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

TESI DI LAUREA MAGISTRALE IN MANAGEMENT ENGINEERING INGEGNERIA GESTIONALE

Author: **Silvia Carcangiu**

Student ID: 991312
Advisors: Prof. Davide Chiaroni
Co-Advisor: Lucrezia Sgambaro
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Abstract

Industrial symbiosis (IS), one of the strategies to achieve a circular economy, emerged from the field of industrial ecology in the '70s and has become increasingly important since the 2000s. In this work, the spotlight is on the Italian field researching how this strategy is applied in various sectors, which are the relationships and exchanges among the actors that partake in an IS and the role of digital technologies in this strategy. In addition an analysis of the role of ENEA as IS facilitator was conducted.

The research employs both quantitative and qualitative methodologies. First, a detailed literature review was performed to understand the state of the art and the gaps in the literature. Then a database of Italian cases of IS was created using academic and grey literature as sources; from the quantitative analysis of this database emerged 50 cases of in different developing stages, productive sectors and geographic regions. As result of the literature review and the database analysis, an interview guideline and a list of cases to deepen with interviews were defined. Structured interviews were conducted with 10 companies to further investigate 5 case studies and the role of ENEA in disseminating IS in Italy.

Five case studies are presented showing how they developed, the relationships among the stakeholders and the employed digital technologies. Two cases focus on the symbiotic exchanges among steelmakers and heat recovery, one describes the symbiosis in the Fiemme Valley that recovers forestry and sawmill by-products for energy recovery, another presents the cases of the tannery district of San Miniato and the related gelatine and collagen production, concluding with a small case where organic by-products from grocery stores are recovered for snail farm.

The analysis of the database and interviews provided insight into the Italian working field of IS, uncovering that contractual agreements and shareholder mechanisms are the most common inter-firm relationships and that communication and information systems are the most employed technologies in IS. About ENEA it emerged that the public agency supports companies in the research and planning of symbiosis but not in the execution of the exchanges, its activities are to disseminate the strategy.

Key-words: industrial symbiosis, circular economy, case studies, Italy, inter-firm collaboration, facilitator.

Abstract in italiano

La simbiosi industriale (IS), una delle strategie per applicare l'economia circolare, è emersa dal campo dell'ecologia industriale negli anni '70 ed è diventata sempre più importante dagli anni 2000. Questa tesi si concentra sullo studio del contesto italiano indagando come questa strategia viene sviluppata e implementata nei vari settori, quali sono le relazioni e gli scambi tra gli attori che vi partecipano e il ruolo delle tecnologie digitali in questa strategia. Inoltre è stata condotta un'analisi del ruolo dell'ENEA come facilitatore.

La ricerca si avvale sia di metodologie quantitative che qualitative. In primo luogo, un database di casi italiani di IS è stato creato utilizzando la letteratura accademica e grigia come fonti. Dall'analisi quantitativa di questo database sono emersi 50 casi di simbiosi in diverse fasi di sviluppo, settori produttivi e regioni geografiche. Come risultato della revisione della letteratura e dell'analisi del database è stata definita una linea guida per le intervista. Sono state condotte interviste strutturate con 10 aziende per approfondire 5 casi studio e il ruolo dell'ENEA nella diffusione della IS in Italia.

Si presentano cinque casi concentrandosi sul loro sviluppo, le relazioni tra le parti interessate e le tecnologie impiegate. Due casi si concentrano sugli scambi simbiotici tra i produttori di acciaio e il recupero di calore, uno descrive la simbiosi nella valle di Fiemme che recupera i sottoprodotti forestali e delle segherie per il recupero energetico, e un altro presenta i casi della conceria toscana di San Miniato e la relativa produzione di gelatina e collagene, concludendo con un piccolo caso in cui gli scarti vegetali della GDO vengono recuperati per l'allevamento di chiocciole.

L'analisi della banca dati e delle interviste hanno portato alla realizzazione di una panoramica della situazione italiana dello sviluppo delle simbiosi industriali. Mostrando che le relazioni tra stakeholders più comuni nei casi sono accordi contrattuali e meccanismi di partecipazione degli azionisti, e che i sistemi di comunicazione e di informazione sono le tecnologie più impiegate nelle IS. A proposito di ENEA è emerso che l'ente pubblico sostiene le imprese nella ricerca e pianificazione della simbiosi ma non nell'esecuzione degli scambi, le sue attività sono concentrate nella divulgazione del concetto di simbiosi e nella raccolta di storie di successo.

Parole chiave: simbiosi industriale, economia circolare, casi di studio, Italia, collaborazioni inter-aziendali, facilitatore.

Contents

1 Introduction

The Earth Overshoot Day (EOD) represents the day in which humanity has consumed all resources that Earth normally generates in one year. An EOD lower than 365 days means that humanity consumes more than Earth can produce. The result is the depletion of global resources since they are consumed faster than how they are regenerated. This indicator is the ratio between the planet's biocapacity, that is the amount of ecological resources Earth can generate yearly, and humanity's ecological footprint, namely the resource demand for that year, and then multiplying by 365. Both biocapacity and ecological footprint in this ratio are measured in global hectare (gha), which is a biologically productive hectare with world-average productivity [1].

Equation 1. Earth Overshoot Day

$$\frac{\text{Planet's Biocapacity}}{\text{Humanity's Ecological Footprint}}\left[\frac{\text{gha}}{\text{gha}}\right] * 365 \text{ days} = \text{Earth Overshoot Day}$$

As can be seen in Figure 1-1 the EOD is reached sooner every year. Therefore, humanity cannot continue to chase economic growth using the linear economy as is. It is vital to find a way to decouple prosperity from resource consumption.

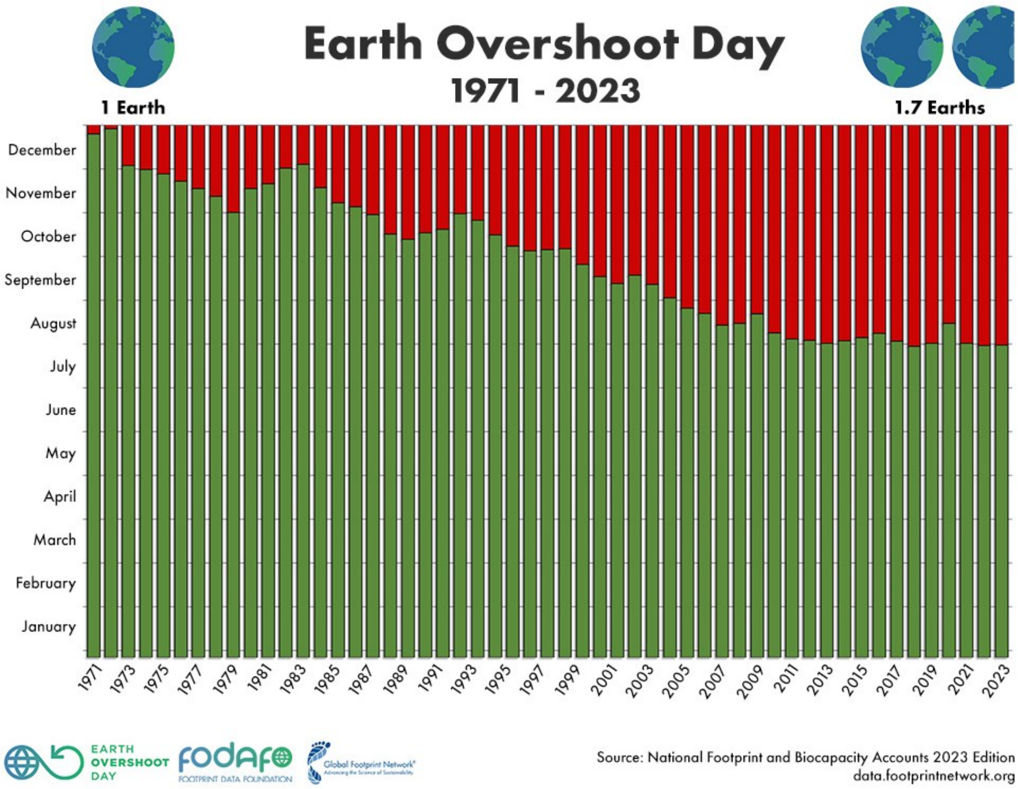

Figure 1-1 Earth Overshoot Day [2]

United Nations (UN), European Union (EU) and many other international agencies recognise the importance of sustainable development (SD) to solve or at least mitigate the criticalities of today's economy and resource depletion. The concept of sustainable development has been defined the first time in 1987 in the Brundtland Report as the development that meets the needs of the present without compromising the ability of future generations to meet their own needs [3]; and since then it has become increasingly relevant.

