameworks. Song et al. [25] and Song et al. [24] highlight region-specific governance and regulatory influences, particularly within eco-industrial parks and hazardous waste sectors. Yao et al. [30] analyse the governance-driven regional communication frameworks, detailing how local regulatory policies within the Yangtze River Delta shape effective urban-industrial integration processes. Li et al. [17] further emphasise the importance of local informal communication networks, which encourage resilience in rural Chinese manufacturing clusters. Besides China, research is also conducted in South Asia, specifically in Nanjangud, Southern India. Ashton and Bain applied their communication framework to implement it in the real world, such as lowering "short mental distances" and fostering trust, openness, and mutual understanding among companies [2].

Regional characteristics, including political and regulatory contexts, influence communication practices in North America and the Caribbean. Ashton [1] highlights how unique regional systems and cultural practices within Puerto Rico shape effective communication in the pharmaceutical sector.

In the Middle East, notably Turkey, geographic proximity and regional organisational structures facilitate innovation-driven communication within industrial clusters. Kaygalak and Reid [16] underscore how regional geographic proximity supports knowledge spillovers and effective communication among innovation actors.

5.2.3 Actors This section will answer sub-RQ2 and determine whether actors within IS networks serve as critical intermediaries, brokers, and facilitators who shape communication through their roles and interactions. Governmental and regulatory actors influence stakeholder coordination and structured communication frameworks. Song et al. [24] detail the crucial roles of governmental bodies in structuring stakeholder interactions within hazardous waste management contexts, highlighting the importance of clarity and regulatory alignment. Likewise, municipal authorities are implicitly influential, shaping communication frameworks essential for sustainable urban-industrial integration [30].

Network brokers and facilitators also significantly influence the effectiveness of communication and innovation outcomes within IS. Filippini et al. [10] and Martinez-Chafer et al. [19] refer to brokers as enabling open and structured communication channels for improving technological adoption and innovation success in agro-industrial settings. In contrast, Galaso, Miranda, and Picasso [12] highlight strategic intermediaries influencing innovation decisions through selective communication.

Intermediaries who build trust facilitate effective communication through informal relationship-building and the development of social capital. Ashton [1] explained how informal communication practice enables flexibility as well as resilience in the pharmaceutical setting. According to the examples in articles [2] and [8], trust facilitators are essential intermediaries for ensuring long-term cooperation and robust relational networks.

Knowledge intermediaries, including small and medium enterprises (SMEs) and regional actors, have crucial roles in managing heterogeneous knowledge flows and innovation practices through structured communication. SMes intermediaries enhancing explicit knowledge in exchanges across organisational boundaries [23]. Correspondingly, the roles of regional intermediaries strengthen informal networks that underpin practical regional innovation [22].

Operational intermediaries ensure the systemic integration and coordination of communication within regional IS contexts. Vahidzadeh et al. [28] emphasise the importance of structured regional intermediaries that facilitate systematic operational coordination and the accuracy of communication processes. This argument is also strengthened in [3], where the author averred that structured stakeholder communication enhances effective collaboration in ecological management systems.

5.2.4 Limitation of Communication in IS This section will answer sub-RQ3 and give perspectives on the limitations of communication that occurred in IS. Despite the acknowledged centrality of communication in IS networks, scholars have identified several methodological and conceptual limitations that affect the understanding and implementation of these networks. Quantitative approaches, notably SNA, often inadequately capture informal, implicit, and relational communication dynamics. Using purely quantitative methods overlooks essential informal relationships, advocating complementary qualitative analysis [1]. Domenech and Davies [8] reinforce these limitations, recommending qualitative methodologies to capture nuanced, embedded social interactions. Another method, like qualitative triangulation, can be implemented to understand complex inter-firm knowledge exchanges beyond purely quantitative measures [23].

Information-sharing and stakeholder coordination gaps constitute additional communication limitations within the IS network. A gap in information-sharing practices suggests that mixed-method solutions are needed to address barriers and enhance the efficacy of structured communication [24]. Thus, Vahidzadeh et al. [28] comment on methodological limitations, explicitly calling for the combination of qualitative stakeholder feedback to mitigate inherent issues related to communication clarity.

