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EXECUTIVE SUMMARY OF THE THESIS

Inter-firm collaborations, networks and facilitators: how industrial symbiosis disseminated in Italy.

TESI MAGISTRALE IN MANAGEMENT ENGINEERING – INGEGNERIA GESTIONALE

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1. Introduction

Resources on Earth are limited but every year humanity consumes more than what the planet can regenerate. The linear economy, the take-make-waste approach, is not sustainable nor at environmental nor at economical level.

Among the possible solutions to this challenge, one is circular economy, which aims to design out waste and pollution, extend the lifespan of resources, and regenerate natural systems [1].

Industrial symbiosis (IS) is a strategy to achieve circular economy and on a wider aspect sustainable development and has been defined as an inter-firm exchange of materials, water, energy and byproducts for mutual benefits [2].

The subject of IS gathers more relevance every year, private and public organizations all around the world are working to foster the development of this strategy in manufacturing and urban context.

The aim of this research work is to better understand the development of industrial symbiosis practices in Italy. Particularly providing novel contributions about the role of digital technology in the development of IS, and on the relationships and collaboration among the stakeholders in a symbiosis. In the existing literature there are few publications on the employment of digital technologies in IS and even fewer on the collaborations and relationships among the stakeholders of a symbiosis, therefore the aim of this research is to reduce the gap in the existing literature.

In summary the scope of this research is to answer the following research questions:

1. How and when industrial symbiosis cases emerged in Italy?
2. What kinds of relationships and exchanges exist among the stakeholders of the industrial symbiosis?
3. What are the digital technologies used in industrial symbiosis?

2. State of the Art

A narrative literature review has been performed to deepen extant literature about IS and, for

instance, provide an overview of IS genesis and the evolution of IS definition over time.
The field of IS came from industrial ecology, a field that examines the interconnections between society, the economy, and the natural environment. It focuses on optimizing the entire materials cycle, from raw materials to disposal, by promoting resource reuse and recovery [3].
Industrial ecology and circular economy share tools, technologies and regulatory frameworks, in fact IS is a strategy to achieve both.

The concept of IS evolved in the last decades, but the most common definition and classification used is the one from Chertow's Taxonomy [2] that identified five types of material exchanges considering the proximity among involved companies and the kind or resource exchanges.
The resources exchanged in a symbiosis are material, by-products, utility, infrastructure, services, information and knowledge.
Proximity among the involved companies is a relevant dimension, it emerged that in most of the cases of IS in Europe the distance among the stakeholders is lower than 30 km.
The development phase of an IS can be research & planning, emerging, developed or declining. While the emerging phase of IS can be classified as: planned, facilitated or self-organized, the first two items of the list involve a management body or coordinator that planned or just supported the stakeholder in the execution of the symbiosis [4], while the latter emerge spontaneously from interfirm collaborations and material exchanges. Facilitated symbiosis can be both top-down and bottom-up, while planned symbiosis are always top-down.

Drivers and barriers to the emergence of ISs can be grouped into macro subjects: economic and financial, technical, legal and political, informational, organizational and motivation, geographic context, intermediaries, environmental, social. While the benefits can be economic, environmental and social, with a particular focus on the first two. Drivers, barriers and benefits were presented in detail with attention to the most recent literature review on the matter [5, 6, 7].

The last subject discussed in this chapter is the first documented case of IS, Kalundborg. The symbioses evolved spontaneously over more than 50 years. The drivers for its development were minimize the cost of compliance with the stricter environmental regulations of the 70s and interest in finding new market opportunities for the by-products of the industrial district [3].

3. Methodology

The research followed a mixed approach to address the research questions. The first phase was a systematic literature review on IS to develop an understanding of the current academic landscape and to find the gaps in the literature. The literature review was performed using as main sources Scopus, Google Scholars and Symbiosis Users Network, the website of the Italian network for industrial symbiosis. After the cleaning of the search result the final output was a list of 310 articles and 37 reviews.