To reach the ambitious targets of a sustainable development a systematic change in government, businesses and people mindset is needed. Today the dominant mindset demands fast return of investment and has a short-term view. However, to reach sustainable development we all need to switch to cathedral thinking, a mindset that goes far beyond short termism and even long term logic, which considers multiple generations as the time horizon to reach the final goal. We may not see a future where sustainable development will be a reality for the whole world, but we must commit and begin to work toward that future for the new generation and the ones to come.

The term cathedral thinking can bring back the Middle Ages when castles and cathedrals required the commitment and labour of several generations, however there is a recent example of successful cathedral thinking: the mitigation of the ozone layer depletion thanks to the Montreal Protocol adopted the 16 September of 1987. In the '70s new kinds of halogenated hydrocarbons, chlorofluorocarbons (CFCs), were invented and widely used as refrigerant gasses and aerosol propellants. However, once released into the atmosphere CFCs reach the stratosphere and break down ozone molecules, leading to the depletion of the ozone layer. The ozone layer in natural conditions absorbs a portion of solar radiation acting as a shield against UVB light that has many adverse effects on human and environment health causing skin cancers, cataracts, and damages to some crops and marine life. The reaction between CFCs and ozone quickly created a hole in the ozone layer causing numerous risks to human health and potentially the end of life on Earth. The Montreal Protocol responded to this crisis by establishing a step by step action plan to progressively reduce and eliminate the production and use of all the ozone depleting substances (ODS). It is currently the only protocol signed by all the countries in the world.

The protocol defined different action plan and timelines for developed and developing countries. The former terminated their production and consumption of halons by 1994, those substances were used in fire-fighting equipment, freeze the production and consumption of HCFCs in 1996 and are planned to be completely phased out by 2030, phase out methyl bromide by 2004. The latter phase out halons by 2010, in 2013 they freeze their production and use of HCFCs, phase out methyl bromide by 2015. Thanks to these actions the ozone layer is expected to return to 1980's values by 2066, if nothing had been done, the ozone in the atmosphere would have been over by 2040 [4, 5]. To reach the final goal of a healthy ozone layer the commitment of more than three generations is necessary.

Returning to sustainable development, the United Nations published in the agenda 2030 seventeen Sustainable Development Goals (SDGs), together with the goals there are some targets, indicators and actions to follow; these can be subdivided in three sustainability pillars: economic, social and environmental.

Among the various pathways to reach a sustainable development and mitigate overconsumption there are three main approaches:

1. Increasing the efficiency of linear economy to use less input for the same output.
2. Reducing the market demand through austerity.
3. Switching to a circular economy where the lifecycle of a resource is extended, and the demand is the market one.

Among those three strategies the one that will be addressed in this thesis is the third one, circular economy can be defined as an economy based on the principles of designing out waste and pollution by keeping products and materials in use, and maximizing the value of resources, thus regenerating natural systems [6].

Circular Economy (CE) and Sustainable development partially overlap, particularly on the environmental and economic dimensions. On one hand circular economy's objective is to close the loop and reduces extraction and use of virgin raw materials favouring a smarter and more efficient use of resources and a lower environmental impact, to do so it promotes the switch from linear to circular and regenerative production system. CE primarily impacts on manufacturing and economic systems on the economic and environmental pillars. On the other hand sustainable development is more diverse, it aims to benefit humanity as a whole and works on all the three pillars of sustainability [7].

Among the several business models and strategies that enable circular economy this thesis will focus on industrial symbiosis, which is a part of industrial ecology characterised by collaboration among organizations in a way that resemble symbiotic relationship in the natural environment. Industrial symbiosis has been defined as an inter-firm exchange of materials, water, energy and byproducts [8] from which the involved companies get mutual benefits.

The discipline of industrial ecology (IE) emerged in the 1980s and bloomed in the 1990s and early 2000s. The focus of industrial ecology is analysing and studying productive system considering all the exchanges and relationships among the parties, the aim of this discipline is to reduce the environmental impact of manufacturing processes considering each plant as a part of a wider system and technology as a tool to reconcile human development with environmental stewardship while recognising the importance of socioeconomic factors in achieving these goals [9].

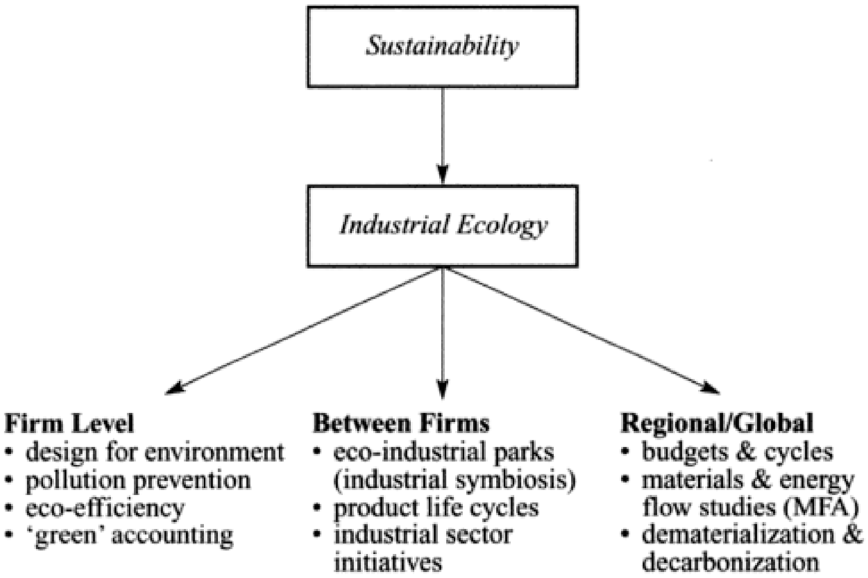

Figure 1-2. Industrial Ecology as a tool to reach sustainability [9, p. 10]

Since the 2000s the topic of industrial symbiosis gathers more and more interest from academia, governments and international agencies. It has been covered extensively in the collection of case studies in different geographic contexts, barriers and drivers to its development, analysis of the exchanged materials and some possible classifications and taxonomies to describe this phenomenon.

However, the literature on the inter-firm collaboration and the formal relationships among stakeholders in a symbiosis is not exhaustive, particularly there are few publication on how ISs emerged in the Italian context. In addition, there are few publications on the role of digital technologies in the development and support of this strategy. For these reasons the intention of this thesis is to gather information about the diffusion of industrial symbiosis in Italy considering three main subjects: how industrial symbiosis emerged, the relationships among the stakeholders, and what technologies are used for the symbiosis.

The research questions of this thesis are the following:

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?

The first question will lead to clarify the state of development of the IS in Italy, with particular attention to the construction of a timeline that allows us to understand what led each symbiosis to occur and if there are consistent differences among sectors and geographic areas. Currently the literature offers some insight of the Italian field focusing on ENEA's industrial symbiosis projects [10, 11], technologies and process research on industrial symbiosis opportunities and some case studies [12, 13].

The second question aims to highlight the kind collaborations in an industrial symbiosis, considering the supply network, the level of formalisation of the resource exchange, the kind of contractual agreement and the trust among the stakeholders. In addition, it wants to undercover the kind of exchanges that take place in the Italian field of industrial symbiosis. Currently the resources on this subject are quite limited, they focus on the potential IS identified during ENEA's projects and there are few cases on the developed cases.