Sector-specific methodological complexities further challenge effective communication analysis within specific industries. There are methodological barriers in capturing informal communication practices in the construction industry, arguing for qualitative methodological advancements [6]. Communication in every sector presents its challenges when implemented. In the ecological management sector, methodological complexities arise in implementing mixed-method approaches to accurately map and understand intricate stakeholder interactions [3].

5.2.5 Communication in IS networks This section will answer RQ1 and synthesise the findings from sections 5.2.1 through 5.2.4. Scholars present varied yet interconnected conceptualisations of communication within IS networks. Rather than viewing communication solely as generic information exchange, researchers interpret it through multiple nuanced dimensions influenced by industrial context, geographic factors, involved actors, and acknowledged methodological limitations.

In various industrial contexts (5.2.1), communication is conceptualised in diverse ways, reflecting the specific interaction and operational structures of each industry. Within the chemical and pharmaceutical industries, they outline communication throughout relational and cognitive frameworks such as reducing "short mental distance", structured governance dialogues, advisory interaction, and formal stakeholder agreements [2];[24]. In contrast, waste management and recycling contexts convey communication through resource exchanges and organised operational interactions, facilitating communication between firms [25]; [30]. Agro-industrial clusters offer a distinct perspective on conceptualising communication, where communication becomes a strategic interaction, and brokerage roles are crucial for innovation and regional competitiveness [11]; [19]. The manufacturing context exhibits a duality, with researchers explaining communication in terms of informal community relations [4] or formalised strategic interactions for competitiveness reasons [17]. Finally, in broader sustainability settings, communication is explained in terms of informal relational networks [1] and embedded social processes, such as trust and reciprocity [8], observing both formal and informal stakeholder interactions as crucial to collaborative efficacy [3].

Geographic contexts (5.2.2) further shape conceptualisations of communication. Scholars argue that regional factors, including governance structures, proximity, and cultural dimensions, influence communication patterns. For instance, European studies define communication as embedded regional social interactions involving trust and reciprocity, which are critical for collaborative innovation [8]; [10]. In Latin America, strategic communication supports regional identity, collaborative innovation, and informed decision-making [11]; [12]. In contrast, in Asian contexts, specifically China, communication is shaped by governance-driven interactions within industrial clusters and urban-industrial integration [25]; [30]. In India, they discovered that their communication framework (" short mental distances", trust communication, and openness communication) can be implemented in real-world situations. Similarly, geographic proximity facilitates communication and knowledge exchange in Middle Eastern industrial contexts, as noted by Kaygalak and Reid [16].

Actors within IS networks (5.2.3) make the evolution of communication, serving as intermediaries, brokers, and facilitators. Governmental and regulatory actors structured stakeholder communications through regulatory compliance and governance frameworks, as described by Song et al. [24] and Yao et al. [30]. Scholars define network brokers explicitly as mediators of structured interactions, directly influencing innovation outcomes and cluster dynamics [10];[19]. Additionally, trust-building intermediaries encourage informal relational networks and embedded social mechanisms that are critical for long-term collaborative relationships [1]; [8]. Knowledge intermediaries, such as SMEs and regional actors, shape structured and informal knowledge flows across organisations [23], underscoring their importance as critical communicative actors within IS networks.

Communication in IS networks faces methodological limitations 5.2.4. Scholars identify significant gaps regarding quantitative methods, such as SNA, which often inadequately capture the informal and tacit dimensions of communication [1]; [8]. Explicit calls have been made for mixed-method approaches integrating qualitative insights to address these limitations and better reflect the complexity and subtlety of communication dynamics within IS networks [6]; [3].

Lastly, scholars conceptualise communication in IS networks as multidimensional, contextual, and conditioned by geographic attributes, actor positions, and methods. Communication is often portrayed as comprising structured operating interactions, informal

social processes, strategic alliances, and mediated brokerage functions, which are inherent in successful resource exchange, innovation development, and the sustenance of collaborative partnerships.