Table 3-1 Framework for the case studies database

Dimensions of the case study framework
Industrial Symbiosis Code
Description
Involved Companies
Number of involved organizations
Geographic Area
Productive sectors
ATECO Code
Digital Technologies
Proximity
Taxonomy
Shared or exchanged resources
Top-down o bottom-up
Public administration involvement
EU or regional initiatives used for funding IS initiatives
Facilitator
Current State of IS
Emerging Phase
Butterfly Diagram
CE Matrix
Sources

The second step was the creation of a database of IS cases in Italy using as main sources Scopus, Google Scholars and Symbiosis Users Network for the academic papers while for grey literature the main source has been EcoCamere, the official website of the Italian Chambers of Commerce. The output of this phase was the creation of a database

of 50 case studies on the Italian context with different level of development and sizes.
In table 3-1 are presented the dimensions considered for the creation of the database.

The third phase was the definition of an interview guideline, a series of open-ended questions grouped in 3 topics, and the selection of some case studies to deepen to better understand the relationships among symbiosis stakeholders, the role of digital technology in this strategy and how each case developed. Five case studies and the role of ENEA as IS facilitator were deepened running 10 interviews that involved 12 interviewees. Each interview was transcribed and manually analyzed.

The fourth phase was the analysis of the database and of the interviews. The collected data enabled the identification of recurring patterns, themes, and the identification of the categories within the various cases of industrial symbiosis in Italy.

4. Findings

Database on industrial Symbiosis

Starting with the quantitative analysis of the database, 27 of the 50 cases are self-organized and were developed without the support of a facilitator. The most common facilitators are public administration, such as universities and national agency, that support firms in the identification of the potential symbiotic exchange and in the assessment of the benefit of each resource exchange considering the economic and environmental dimension.

A distinction was observed between the 7 cases that emerged from industrial districts and the other 43, the formers involved on average more than 200 companies while the latter only 5.

Figure 4-1 Number of IS cases for each Italian region.

As can be seen in Figure 4-1 the regions of Campania, Basilicata, Liguria and Val d'Aosta do not have documented cases of IS, while Lombardy, Sicilia, Calabria and Umbria have more than 4 cases.

Manufacturing, environmental service and agri-food are the most common sectors involved in industrial symbiosis. By-products and material are the most commonly shared resources followed by energy and water, while information, infrastructure and knowledge are rarely shared in industrial symbiosis.

Industrial Symbiosis case studies

The main chapter of the finding presents the five case studies deepened with interviews.
Case S1 takes place in Lombardy, specifically in the province of Brescia. It is a case of self-organized symbiosis that involves the steel plant of Calvisano, that processes scrap steel through electric arc furnace, and a fish farm. The two plants were designed and developed together in the 1970s with the scope of saving costs and finding additional profit sources. The resource exchanges between the stakeholders are regulated with traditional contract excluded information that is shared mutually. The development of this symbiosis didn't require digital technologies; however, they are used in the manufacturing processes of the two companies.

Case T1 is about the tannery district of San Miniato, Tuscany. Where two main resource flows can be identified: wastewater and material by-products.

The former is a case of planned symbiosis that was pushed by a normative change in the 1970s, while the latter is a case of spontaneous symbiosis with a longer history. The tanning industry is intrinsically characterized by industrial symbiosis and has a long history of circular economy. The input of this industry is animal skin, a by-product of cattle farming, and its outputs are leather goods and by-products that are used as input for the manufacturing of fertilizers and gelatine for the food and pharmaceutical industries. The exchange of material and by-products in the symbiosis does not use any digital platform and everything is managed and regulated through traditional business contracts.

Case M1 takes place in Fiemme Valley, Trentino Alto Adige, and began in 1999. It is a case of planned symbiosis with Bioenergia, an energy and heat provider, as coordinator and management body. The utility provider recovers and exploits forestry's by-products from local sawmills and logging activities. Its plant in the village of Cavalese produces heat burning wood chips in a boiler for the urban district heating. It also produces electricity through a cogeneration plant and promotes the installation of PV panels in the villages. No digital technologies were identified as necessary for this symbiosis; however, all the companies employ digital sensors in their processes control. The relationships among the parties are regulated by contractual agreements, in addition the sawmill of the Magnifica Comunità di Fiemme and the municipality of Cavalese are shareholders of Bioenergia.