The third questions can provide additional insight to the existing literature on digital technologies as support tool for industrial symbiosis [14, 15, 16]. To tackle this question is fundamental to interviews or submit dedicated surveys to companies involved in industrial symbiosis, in this research work the former approach was selected and implemented.

These queries are relevant and add novelty to the current literature landscape as disclosed in the previous paragraphs. Most of the articles on European and Italian industrial symbiosis cases focus on the assessment of the environmental impact of symbiosis, particularly measuring the Life Cycle Assessment of the manufactured products, the definition of the drivers and barriers for the success of the symbiosis, or the kind of resource shared, and processes employed in the symbiosis.

To briefly present the applied methodology, that will be deepened in the third chapter, a mixed approach was followed. First, a detailed literature review was performed to understand the state of the art and the gap in the literature. Then a database of Italian cases of IS was created using academic and grey literature as sources; from the quantitative analysis of this database emerged 50 cases of symbioses in different developing stages, productive sectors and geographic regions. As result of the literature review and the database analysis, an interview guideline and a list of cases to deepen with interviews were defined. Structured interviews were conducted with 10 companies, involving 12 interviewees, to further investigate 5 case studies and the role of ENEA in disseminating industrial symbiosis in Italy. It is important to highlight that the number of companies interviewed is a small part of those identified in the database, this is related to the decision of selecting cases that are different one from another to have a wider view of the context.

In the introduction the context and the motivation behind this research work are presented together with the research questions. In the second chapter, the state of the art resulting from the literature review about industrial symbiosis is presented with a particular focus on Europe policies and case studies. The methodologies are presented in the third chapter, where the description of the research work through database creation and interviews is presented.

The body of the text is made of three chapters: database on industrial symbiosis, industrial symbiosis case studies, and ENEA: industrial symbiosis facilitator. In the first of which the database on industrial symbiosis case studies is presented showing the data. In the second are presented and described the five case studies deepened through interviews. The chapter on ENEA explore its role as facilitator and introduce the methodology and projects that the public agency is making to promote and disseminate the concept of industrial symbiosis in Italy.

This thesis is completed and concluded with the chapter named findings discussion. This section present the key findings of the research, and the limitations of the work are acknowledged highlighting the boundaries and constraints of the research process and of its findings. Moreover, possible future research are presented highlighting the area that need further research and works. In the findings there is the critical analysis of the result of the research. Lastly, the conclusion provides an overviews and summary of the finding and of the research work.

1.1. Policies about Industrial Symbiosis

It is relevant to clearly define the normative context where the case studies that will be presented took place. The context will be defined starting from the international perspective, United Nations and European Union, and then deepened with an overview on the Italian regulations. A policy, according to the Cambridge Dictionary, is a set of ideas or a plan of what to do in particular situations that has been agreed to officially by a group of people, a business organization, or a government. In this work the spotlight will be on international organizations and government policies on Industrial Symbiosis.

1.1.1. International policies

This paragraph focuses on industrial symbiosis policies and projects outside the borders of European Union. In 2015 the United Nations identified industrial symbiosis and eco-industrial park (EIP) as suitable strategies to decouple resource consumption from economic growth, considering those strategies as tools to reach sustainable development. An EIP is defined as a community of businesses located on a common property in which businesses seek to achieve enhanced environmental, economic and social performance through collaboration in managing environmental and resource issues [17].

According to the literature most of the activities and policies in favour of industrial symbiosis take place in Europe and China, in the latter the most common configuration is the planned eco-industrial park due to the central controlled economy, while in Europe most of the cases are spontaneous and self-organized [18], these concepts will be further developed in the second chapter.

In the west, not considering EU, there are some policies and programs to foster industrial symbiosis, mainly in Brazil and the United Kingdom. In Brazil there are some policies on waste management, the most important is the National Solid Waste

Policy of 2010 that defines the shared responsibilities on waste management among manufacturers, traders, consumers and public agents, its scope is to minimise the volume and impact caused by waste disposal. Beside policies on waste in the south American states there are some developed case of industrial symbiosis mostly in the south of the country [19]. The most documented programs to promote symbiosis in Brazil are: Green City Project-Footwear Sector [20], Minas Gerais Industrial Symbiosis Program [21] and Rio Ecopolo Program [22] [23].

The United Kingdom has been the first country to develop an industrial symbiosis network. In 2003 the International Synergies Limited initiated the **National Industrial Symbiosis Programme (NISP)** in three English regions. The UK government in 2005 invested in the initiative as an externally audited programme of the DERFA[1], the program was concluded in 2013 when the public participation reach an end [24]. NISP's scope was and is to facilitate and aid various businesses to come together to find uses for unwanted materials, aiming to divert significant waste loads from landfill and produce benefits for companies through reduced disposal costs and new commercial opportunities, by sharing assets, resources, logistics and expertise. In the last two decades this model has been replicated at national and regional levels in 20 countries in Asia, Africa and South America [25, 26].

Moving to the east the focus is on China and South Korea. China began to foster the development of industrial symbiosis since the 2000s through national programmes and policies promoting the construction of eco-industrial park and a circular transformation, aiming at symbiotic and sustainable development in industrial parks. In 2000, the State Environmental Protection Administration (SEPA), now known as the Ministry of Ecology and Environment, started to implement EIPs in different regions involving various industries, including sugar, aluminium, chemical and high-tech. The SEPA promoted the construction of EIPs issuing many documents and regulations.

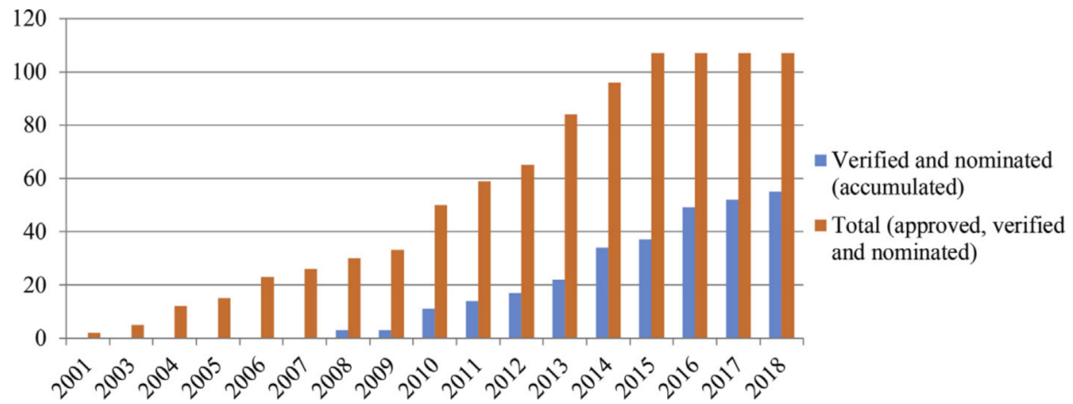

Fig. 1. Number of ND-EIPs in China. Source: Developed with data collected from the Ministry of Ecology and Environment.

Figure 1-3. Number of EIPs developed in China according to [27, p. 3]

[1] The UK Department for Environment, Food and Rural Affairs

In 2005 the **Park Circular Transformation** has been explicitly listed as a key project of the circular economy in the Outline of the 12th Five-Year Plan for the National Economic and Social Development of the People's Republic of China.
Hundreds of EIPs have been developed and built in the last decades, China fostered the development of industrial symbiosis in industrial parks through space optimization, symbiosis planning, resource reuse, integrated pollution treatment and shared infrastructure [28, 27]. Therefore, China formally invested and committed in this sustainable development strategy as can be seen in the Figure 1-3 extracted from the work of Hong & Gasparatos (2020).