6 Study Case

To answer research question two, a case study is conducted to investigate how SNA can be used to map and analyse communication patterns among stakeholders within the Twente Hub industrial symbiosis network. Twente Hub [15] is part of the IS2H4C project, which features a hydrogen hub comprising around 20 industry companies connected to the nearby village of Aadorp. This project aims to develop into a Hub for Circularity by limiting its reliance on fossil-based electricity and natural gas. In the meantime, the project is still in progress due to time constraints and the development of new energy (wind energy) that they want to implement in the Twente Hub.

6.1 Methodology

The case study analysis related to communication, regulatory, and monetary perspectives was conducted using SNA in the Twente Hub. In this analysis, communication is categorised into three perspectives: information sharing, monetary, and regulatory. This study aims to provide a deeper understanding of social dynamics that extend beyond a communication perspective, encompassing formal regulations and financial flows to capture a more comprehensive view of stakeholder coordination. To effectively analyse the structure of IS, it is essential to understand the definition of SNA and how it will be implemented at the Twente Hub. SNA is a strategy for investigating social structures that can be applied in various fields, including cooperation, acquaintance, disease transmission, social communication, and resource utilisation [20]; [25]. Social network structures have characteristics such as nodes representing individual actors or entities within the network and edges symbolising the relationships or interactions that connect them [20]. For the Twente Hub case, the nodes consist of Industrial Companies, noted as squares, Research and Technology Organisations, symbolised as triangles, Community Organisations, represented as circles, and Regulatory Bodies, represented as stars. Hence, the edges consist of communication, monetary, and regulatory. As the yellow line represents, communication encompasses information exchange, knowledge sharing, collaborative discussions, and trust-building interactions. The monetary line denotes financial transactions, resource exchange with economic value, and contractual agreements. The regulatory line, indicated by a dashed red line, is associated with compliance-related interactions, policy implementation, permitting, and oversight.

In this study, we employed a quantitative method for visualisation purposes. The IS4HC project research team collected the dataset for this analysis. After collecting the data, we model the SNA using Python [21] with the documented data in comma-separated values (CSV) format. Python software was utilised strictly for network visualisation. For confidentiality purposes, stakeholder identities are anonymised using abbreviations in the network visualisation.

6.2 Results and Analysis

The specific data analysed for the Twente Hub network are shown in Figure 2. As shown in Figure 2, there is a node that

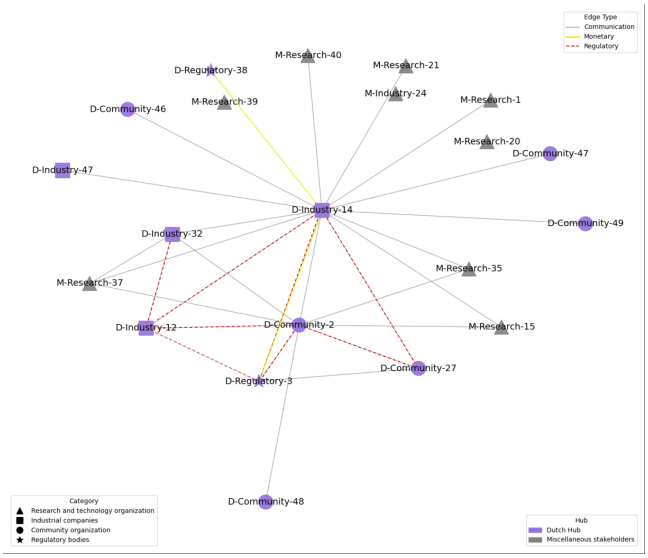

Figure 2: Social network structure of IS in Twente Hub (bigger picture can be seen in Figure 3)

demonstrates high connectivity, spanning all three relationship types and encompassing a diverse range of stakeholders, which is D-Industry-14. Consequently, D-Regulatory-3 also spans three relationship types, which play a crucial role in IS networks. Furthermore, from a community perspective, there is an actor quite helpful in working with the regulatory authority, which is D-Community-2. D-Community-2 impacts the IS network because the community communicates with D-Community-27, D-Industry-12, and D-regulatory-3, which are related regulators.