Cace S2 is a case of facilitated and planned symbiosis when speaking about heat recovery, and of spontaneous symbiosis about material resources and by-products. It takes place in Lombardy, specifically in the province of Brescia, and is the result of the regional project and fund Banco EnergETICO. The residual heat of the production process of Alfa Acciai is recovered from the pipe-to-pipe fumes line, coming out of the melting furnace. A2A Calore e Servizi produces thermal energy from the recovered heat, which is distributed through the urban district heating of the city of Brescia. Thanks to the symbiosis, the steel mill doesn't need to use its evaporative towers with the same intensity and less heat is dissipated in the atmosphere, in addition the utility company consumes fewer fossil fuels to run the district heating. The relationship between the utility provider and the steel mill is regulated by traditional contract and the heat exchange is manged on a dedicated platform. Also the relationships between the steel mill and the companies involved in the by-products exchange are regulated via contracts.

In case A1, Molhelix, a snail farm, produces snails and cosmetic products using snail secretion. It takes place in Campobasso, Molise. The company opened in 2020, just after the first covid-19 national lockdown and involves five local grocery stores in the recovery of vegetable organic produce as animal feedstock. The relationships between the stakeholders are regulated by contractual agreements but the collection of the products is managed with mobile messages.

ENEA: Industrial Symbiosis facilitator

The last chapter of the findings focus on ENEA, the Italian national agency for sustainable development, and its role of industrial symbiosis facilitator. The literature review and the interview conducted with a researcher of the RISE, resource valorization laboratory, led to the creation of an all-round overview on ENEA projects, industrial symbiosis network, platform and methodology.
ENEA is a facilitator for industrial symbiosis mostly in the planning and research phase, supporting companies in the identification of potential symbioses and in the assessment of their environmental impact. Its projects are assessed with indicators on the number of involved companies and potential IS identified and there is not a focus on the ratio between developed and identified symbioses. Beside the projects ENEA is also a partner of the Symbiosis Users Network that acts to foster IS with activities that go from collection of success stories to normative changes at national and regional level.
Therefore, ENEA is an IS facilitator mostly in the planning and research phase, its projects are to inform and disseminate the concept of IS and not to support companies in the emergence and development phase, since the weight of the execution is left to the operating companies.

5. Finding Discussion

From the database analysis emerged that there are more companies interested in finding a market for their by-products, rather than companies that are looking for secondary raw material. This mismatch between demand and offer can be related to the additional costs and time needed to transform by-products into usable resources. This finding is aligned with those disclosed by ENEA, which identified more output resources available for symbiosis compared to inputs.

Geographic distribution was discussed, there are different trends across the regions. Some regions have no reported cases, while others have more than the average (4). In most of the cases the proximity among stakeholders is a radius shorter than 30kms, material flow optimization and logistics cost reduction are the main reasons behind this phenomenon, for companies is fundamental to reduce transportation costs of by-products to the maximum extent due to the low value of the material. Furthermore, if IS emerged in an industrial district the number of stakeholders is on average 200 companies while in the other cases it is 5 companies, highlighting the difference among the industrial environments.

The majority of IS cases in Italy involve companies in manufacturing, environmental service, agriculture, and energy production sectors. Cross-sectoral symbioses are the most common, with manufacturing-environmental service, manufacturing-energy production, agriculture-energy production, and agriculture-environmental service being prevalent combinations. The high occurrence of firms in manufacturing sectors like steelmaking, cement production, and power generation reinforce the existing literature on IS.

The resources exchanged in the case studies are many, including by-products, materials, energy, water, services, infrastructure, information, and knowledge. The database shows that by-products and materials are the most exchanged resources, followed by energy and water. Information and knowledge sharing are less common due to challenges in the regulation and definition of these exchanges, as well as concerns about competitiveness. In fact, trust among stakeholders is crucial for successful information sharing, often established through long-standing partnerships or personal relationships.

Universities, research institutes, public funding and digital platforms are the most common facilitator of IS. The first two in the list support companies in the research and planning phase, public funding provide economic support especially for infrastructure development, and the latter are used for resource matchmaking.

It is important to report that during the interviews not all companies were familiar with the concept of industrial symbiosis, particularly in small and medium enterprises. This lack of awareness may have contributed to the limited number of responses and interest in the interviews that occurred in the company contact phase.
Figure 5-1 shows the positioning of the five case studies considering their emergence and the kind of formal inter-firm collaborations. This figure provides an overview to answer the research questions.