In South Korea the development of industrial symbiosis and eco-industrial parks is the result of the implementation of environmental regulations, which are the result of the United Nation Conference on Environment and Development that took place in Rio de Janeiro in 1992, that led preexisting industrial park to change their practices toward environmental sustainability to reduce pollution. In 2005 the Korean National Cleaner Production Center and the Institute of Industrial Technology began a 15 year project to convert industrial parks in EIP with the support of the Ministry of Commerce, Industry, and Energy; the project consisted of 3 phases: pilot EIPs (2005-2010), diffusion of EIPs (2010-2014), and edge tech connecting the developed EIPs (2015-2019) [29]. The main outcomes of this projects are: increased production and resources use efficiency, pollution prevention, business network creation, improved industrial sector reputation [30, 31].

Beside the policies just presented, there are also some cases of IS programs in Australia, Africa and the South East Asia. In Australia the best-known cases are Kwinana industrial area and Gladstone [32], in the African continent there are some cases that are collected in the work of Oni and colleagues [33], Neves and al. (2019) identified other countries where IS emerged in the past decades [34]. This shows that the interest in industrial symbiosis is spreading and disseminating all around the globe, involving both developed and developing countries.

1.1.2. European Union policies

In Europe the first environmental policies can be dated back to 1970s [35], when the European Commission launched its first Environment Action Plan, while the first policies and regulation about resource efficiency and circular economy are dated respectively to 2000 (Directive 2000/53/EC) and 2015 [36]. The **first European circular economy action plan** was adopted in 2015 by the European Commission. It included measures to help stimulate Europe's transition towards a circular economy, boost global competitiveness, foster sustainable economic growth, and create new jobs. The action plan established actions and measures to reach a circular economy covering the whole life cycle of a product: starting from material extraction and concluding with waste management and end of life, passing through the creation of a market for secondary raw materials and a revision of the wate and by-products legal framework.

It gathered 54 actions to guide Europe towards the circular economy. By 2019, the first circular economy action plan was fully completed, covering all the predefined actions and reaching the targets, however, some works and projects continued even after 2019 [37, 38].

The action plan can be grouped in macro areas: production, consumption, waste management, secondary raw material market, plastic, food waste, critical raw material, construction and demolition, biomass, innovation and investment and monitoring. It operated on waste reduction, waste legislation revision, circular product design, sustainable consumption, eco-design and innovation, resource efficiency in business, closing the loop for critical raw materials, promote reuse and repair and foster investment in circular economy.

In 2018 the EU presented the Monitoring Framework for the Circular Economy that includes 10 key indicators covering each phase of the lifecycle of products as well as competitiveness aspects. The indicators are grouped into 5 groups: production and consumption, waste management, secondary raw materials, competitiveness and innovation, global sustainability, and resilience. All indicators are regularly updated and available on a dedicated website [39].

The **European Green Deal (EGD)** was launched by the European Commission in 2019 and shows the commitment of the member states to reach climate neutral and competitive economy by 2050. It is made of a set of policies and strategies to accelerate the transition to a greener continent and a sustainable future. The European Industrial strategy is one of the most relevant actions of the EGD and addresses the challenges of the green and digital transformation of manufacturing sector. Beside the strategy, since the presentation of the deal some action plans were launched: investment plan, circular economy action plan, organic action plan, and zero pollution action plan.

The EGD is the representation of the commitment of all the states of the EU to climate neutrality by 2050. It has an impact on the dissemination and development of industrial symbiosis through some actions:

- Ecodesign for Sustainable Products Regulation is a part of the Sustainable product initiative that EU adopted in March 2022. The proposal defines a framework to set ecodesign requirements for specific product groups to significantly improve their circularity, energy performance and other aspects. Changes in product design will require new production processes that could enable newer symbiosis.
- The plastic strategy was launched in 2018 aiming to reduce greenhouse gas emission, protect the environment, and reduce European dependence on imported fossil fuels. The plastics strategy also aims to transform the way plastic products are designed, produced, used and recycled in the EU.
- The new proposal for the Waste Framework Directive sets out the basic concepts and definitions of waste management, including definitions of waste,

recycling and recovery. Clearly, the definition of by-product came from this framework and changes in the definition will impact industrial symbiosis, both the existing one and the potential.

- The Zero Pollution Action Plan recognises that pollution in all its forms has negative impacts on humanity and the environment. Therefore it provides guidelines to prevent pollution, this action plan will be reflected in all the European policies and legislations.

The **new circular economy action plan** and the Industrial Strategy were launched in 2020, they support the transition to a greener economy in the EU. The scope of this action plan is to modernise the economy and creates opportunities for the circular economy domestically and globally. The action plan pushes for a sustainable product policy framework that enables the reduction of resource extraction, to do so it promotes: design products for sustainability, empowering consumers through the right to repair and protection against green washing, circular production processes where industrial symbiosis is the main strategy [40].

Beside promoting a greener economy, the European Commission also wants to favour international and national policies on waste and secondary raw materials. There are many challenges and barriers to symbiosis and circular economies, one of the most critical is the lack of clear and shared regulation among European countries and in some cases at national level. To favour the establishment of an international market for secondary raw material in Europe and in each state the commission is defining regulations about: recycled content in products and by-products classification.

The EC clearly expressed its dedication toward a more sustainable future with publications and some centralized regulations, especially on waste and byproducts. In addition to these activities, it also promotes circular economy and industrial symbiosis through community projects and fundings such as: EU4Environment, CORALIS (industrial symbiosis in Energy Intensive Industries), LIFE Programme.

1.1.3. Italian policies

Italy, as the other state member of European Union, aims to promote circular economy and the reduction of waste produced yearly. Its effort to reduce the environmental impact of manufacturing and industrial activities began in the last century.

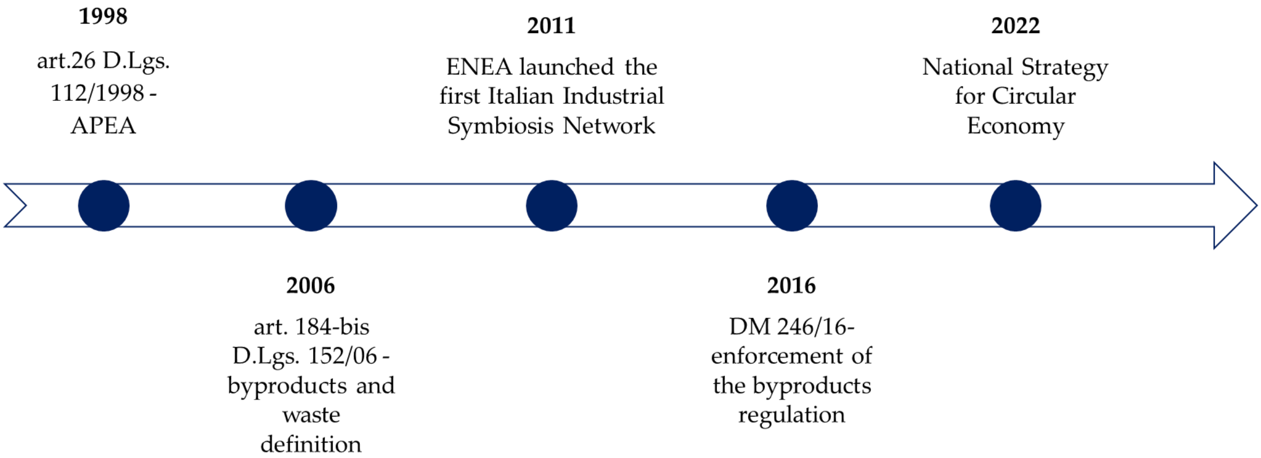

Figure 1-4. Timeline Italian policies on Industrial Symbiosis

The first national policies that can be related to the concept of industrial symbiosis can be dated to 1998 when the APEA[2] was introduced. An APEA is an industrial area equipped with the infrastructure and systems necessary to ensure the protection of health, safety and the environment (art.26 D.Lgs. 112/1998). This production system can be considered quite similar to an eco-industrial park.

The normative delegates to the single region the task of regulating the issue of the APEA, therefore the diffusion of this kind of industrial areas is in function regional regulations meaning that it is not centrally regulated and promoted. This distinction between central and regional authorities and policies is common in the Italian regulation, this in some cases is an advantage while in others it is a barrier to inter-regional collaborations.