The network shows the flows of structured communication, originating primarily from D-Industry-14, to boundary actors such as community actors (e.g., D-Community-2, D-Community-27, and D-Community-47) and research actors (e.g., M-Research 1, M-Research 15, M-Research 21, M-Research 35, M-Research 39, M-Research 40, and M-Research 41). These structured stakeholders correspond to the state described by Song et al. [24]. In his study, successful implementation was the result of effective coordination among stakeholders, which minimised hazardous waste treatment to almost zero. However, the D-Industry-14 also presents a situation where possible vulnerabilities, such as information bottlenecks or reliance on a single actor for critical communication, exist, which could compromise network resilience and adaptability.

The yellow line indicates that monetary interactions are limited, specifically between D-Industry-14 and D-Regulatory-38, and between D-Industry-14 and D-Regulatory-38. This targeted financial interaction likely involves contractual agreements or formalised economic exchanges for regulatory compliance or project implementation. Due to the limited monetary interactions, D-Industry-14 has control and compliance with the monetary aspects of this project. However, this scenario has flaws, including restricted flexibility and responsiveness in resource allocation.

The regulatory interactions (red dashed lines) include the key regulatory body, D-Regulatory-3, in close interaction with community organisations (D-Community-2 and D-Community-27) and industrial companies (D-Industry-12). Industrial companies (D-Industry-12) also support various stakeholders in regulatory discussions, including other industry companies (D-Industry-32), community organisations (D-Community-2), and regulatory bodies (D-Regulatory-3). This structured and clear regulatory communication aligns closely with the literature's depiction of regulatory stakeholders as influential facilitators and compliance overseers [24];[6]. Twente Hub regulatory authorities play a crucial role in ensuring compliance, directing resource allocation, and shaping policy in the IS setting.

From a stakeholder categorisation perspective, the community organisation appears to have actively integrated the communication and regulatory processes, indicating an influential role in the IS system, which aligns with previous interpretations of communication (as discussed in Section 5.2.3). Industrial companies facilitate all communication, regulatory, and monetary interactions. Another important stakeholder is a research and technology organisation that provides advisory support and technological input for operational innovation and sustainable practices in IS networks. Lastly, the regulatory bodies that influence policy decisions ensure that the resource will not impact other industries, communities, or society.

This case study provides information on various perspectives of communication among different stakeholders, using SNA. It visually maps communication patterns to evaluate the network structure and assesses the roles of diverse stakeholders. This comprehensive understanding of communication dynamics is essential for improving stakeholder coordination and collaboration, thereby supporting ongoing sustainability initiatives within the Twente hub.

7 Conclusion

In conclusion, this study presents a communication dynamics within IS networks through SNA by applying an SLR and a practical case study of the Twente hub within the IS4HC project. The research contributes to understanding how scholars conceptualize communication in diverse industrial contexts, drawing on their perspectives within the communication framework when dealing with real-world situations. Moreover, geographic regions significantly influence these conceptualizations, with differences in regional governance, trust, and cultural proximity shaping communication patterns within IS networks. Notably, the role of intermediary actors highlights the importance of brokers, governmental entities, and community organizations as essential facilitators in network communication. Thus, the methodological limitations of quantitative methods alone in capturing insufficient aspects of informal communication necessitate the use of mixed-method approaches that integrate qualitative insights to fully understand the nuanced social dynamics in IS.

Applying these insights to the Twente Hub case study demonstrates the practical value of SNA for mapping and analyzing stakeholder interactions. The visualisation in Figure 2 identified a central industrial stakeholder (D-Industry-14) as a critical communication broker and potential vulnerabilities resulting from centralised communication patterns. Regulatory and monetary aspects provide additional insights into understanding the significant impact on every stakeholder, as well as the structured regulation and financial flows within the Twente Hub.