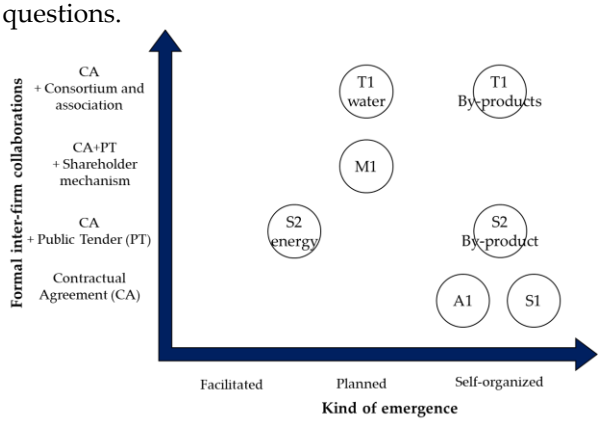

Figure 5-1 Positioning of the case studies on the collaboration - emergence matrix.

How and when industrial symbiosis cases emerged in Italy?

Most of the case of industrial symbioses in Italy developed spontaneously, precisely there are 27 cases of self-organized symbiosis and 23 facilitated or planned cases, among which there are 6 cases that are in the research and planning phase. Digital platforms, funding, normative changes and projects can facilitate IS. For example, in case T1 the development of a consortium for the management and treatment of the wastewater of the tannery district was pushed by a normative change, and case S2 was facilitated by project Banco EnergETICO funded by Lombardy region. a

regional project funded a pilot project leading to a symbiosis between a steelmaker and a utility company.

The industrial symbiosis readiness of each company is strongly related to the presence of economic and financial drivers. If a company is not able to find an economic benefit in the development of a symbiosis, considering operating cost reduction, new market opportunities or reduced environmental taxes, it will not develop the previous mentioned strategy.

There are sectors with a long history of circular and symbiotic practices, among them there are steelmaking, agriculture, and cement manufacturing, while the case of symbiosis in the machinery and food production identified are more recent.

Thanks to the interviews it was possible to discover that a case of symbiosis can be both spontaneous and facilitated, meaning that different resource exchanges in the same symbiosis can be originated by different drivers and that the participation of facilitator in a symbiosis can be limited to a single resource flow.

Furthermore, the interview with ENEA provided an insight on the dissemination of the topic of IS. The interest is steadily growing since the 2010, the projects of the national agency are slowly raising awareness among companies. However, industrial symbiosis awareness among the public and even small and medium enterprises is quite low.

What kinds of relationships and exchanges exist among the stakeholders of the industrial symbiosis?

To gather information on inter-firm relationships and collaboration the interviews were necessary, without them it would be impossible to tackle this theme. Briefly, most symbiotic relationships are defined and guided by traditional business contracts, the involved parties define the quantity, quality and frequency of withdrawals of each resource and the transportation agreement. A structured agreement provides a clear understanding of the mutual commitment of the involved parties.

Relationships among companies in symbiosis can be facilitated and managed by consortium and enterprise associations, especially in industrial districts characterized by small, specialized enterprises. In some case companies involved in symbiosis also hold stakes in other participating organizations, providing additional control over the relationship.

Database analysis and the interviews provided valuable information on resource exchanges. By-products and materials are the most frequently exchanged resources, followed by water and energy. However, knowledge and information exchanges are challenging to detect and are seldom publicly reported. While information sharing according to contractual agreement is a rarity, within long-lasting and well-established symbiotic relationships information exchange becomes a mutual commitment, built on trust and facilitated by the assurance that each party would manage data with a sense of reliability and confidentiality.

What are the digital technologies used in industrial symbiosis?

The research offers insights into digital technologies used in industrial symbiosis, including sensors, internet of thing, (IoT) and information systems. The most employed technologies are information systems, digital communication, and collaboration tools like Microsoft and Google suites. However, communication and information management technologies are most critical.

Companies in industrial symbiosis rely on data and information to facilitate resource sharing. IoT, cyber-physical systems, and ERP systems are commonly used.

Communication technologies, such as email and phone calls, play a vital role in coordination. Mobile messaging apps are used in smaller companies. Mobile computing and remote-control technologies are reshaping operations. Platform usage for resource exchange is limited. ENEA's symbiosis platform is notable, providing data on available resources and facilitating connections. However, it primarily serves as a guideline, not an operational tool.