A big step in the direction of circular economy and IS has been the formal definition of a by-product in 2006 (art. 184-bis D.Lgs. 152/06); since then according to the Italian regulation an object or substance is a by-product and not a waste if it meets all the following conditions:

- It originates from a production process, of which it is an integral part and whose primary purpose is not the production of that substance or object.
- it is certain that it will be used in the same or a subsequent process of production or use, by the producer or third parties.

[2] Area Produttiva Ecologicamente Attrezzata

- It may be used directly without any further treatment other than normal industrial practice.
- Further use is legal, namely the substance or object meets, for the specific use, all relevant requirements concerning products and the protection of health and the environment and will not lead to overall negative impacts on the environment or human health.

Further enforcement of the distinction between by-products and waste was published in 2016 (DM 246/16), this regulation clarifies that the requirements for excluding a production's residue from the waste legislation must be met at all stages of residue management, from production to use in the same process, or in a subsequent process. Therefore, if the residue is classified as waste at any phase it cannot return to be a by-product.

The DM 246/16 also provides the first, and currently the only, operational guideline on by-products in Italy. It provides a common basis for producers and control bodies by defining data sheet and contracts for the classification and exchange of by-products. In the 10th article of this DM it is made explicit that local Chambers of Commerce need to facilitate the exchange and disposal of by-products, to do so they must establish a special list in which producers and users of by-products are registered, without any charge. This list is made public and available on a dedicated section of the Chamber of Commerce's website or on a website indicated by the same [41].

The ENEA[3], the Italian national agency for new technologies and sustainable development, developed the first **Italian network for industrial symbiosis** within the project "Ecoinnovazione Sicilia" in the period between 2011 and 2015. To favour and develop industrial symbiosis among Italian industries the ENEA developed some tools: platform, network, methodology and projects with guidelines for symbiosis. The Symbiosis Platform is a tool to support businesses and other operators in the exchange of resources such as materials, energy, by-products, water, services and expertise. On the platform organizations can register and publish the resources that they can share. The aim of the platform is to find a match among the users' resources and the inputs that they need.

The network organizes meetings and programs around Italy to spread knowledge and awareness on the topic of industrial symbiosis. Currently, in 2023, the network is made of 284 organizations that registered in the platform 2672 resources, and 1946 possible industrial symbiosis have been identified [42, 43]. The activities of ENEA to foster IS will be presented with more details in the 6th chapter.

In June 2022 the new **national strategy for circular economy** was published by the Ministry of Ecological Transition. It was published to be compliant to the conditions to get the funding for the PNRR[4] from European Union. The national strategy defines

[3] Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile

[4] Piano Nazionale di Ripresa e Resilienza

the new instruments to strengthen the market for secondary raw materials, so that they are competitive in terms of availability, performance and costs compared to virgin raw materials. The Strategy acts on: procurement of materials, the criteria for the definition of End of Waste, extended producer responsibility and the role of the consumer, the dissemination of sharing practices and product as a service.

The national strategy aims to pursue the principles of circular economy transforming the production processes through new business models; the industrial symbiosis model is one of those. The PNRR will be used as a tool to reform the existing circular economy strategy, including concrete measures aimed at supporting industrial symbiosis projects through appropriate regulatory and financial instruments. Specifically, Mission 2 of the PNRR promotes the funding of proposals for the implementation of "lighthouse projects" on circular economy in the framework of the "plastic waste recycling, including marine plastic litter", enhancing projects that, through practices of industrial symbiosis, promote the utilization of recycled material or second raw material in industrial processes [43].

One of the specific targets of the national strategy is the development of the right conditions for the “by-products market” in terms of higher certainty in recognition, availability, standardisation and acting on the revitalisation of the by-product exchange platform, to concretely support operators in the full realization of the industrial symbiosis also within the bioeconomy.

Industrial symbiosis is also recognised as one of the actions to be taken in order to achieve circular economy. The table below provides a list of all the industrial symbiosis actions outlined in the national strategy for circular economy. These actions are expected to be implemented by 2035 [43]:

Table 1-1 Industrial Symbiosis actions for the Italian national strategy for Circular Economy

	Actions
Industrial Symbiosis	To give additional points to subjects who have developed or intend to develop circular district models when participating in tendering procedures;
	Introduce tax benefits in favour of companies that adhere to network contracts for the initiation of circular economy processes;
	Simplifying the granting of authorisations involving different disciplinary profiles that need to be examined in an integrated manner;
	Insert circular districts as a virtuous example in industry guidelines;
	Provide for integrated financial statements that refer to the whole synergistic process even if they relate to separate establishments or to the ownership of different legal entities; for example, through LCA approaches;
	Equate carbon neutrality of hydrogen production by electricity drawn from the network in circular districts to green hydrogen

2 State of the Art

The state of the art regarding industrial symbiosis involves many fields and disciplines. It considers industrial ecology, circular economy, sustainable development, national and international policies and initiatives, and environmental and social impact assessment. This is the result of a literature review conducted between March and July 2023 as is presented in detail in chapter 3.

On one hand, in the previous chapter policies and regulations were presented going from the international to the national level providing a common understanding of the legal and political context where IS take place. On the other hand, the findings of the literature on IS are presented in this chapter to gather a more conscious understanding of the current and past academic works on this subject.

2.1. Relationships between Industrial Ecology and Circular Economy

Industrial Ecology (IE) is a discipline that studies the systemic relationships between society, the economy, and the natural environment. The field developed from the late '80s with the work of Frosh and Gallopoulos [44], but the first indirect references to the concept can be dated back to 1970s. It focuses on the stages of the production processes of goods and services from a point of view of nature, trying to mimic a natural system by conserving and reusing resources [45]. In IE an industrial system is viewed not in isolation from its surrounding systems but in concert with them. The objective of IE is to optimize the total materials cycle from virgin material, to finished material, to component, to product, to obsolete product, and to ultimate disposal; to do so it promotes the reuse and recovery of materials inside the industrial system through the creation of resource loops and optimization [46].

In addition, according to Ayres (2002), IE is a discipline that aims to reduce the environmental impact of manufacturing processes considering each plant as a part of a wider system, an ecosystem, and technology as a tool to reach a sustainable development. He also identifies tree levels of action that industrial ecology can promote [9]:

1. Firm Level: design for environment, pollution prevention, eco-efficiency and green accounting. Internal practices for a more sustainable and efficient use of the firm's resources.

2. Between Firms: development of eco-industrial parks that are a form of industrial symbiosis, product life cycles, industrial sector initiatives. Wider resource and supply chain vision considers interfirm relationships.
3. Regional/Global: budgets and cycles, material and energy flow studies, dematerialization and decarbonization. International trends and practices toward a more sustainable manufacturing and industrial sector.

As stated in the introduction, industrial symbiosis (IS) is an important subject of IE with high attention on material and energy exchanges. It is the extension of the concept of biological symbiotic relationships that take place among organisms and natural systems to the industrial system. IS emerges when two or more unrelated organizations exchange materials, energy or information in a mutually beneficial manner [8]. The literature shows a growing interest toward the subject of IS, the number of yearly publications is growing steadily and so are the number of national projects to foster this practice. However, despite the growing interest in sustainable development and the increasing progress of IE, the global economy is still dominated by the linear materials flow, the extract and dispose model, that pretend not to know that the resources of planet Earth are limited and that anthropic actions are endangering the global ecosystem [47].