7.1 Limitations

This research has several limitations that must be acknowledged. Firstly, time constraints, one of the main obstacles when conducting this thesis, were a limitation on time, which impacted the results of the analysis and validation of findings. Secondly, a knowledge gap concerning the advanced application of the SNA posed methodological challenges. Due to limited familiarity with in-depth quantitative analysis, this study adopted only general SNA characteristics (nodes and edges), which can provide potential insights, such as network density, centrality, and network growth over time, similar to the work by [20] when using the SNA method. Moreover, since the data collection for the SNA visualisation relied on secondary data provided by the IS2H4C project team, the analysis is dependent on the completeness and accuracy of their dataset. The absence of primary data collection means the results presented might not fully capture all nuances of stakeholder communication dynamics, particularly informal or tacit knowledge exchanges that are often inadequately documented. Thus, there is an incomplete understanding of the roles and functions of individual stakeholders within the Twente Hub. For example, the role of miscellaneous stakeholders, or why D-Community-2 is crucial in regulatory interactions. This limited clarity prevented a deeper interpretation of their influence in IS networks.

Moving forward to SLR, the topic of communication remains small, making it difficult to find and understand the author's meaning from a communication perspective. Another limitation is the reliance on databases from only Scopus and Web of Science, which could be expanded to include additional databases for a more comprehensive analysis.

7.2 Future Work

This study makes several recommendations for further research. The first is an extensive application of SNA in quantitative methods (measuring density, centrality, or network growth). The second is expanding the scope of analysis beyond the Twente Hub to include Germany, Türkiye, and the Basque Country. Thirdly, the area of IS can still be explored. For example, from a resource or regulatory perspective, the IS can be implemented in those four countries and worldwide by exploring that new perspective. Lastly, adding additional databases for the literature review.

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A Appendix- Disclosure

During the preparation of this paper, the author used Grammarly to improve the use of language and consistency in writing. ChatGPT was also used to make the table in LaTeX format. After using this tool/service, the author reviewed and edited the content as needed and takes full responsibility for the content of the work.

B Appendix- List of all papers used for the SLR and insights from each paper

In the next page

Ref. no.	Title of the Article	Industrial Context	Geographic Region	Actors	Limitations
[1]	Understanding the organization of industrial ecosystems: A social network approach	Pharmaceuticals industry	Puerto Rico	Informal relationships	Challenges capturing informal communication through quantitative methods
[2]	Assessing the Short Mental Distance in Eco-Industrial Networks	General industrial ecosystems	South India	Social capital and intermediary roles	
[3]	Mapping stakeholder networks for the co-production of multiple ecosystem services: A novel mixed-methods approach	Ecosystem services		Stakeholders in ecosystem service networks	Advocates methodological rigor and qualitative-quantitative integration
[4]	Delving into the technical textile phenomenon: networking strategies and innovation in mature clusters	Technical textiles clusters	Mature clusters (Europe and developed regions)		
[6]	Circular Economy in Construction: Decision-Making Factors and Future Research Avenues	Construction industry			Informal interactions, recommending qualitative methodological enhancement
[8]	The role of Embeddedness in Industrial Symbiosis Networks: Phases in the Evolution of Industrial Symbiosis	General industry perspective	Europe	Trust-building and intermediaries	Advocates for qualitative approaches alongside quantitative SNA
[10]	Social networks as drivers for technology adoption: A study from a rural mountain area in Italy		Italy	Network intermediaries	
[11]	Strategic collaboration in agro-industrial clusters: territorial dynamics within the dairy industry in Uruguay	Agro-industrial dairy sector	Uruguay		
[12]	Inter-firm collaborations to make or to buy innovation: Evidence from the rubber and plastics cluster in Uruguay	Rubber and plastics industry	Uruguay	Inter-firm brokerage roles	
[16]	Innovation and knowledge spillovers in Turkey: The role of geographic and organizational proximity		Turkey		
[17]	Relationships and evolving networks of rural manufacturing clusters: A case study in Yucheng County, Henan Province of China.	Rural manufacturing clusters	Henan Province, China		