6. Conclusions

The research has some limitations. Despite efforts to include a diverse range of IS cases, there may still be sample selection biases. Due to time constraints and stakeholder availability, only 10 out of the initially contacted 20 companies were interviewed. The limited sample size may affect data collection and the study's comprehensiveness.

Additionally, the study primarily focused on the north and center of Italy, potentially limiting the generalizability of the results, especially considering the regional nature of normative. Interviews revealed that regional laws and regulations regarding waste management significantly influence observed practices and that they are defined regionally. Lastly, most cases involved utility or environmental service providers, unintentionally emphasizing symbiosis between manufacturing and these sectors.

This research provides valuable insights into the diffusion of industrial symbiosis practices in the Italian context. It provides an overview of the kind of relationships and collaboration among the stakeholders in an industrial symbiosis and undercover the impact of digital technologies on this strategy.

Contractual agreements are the basis of all the cases investigated, then another common inter-firm relationship is the shareholders mechanism and mutual agreement for information sharing. Moving to digital technologies, the research concludes that digital communication and information systems are essential for supporting symbiosis, while industry 4.0 technologies are not deemed crucial for IS development.

The study identifies new cases of industrial symbiosis in Italy, including a previously undocumented case involving the forestry and service sector in Trentino Alto-Adige and a small-scale symbiosis between organized distribution and a snail farm.

The research highlights that most cases of industrial symbiosis in Italy are self-organized and spontaneous, while that the most common facilitator of IS are universities and research agency that support companies in the planning & research phase.

Additionally, the study provides valuable insights into the activities of ENEA as an industrial symbiosis facilitator, emphasizing its role in collecting success stories and best practices to disseminate IS in Italy.

In summary, the research offers a comprehensive overview of development of industrial symbiosis in Italy, presents detailed case studies, and critically analyzes the activities of ENEA.

In case of future research, figure 6-1 provides a guideline of the strategies to follow to find information on specific topics.

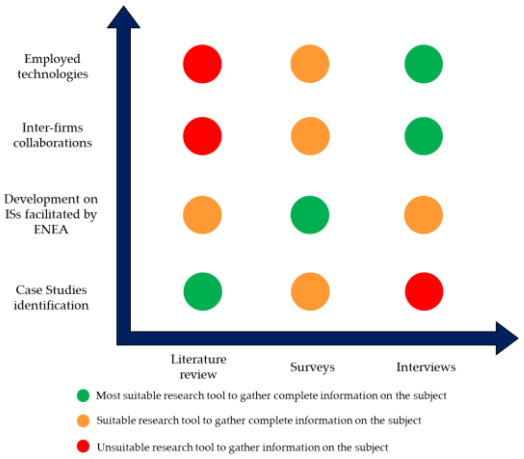

Figure 6-1 Recommended research framework for future research

References

[1] R. Merli, M. Preziosi and A. Acampora, "How do scholars approach the circular economy? A systematic literature review," *Journal of Cleaner Production*, vol. 178, pp. 703-722, 2018.

[2] M. R. Chertow, "Industrial Symbiosis: Literature and Taxonomy," *Annual Review of Energy and The Environment*, vol. 25, no. 1, pp. 313-337, 2000.

[3] M. R. Chertow, W. S. Ashton and J. C. Espinosa, "Industrial symbiosis in Puerto Rico: Environmentally related agglomeration economies," *Regional studies*, vol. 42, pp. 1299-1312, 2008.

[4] L. Baas and F. Boons, "An industrial ecology project in practice: exploring the boundaries of decision-making levels in regional industrial

systems," *Journal of cleaner production,* Vols. 12.8-10, pp. 1073-1085, 2004.

[5] A. Neves and al., "The potential of industrial symbiosis: Case analysis and main drivers and barriers to its implementation," *Sustainability,* vol. 11, no. 24, p. 7095, 2019.

[6] J. Henriques and al., "Industrial symbiosis: A sectoral analysis on enablers and barriers," *Sustainability,* vol. 13, no. 4, p. 1723, 2021.

[7] L. Harfeldt-Berg and al., "The importance of individual actor characteristics and contextual aspects for promoting industrial symbiosis networks," *Sustainability,* vol. 14, no. 9, p. 4927, 2022.

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