Industrial ecology with industrial symbiosis has been recognised as a strategy to achieve sustainable development for a long time, however, in more recent years the concept of Circular Economy (CE) emerged as a new strategy to reach sustainability, this research and practical discipline has been developed and disseminated thanks to the activities of the Ellen MacArthur Foundation and other practitioners. The scope of CE is to develop strategies and actions to maintain products, components and materials at their higher level of utility and value. CE is strongly inspired by the biological cycle aiming to facilitate effective flows of materials, energy, labour and information [6]. In addition, Moreau & al (2017) dd that CE promotes circular flows to reduce environmental impacts while maximizing resource efficiency [48]. The most cited definitions of CE are the one from Ellen MacArthur foundation and the one from Geissdoerfer and colleagues (2017). The former defines CE with three principles designing out waste and pollution, maintaining products and materials in use, and regenerating natural systems; the latter defines it as a "a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling [7]". CE can be analysed using four levels: micro, meso, supply chain and macro. The miso level focuses on initiatives at the firm and organization level and considers consumers' perspectives. Meso level considers inter-firm activities within geographic proximity, among those solutions IS and EIP are enumerated. The supply chain level considers initiatives involving firms within the supply chain, where geographic proximity is not required. Lastly, the macro level studies the societal and system changes and initiatives that public authorities such as city, regions and nation make [49].

Considering the definitions of IE and CE it is clear that they share a sensibility toward the environment and were inspired by the biological cycle. According to Saavedra & al. (2018) IE contributed to the development of CE on three levels: conceptual, technical, political and standard. Conceptually both of them operate on material and resource flows and consider industrial symbiosis as tools to reach their scopes, they share technologies and practices and lastly are regulated and promoted by the same legal frameworks [50].

Technically the tools, like eco-design, industrial symbiosis, eco-industrial parks and eco-efficiency, used in CE are the same of IE.
While the political and standard contribution concerns the application of industrial ecology to support the development of policies, laws and standards for implementing CE at local, regional and global levels.
However, according to some articles, CE is sometimes considered as a broader discipline than IE because of the inclusion of economic and policy issues that the latter doesn't always consider [50].

Both in policy frameworks and academic literature, industrial ecology and circular economy are recognised as strongly related. They share tools, environmental sustainability and resource conservation consciousness [50, 51, 52]. Therefore it is clear that industrial symbiosis can be considered a possible strategy to achieve both circular economy and sustainable development as emerged from the previous paragraphs.

2.2. Industrial symbiosis definitions

The most relevant and quoted definitions about industrial symbiosis will be presented in this paragraph. Starting with the most cited definitions of industrial in the literature, moving to eco-industrial park, industrial symbiosis network and concluding with the distinction between industrial district and IS.

In the literature there are many definitions of industrial symbiosis, the first definition comes from the late '80s and since then it evolved and changed many times. In this paragraph, the most cited definitions are collected and commented on to clear the concept.

The most cited definition comes from Chertow (2000) that defines IS as the part of IE that engages traditionally separate industries in a collective approach for competitive advantage involving physical ex-change of materials, energy, water and by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity [8].

According to Chertow & Lombardi (2005) industrial symbiosis, a sub-field of industrial ecology, is principally concerned with the cyclical flow of resources through networks of businesses as a means of cooperatively approaching ecologically sustainable industrial activity. Industrial symbiosis has the potential to redefine industrial organization by pushing companies to think beyond individual firm boundaries to a broader systems level [53].

In 2007, Chertow redefined IS with the 3-2 heuristic criterion: at least three different entities must be involved in exchanging at least two different resources to be counted as a basic type of industrial symbiosis. In this work "kernel" and "precursor" have been chosen to describe instances of bilateral or multilateral exchange of symbiotic type that have the potential to expand, but do not yet meet the fuller 3–2 criterion [54]. This definition proposes a set of necessary conditions to identify industrial symbiosis, however, still today the exchange of one or more resources among only two organizations is often classified as a case of industrial symbiosis.

Chertow & Ehrenfeld in 2012 observed that the term industrial symbiosis can be use in two ways: (1) as the broad name for the branch of industrial ecology that seeks to understand the development and functioning of interfirm resource exchanges, and (2) as an inclusive descriptor for all arrangements where enterprises exchange outputs that, in the absence of a customer, would normally be discharged to the environment and hence become treated as environmental externalities. These resources include reused water, recovered energy, and material by-products—categories often called wastes [55]. This definition distinguishes between the traditional definition of IS that originates from IE and the new one, that is strongly related to extending and closing resource loops.

In a more recent work, industrial symbiosis is recognized as a process of connecting flows among industrial actors through (1) use of secondary material, water, and energy resources and/or (2) utility and service sharing, such as collective use of infrastructure or environmentally related services across a network. It is a multi-actor economic development characterized by net environmental benefits associated with the connecting of flow [56].

Comparing the five definitions, they all consider IS as an inter-firm exchange of resources, initially considering only material resources- such as waste, byproducts, water and energy- and then expanded to a wider dimension involving also infrastructure and knowledge [56]. Also, the concept of proximity evolved, initially it was considered a necessary condition, while more recent studies consider geographic proximity only as a facilitator and a barriers for water and energy exchanges due to the necessity for utilities infrastructures. Finally, the scope of industrial symbiosis went from pure competitive advantage to mainly environmental consciousness.

Analysing the sources and authors of these definitions, Chertow is clearly an important researcher on IS, she is one of the most prolific authors on the subject and her publications contributed to the spread of the notion and the dissemination of this strategy around the globe.

As clarified in the paragraph 2.1 industrial symbiosis and eco-industrial park are recognised as applications of industrial ecology, they partially overlap because they both focus on resource exchanges, but the latter is more focused on the physical location of the involved companies. According to Lowe and colleagues an Eco-Industrial Park (EIP) is a community of manufacturing and service businesses seeking to enhance environmental and economic performance through collaboration in managing environmental and resource issues. Collaborating the community of organizations seeks to reach a collective benefit that is greater than the sum of the individual benefit each company would realize if it only optimized its individual performances [57]. An EIP is a community of businesses located in the same geographical area, that can also be characterized by the use of renewable energies and the design of green buildings, among others. Eco-industrial park can be top-down or bottom-up initiatives, meaning that not all cases of EIP are the result of central authority planning but that they can occur from spontaneous collaboration among firms. With industrial symbiosis, we can refer to all kinds of companies' resource exchanges even if the involved actors are not colocated, while in EIP the partnerships and exchanges take place only inside the boundaries of the industrial park.

As introduced in the first chapter, industrial symbiosis networks (ISN) are relevant tools for enabling and facilitating symbiosis at the normative and practitioner level. ISNs are relational and knowledge tools to support the resource matching between demand and supply among partners who, by economic and social activity, have no other opportunity to meet (Cutaia & Morabito, 2012). An ISN generally consists of at least one actor that supplies the excess resource and one actor that receives the resource, the creation of the symbiotic exchanges among the parties can take place on a digital platform or through a programme that facilitate the matchmaking. A network can take the form of a platform or of a programme and can be classified as spontaneous or facilitated. Sometimes it may also entail a facilitator who works to support the development of the collaboration supporting companies in the matchmaking or promoting normative changes to favour this kind of strategy (Harfeldt-Berg, Broberg, & Ericsson, 2022). This concept will be further developed focusing on the Italian context and on ENEA's actions in the 6th chapter.

Industrial district is the last relevant concept to understand the evolution of industrial symbiosis, especially to have an all-round view of the Italian industrial and manufacturing context. Italy is famous for being the country of specialised industrial districts, such as tannery and textile districts in Tuscany. These industrial areas are the landscape where some of the Italian industrial symbiosis cases take place, therefore, it is pertinent to clearly state the differences between the two concepts to avoid confusions. The concept of industrial district emerged in the late 19th century with Alfred Marshall works on British economy and industrial sector. The district reality in Italy is characterized by a strong territorial roots in a specific socioeconomic area, a high manufacturing specialization and a high density of small and medium enterprises specialized in different stages of the production cycle. Industrial district is defined by Becattini as a socio-territorial entity which is characterised by the active presence of both a community of people and a population of firms in one naturally and historically bounded area. In the district community and firms tend to merge. Each of the enterprises in an industrial district is specialized in a phase of the typical production process of the district. The district, in short, is a case of localized realization of a process of division of labour that is not diluted in the general market, neither is concentrated in one or few enterprises [60]. The specialization of the district is on a manufacturing sector, not on a specific phase of the production, companies operating in different phases of the same supply chain are colocated. Proximity and knowledge of the supply chain shown to be drivers to foster industrial symbiosis. In fact, analysing the literature on IS case studies it emerged that many symbioses were born in an industrial district, starting with Kalundborg and Prato [61, 62]. However, it can be said that industrial districts occasionally are the initial condition that led to the emergence of industrial symbiosis, but it is not a necessary condition for the development of nether an EIP nor an industrial symbiosis.