Continued on next page

Ref. no.	Title of the Article	Industrial Context	Geographic Region	Actors	Limitations
[19]	The cluster is not flat. Uneven impacts of brokerage roles on the innovative performance of firms	Agro-industrial clusters	Europe	Brokers influencing innovation performance	
[22]	Cluster regions: A social network perspective			Informal network ties and regional development actors	
[23]	Heterogeneity and specificity of inter-firm knowledge flows in innovation networks			SMEs and inter-firm knowledge intermediaries	Methodological limitations in capturing knowledge exchange nuances
[24]	Stakeholder coordination analysis in hazardous waste management: a case study in China	Hazardous waste management, chemical industry	Shanghai Hangzhou Bay, China	Government and third-party supervisors	Limitations of communication and information sharing, mixed-method suggestions
[25]	Social network analysis on industrial symbiosis: A case of Gujiao eco-industrial park	Coal and mining industry	Gujiao, China		
[26]	Designing a stakeholder engagement framework with critical success factors for Hubs for Circularity				
[28]	Regional industrial symbiosis: A review based on social network analysis			Operational intermediaries	Limitations of quantitative SNA and recommendations for qualitative integration
[30]	Symbiotic integration of waste disposal capability within a city cluster: The case of the Yangtze River Delta.	Waste management industry	Yangtze River Delta, China	Municipal authorities	

C Appendix- Interpretation of Communication in Reviewed Studies

Table 6: Interpretation of Communication in Reviewed Studies

Ref	Author	Interpretation of Communication
[1]	Ashton (2008)	Informal relational exchanges among actors, focused on trust, knowledge spillover, and resilience through interpersonal connections.
[2]	Ashton and Bain (2012)	Reducing cognitive barriers or "short mental distances" through trust, openness, and mutual understanding among collaborating firms.
[3]	Barraclough et al. (2022)	Structured stakeholder interactions that can be mapped and analyzed systematically to identify gaps in collaborative governance.
[4]	Belso-Martinez et al. (2020)	Formalized and strategic relational practices, structured knowledge-sharing events, and coordinated interactions driving cluster innovation.
[6]	Chammout and Eladaway (2025)	Structured decision-making processes emphasising stakeholder coordination, clear role definitions, and formal governance approaches in circular construction.
[8]	Domenech and Davies (2011)	Embedded social mechanisms, including trust, reciprocity, and informal interactions that underpin long-term symbiotic relationships.
[10]	Filippini et al. (2020)	Intermediated social interactions and network brokerage roles that enable technological knowledge transfer and adoption within rural clusters.
[11]	Galaso and Rodriguez (2022)	Strategic collaboration embedded in relational networks within regional clusters, involving trust-based interactions and informal dialogue.
[12]	Galaso, Miranda, and Picasso (2019)	Strategic decision-making interactions where firms communicate to determine collaborative or independent innovation pathways.
[16]	Kaygalak and Reid (2016)	Communication influenced by geographic and organizational proximity, enhancing informal knowledge spillovers and innovation collaboration.
[17]	Li et al. (2011)	Informal local community and personal relationships facilitating trust, cohesion, and knowledge sharing within manufacturing clusters.
[19]	Martinez-Chafer et al. (2018)	Mediated through brokerage roles facilitating explicit knowledge exchanges, shaping cluster innovation dynamics significantly.
[22]	Reid, Smith, and Carroll (2008)	Informal relational ties and network interactions underpinning regional economic and innovation dynamics.
[23]	Sammarra and Biggiero (2008)	Structured yet heterogeneous inter-firm knowledge flows facilitated by intermediaries to manage innovation network complexity.
[24]	Song et al. (2021)	Structured stakeholder dialogues and governance interactions for coordinating hazardous waste management responsibilities.
[25]	Song et al. (2018)	Implicit communication represented through structured industrial symbiosis resource flows and operational interactions.
[28]	Vahidzadeh et al. (2021)	Communication as structured interactions managed by operational intermediaries, ensuring clear and coordinated regional industrial symbiosis activities.
[30]	Yao et al. (2023)	Structured urban-industrial exchanges shaped by regulatory governance and resource integration strategies in waste management.