2.3. Relevant dimensions for Industrial Symbiosis

Numerous variables and dimensions have been identified in the literature to describe and characterize industrial symbiosis. These will be presented in this section according to their perceived importance, this paragraph is fundamental to clarify the framework that will be presented in chapter 3. The order will be as follows: taxonomy, types of exchanged resources, proximity, productive sector, presence of facilitators or public administration, and funding.

The most used and cited dimension in the literature is Chertow's taxonomy. It was the first classification of industrial symbiosis that was published in the 21st century, Marian R. Chertow published the taxonomy in 2000 presenting her research findings on industrial symbiosis delineating five distinct categories of material exchange, which are outlined below [8]:

1. Type 1: through waste exchanges.

   Those exchanges require the presence of a third-party intermediary or waste/scrap broker. These actors are in charge of the recovery and redistribution of the materials. Type 1 exchanges are limited to material flows and are the farthest from the definition of industrial symbiosis.

2. Type 2: within a facility, firm, or organization.

   It is possible to perform material exchange within the boundaries of an organization, different business units can exchange resources considering materials, water and energy. Usually, those practices are common in large organizations that often behave as separate entities and may approximate a multi-firm approach to industrial symbiosis.

3. Type 3: among firms colocated in a defined eco-industrial park.

   When firms are colocated in an EIP they can exchange energy, water, and materials and can go further to share information and services such as permitting, transportation, and marketing. In type 3 exchanges can occur both inside and outside the boundaries of the EIP.

4. Type 4: among local firms that are not colocated, not contiguous but close.

   In this case, the starting point of the exchanges is what is already in place within an area, linking together existing businesses, with the opportunity to fill in some new ones. The proximity of the companies permitted them to take advantage of already generated material, water, and energy streams.

5. Type 5: among firms organized "virtually" across a broader region.

   Considering that relocating a firm or production plant solely to be part of an industrial symbiosis may be expensive and challenging. Type 5 exchanges allow the benefits of industrial symbiosis to be expanded to encompass a regional economic community in which the potential for the identification of by-product exchanges is greatly increased by the number of firms that can be engaged. Some examples of virtual exchanges are knowledge, information, and technology.

Referring to the definitions of industrial symbiosis only the third, the fourth and the fifth type are actual symbiosis, while the first two lack the inter-firm characteristic therefore the internal resource recovery and the waste recovery can only be considered example of circular economy or at most industrial symbiosis kernels [8].

Historically the recognised exchanged resources in a symbiosis evolved from simple physical materials and evolved up to information and knowledge. The development of research and literature on IS provided many articles on this subject, this thesis will reference to Boons et al. (2011) and Chertow, Ashton, & Espinosa (2008) [63, 45].

1. Material and by-products exchanges. The exchange of firm-specific materials between two or more parties, the surplus material and by-product are used as substitutes for commercial products or raw materials.
2. Utility and infrastructure sharing that translate to water, wastewater and energy sharing. These kind of exchanges require proximity among the parties and are enabled by shared infrastructure managed as a community.
3. Joint provision of services, such as waste collection, water treatment, fire prevention and logistics. In this way common needs across firms for ancillary activities are meet at a lower price.
4. Information and knowledge, these resources are commonly share in industrial symbiosis national projects and networks.

Proximity is a relevant dimension to characterize an industrial symbiosis case. This dimension refers to the average distance among the stakeholders involved, with particular attention for the operating actors that are industrial plants and waste management centres. The literature highlights that proximity is not a necessary condition for symbiosis; however from real cases analysis it emerged that most of the exchanges take place in a radius lower than 30 kilometres. Therefore, if the average distance is shorter than that benchmark, we can classify that symbiosis as high proximity [64, 65, 66].

The literature, focusing on the case studies analysis, portraits diversified economics and industrial sectors involved in symbiosis. However, most of the companies that participate in symbioses operate in the manufacturing sector, followed by environmental services (water and wastewater management, waste management and remediation activities) and utility provider [18]. The manufacturing industry is responsible for the creation of the majority of pre-consumer by-products and waste, it is also the sector that require the higher supply of material for its activities, for these reasons it is the sector where symbiosis is more common. Focusing on the specific productive activities the most common in industrial symbiosis case studies are: chemical, steel and iron making, cement, pulp and paper, power plant and refineries [18, 8].

Industrial symbiosis can be classified according to their development, mainly considering if they are the result of spontaneous collaborations and exchanges among organizations or planned by a group of organizations or facilitators. Chertow defined planned and self-organized symbiosis as follow [54]:

1. A planned industrial symbiosis often takes form in an eco-industrial park or in a former industrial district. These symbioses are characterized by a conscious effort in the definition of the companies to involve in the exchanges or to locate in the EIP. Those are selected in a way that enables resource sharing across and among them. Examples of successful planned IS are: EIPs in China and South Korea and single industry dominated systems; these industrial models are characterised by the presence of core actors and of industries such as chemical and power generation that generate many by-products and can transform theme.
2. In self-organizing symbiosis, an industrial ecosystem emerges from spontaneous agreement among organizations, from private to public sector, to exchange resources and by-products. There is not necessary a common goal for the firms involved in these symbiosis, but the single firm partakes in those exchanges to reduce costs, enhance revenues, business expansion and to reduce its emissions, briefly to gather competitive advantages [55].

According to the literature review, on one hand, planned symbiosis are quite common and successful in the East while are more prone to failure in the West. On the other hand, spontaneous symbiosis are common the West and are the more successful in that geographic area [67, 24].

The distinction between planned and self-organized industrial symbiosis partially overlap with the concepts of bottom-up and top-down development. A bottom-up symbiosis is characterised by spontaneous agreements among the involved organizations, particularly among the operating actors that will exchange resource and are the ones that manage the symbiosis. While in the case of top-down the symbiosis or EIP is the result of the intervention of a central entity that can be a public or private organization that guides operating actors to join the industrial symbiosis; top-down IS are often planned and can be characterized by management body that governs the system or in other cases by a facilitator that operates in the planning and emerging phase and then left the operating actors free [68]. Between the classification of planned and self-organized there is the possibility of the involvement of a facilitator, which can be organizations of any kinds, public administrations such as public agency and universities, nongovernmental organizations like trade associations, or on-site entities at industrial parks or clusters who might best deliver such function [69].

The literature provides important insight into the funding of IS, distinguishing between those that require the building of utility infrastructures and those where it is not. Usually, if the investments to develop the symbiosis are substantial, like infrastructure or complex plant creation, companies are rarely able to undertake those costs by themselves and a third-party financing is required. The funder can be a government agency or private company. Liu and colleagues (2023) highlight that funding modalities vary a lot considering the geographic and economic context. On one hand, in China were identified cases where infrastructure creation was sponsored by local government and state-owned enterprises acted as management body among the enterprises during the operational process. On the other hand, in Europe, sometimes funds can be provided by government agencies, especially for the realization of utilities infrastructure, but for symbiosis generated via ISN the public administration participation is not identified as necessary. However, occasionally government facilitates symbiosis both with funds and in the definition of norms for their implementation [67].

2.4. Drivers, Barriers and Benefits

In this paragraph will be presented drivers, barriers and benefits of industrial symbiosis. It will focus on the finding from some literature reviews and academic journal articles [69, 70, 34, 59].