D Appendix- Result of SNA (big size version)

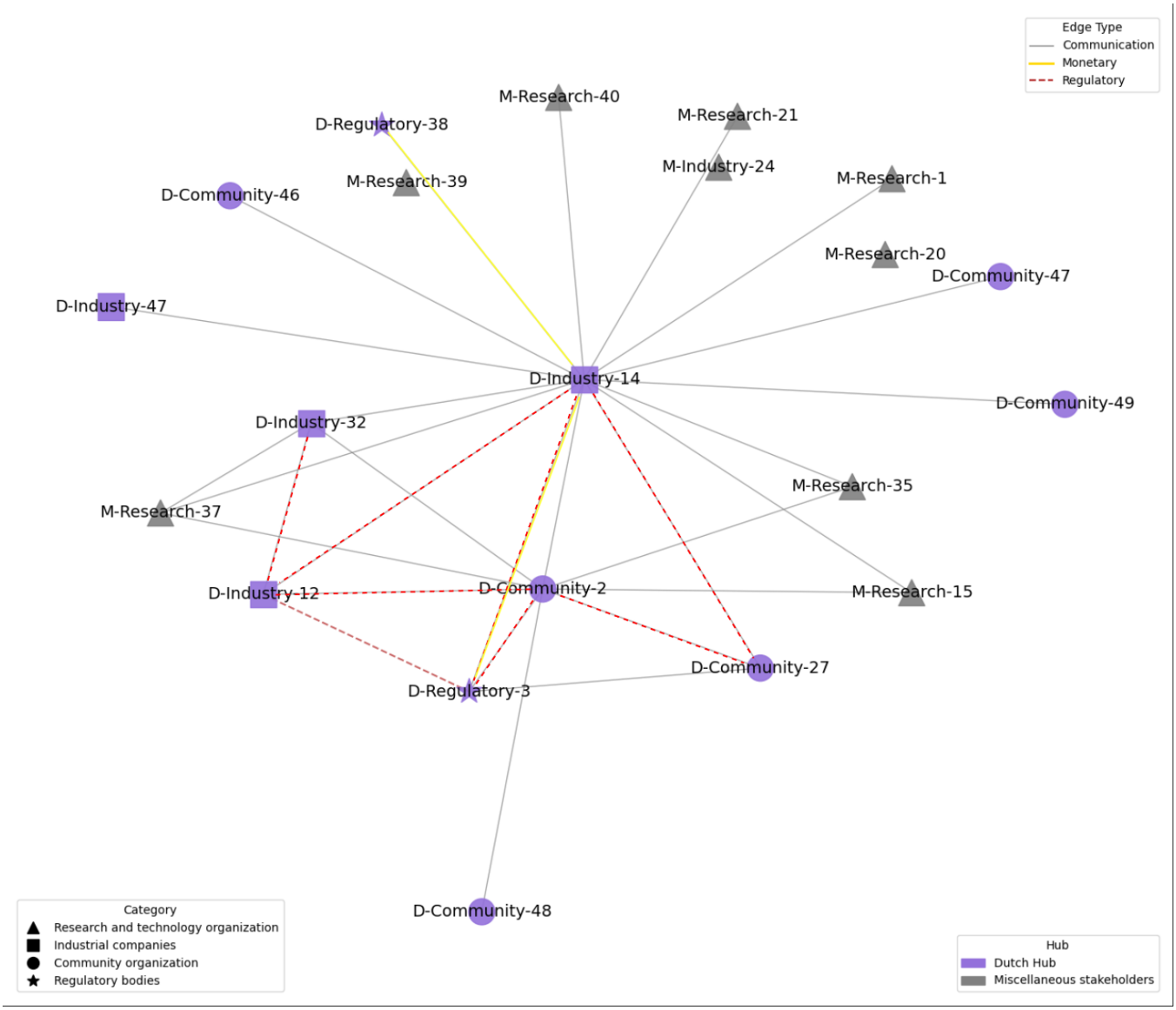

Figure 3: Social network structure of IS in Twente Hub