Industrial symbiosis is driven by various factors that encourage companies to collaborate and exchange resources for mutual benefit and sustainability. At the same time, there are barriers that can hinder the implementation of industrial symbiosis initiatives. A factor can be both driver, barrier or benefit according to different actors, for example the factor "public administration participation" can be a driver when the PA facilitates or changes normative to push toward IS, but in a different context it can hamper the development of a symbiosis with rigid regulation and outdated policies on waste and innovative processes research [59].

Let's define what each term means in this thesis. On one hand, driver refers to conditions and activities that can push toward industrial symbiosis practices. On the other hand, barrier refers to situations and activities that hamper and limit the development of a symbiosis. Lastly, benefit refers to the positive returns and outcomes that actors who partake in IS can gain.

In the following tables will be summarised drivers and barriers identified in the literature review. The aims of those tables is to facilitate the understanding of the different shades that each factor can play.

Table 2-1. Industrial Symbiosis Drivers

Drivers	Description	Source
Economic and Financial		
• Decreasing company operating costs	Reduction of operating costs such as waste disposal, raw material procurement, and energy costs	[54, 71, 24, 69, 72, 73]
• Raw Material cost vs Secondary raw material and by-products cost	When virgin raw material are more expensive than secondary raw material the latter are used	
• New business opportunities	Finding an alternative route for waste and by-products can lead to new business opportunities	
Technical		
• Resource security and availability (water, material and energy)	Recovering material and resource provide companies with resource security.	[71, 54, 74, 75, 69, 55]
• Resource exchanges and sharing		
• Service and Infrastructure availability	Ancillary services and infrastructure foster network and give strength to an exchange	
• Availability of affordable and reliable technologies	Technologies both at IT and manufacturing level are important drivers for symbiosis	
• Digitalization	Without digitalization especially of information industrial symbiosis is challenging	

Legal and Political		
• Policy • Waste Laws and Regulation • Environment Laws and Regulation	The presence of these kind of policies and regulation foster symbiosis from the planning phase up to the developed phase	[71, 54, 76, 77, 24, 55, 63]
Informational		
• Information disclosure • Information sharing • Information access and availability • Information management system	If companies have wide availability of data and are willing to share them this situation can foster symbiosis	[71, 74, 75, 69]
Organizational and Motivation		
• Strategic vision	Organizations that have sustainability and circular economy in their strategic vision are more likely to join or develop a symbiosis	[71, 74, 74, 59]
• Organizational structure	Vertical integrated firm and group are more likely to develop internal symbiosis	
• Stakeholders' relationship and trust	Strong and consolidated relationships among stakeholders give strength to a symbiosis and can foster it	
Geographic context		
• Geographic proximity • Strategic position • Logistic network	Proximity among companies foster relationship and make logistics and other resource exchange costs more affordable. Companies in an industrial district are more likely to have resource exchanges that can lead to symbiosis.	[55, 69, 77, 59]
Intermediaries		
• Research institutions • Public administration • Private and public network	The availability of intermediaries such as research institutes, ISN and public administration support the creation of the symbiosis. They act as facilitator.	[69, 77]

Environmental • Reduction of resource consumption • Reduction of energy consumption • Emission reduction • Waste and landfill use reduction	The development of more sustainable production systems can lead to symbiotic practices and exchanges	[18, 24, 69, 59]
Social • Community awareness • Environmental awareness	Customer awareness on sustainability and circular economy lead the market for this kind of practices	[24, 77, 69]
• Job creation	Policies for job creation can lead to development practices	

The term barrier in this context refers to a circumstance or obstacle that prevent the occurrence of a phenomenon. In this text it specifically refers to situations and circumstances that are preventing the evolution and diffusion of industrial symbiosis.

Table 2-2. Industrial Symbiosis Barriers

Barriers	**Description**	**Source**
Economic and Financial • High investment and long return on investment • Excessive operating costs • Lack of financial funding and incentives misalignment • High transactional cost • Unclear economic benefits	Especially for IS that require dedicated infrastructure and changes in the production processes	[24, 18, 78, 70, 69, 79, 80, 59]
• Risk of discontinuity	A change in by-products production can stop the symbiosis and the supply chain	
Technical • Lack of infrastructure and service • Supply risk and predictability • Resource exchange complexity	Without a path to exchange resources symbiosis is impossible	[24, 18, 78, 74, 70, 56, 72, 59]
• Lack of recovery and recycling technologies • Lack of technical knowledge	Lack of appropriate technical skills and technologies in the context may limit the development of a symbiosis	

Legal and Political • Uncertainty in regulations • High complicate bureaucratic procedures	A complex regulation process hamper the development of industrial symbiosis	[24, 78, 70, 69, 72, 59]
Informational • Information asymmetry • Lack of information access • Lack of information on waste and byproducts • Complexity of information exchange	Without information and commitment to share them among stakeholders a symbiosis is not possible	[24, 78, 74, 70, 59]
Organizational and Motivation • Lack of awareness of industrial symbiosis concepts • Cognitive barriers • Lack of trust • Organization culture • High Risk perception • Organization size and internal exchanges • Conflicts of interest	Small and medium enterprise usually are not familiar with IS Particularly relevant for knowledge and information exchange Vertically integrated firm can develop symbiosis practices inside their boundaries	[18, 78, 70, 69, 81]
Geographic context • Long distances between stakeholders • Lack of infrastructure for energy and water exchanges	Without infrastructure and efficient logistics IS are avoided	[69, 59]
Intermediaries • Lack of communications • No intermediaries available • Lack of participation in the network	Complex symbiosis require intermediaries and well defined communication among parties, if these fail the symbiosis cannot develop	[69, 59, 72]
Environmental • Environmental regulation • Potential risk for human health	Not all the possible symbiotic practices are environmentally sustainable or safe for health, those are rightly prevented by regulations	[78, 70, 59]
Social • Social inertia • Lack of awareness of industrial symbiosis concepts	Resistance to change and local communities worries on the safety of the symbiosis.	[69, 59]

Drivers and barriers of IS cover various dimensions, the most relevant according to the literature review are: Economic and Financial, Technical, Legal and Political, Informational, Organizational and Motivation, Geographic context, Intermediaries, Environmental, Social.

According to Domenech & al. (2019), the drivers for IS are: decreasing company resources costs, reducing waste generated by the company, creating new areas of revenue, increasing turnover for the company, building new partnerships with other companies, helping to achieve the environmental policy and targets of the company, changing the company's business model to a more sustainable one, help divert waste from landfill, access to innovation, acquiring new clients, improve quality/security of inputs, satisfaction of CSR requirements, create jobs [24].

Domenech and colleagues also identified barriers to symbiosis: risk and uncertainty linked to difficulty to identify costs-benefits and return on investment ex-ante, lack of time, logistics (high transportation costs and dispersed production sites), high costs for the IS transition, lack of technical information, lack of information needed, transactional costs, upfront costs for participating in IS network or transaction, difficult to assign benefits among parts, once the transaction has been successfully implemented, storage space, other organizational barriers [24].

In a recent study, Agudo and colleagues identified [74] five drivers for the implementation of an IS, those are: water and energy, waste and by-products, matches the variables of information access, information sharing and trust, access conditions, infrastructure and partnerships. The first two drivers deal with the resource exchanges, while the last three deal with the exchange capacity dimension manly considering information and infrastructure availability. Mirroring the drivers this study also identifies some barriers: lack of an adequate infrastructure for water and energy exchanges, lack of information sharing between co-located companies, little information available on waste and byproducts generated by neighbouring factories and resources availability. To mitigate these barriers, companies need to develop a sharing culture and to employ digital technologies for aiding the security and easiness of information exchange.

Companies and organizations involved in IS can achieve environmental, social and economic benefits. It is meaningful to present the benefits of industrial symbiosis according to sustainability triple bottom line: environmental, economic and social. The latter is the most challenging dimension to assess and measure.

Table 2-3. industrial Symbiosis Benefits

Benefits	Description	Sources
Economic • Reduced operational costs • New market opportunities • Reduced tax	Symbiosis provide new market opportunities for by-products and can save cost via secondary raw material procurement Due to emission reduction and environmental practices promoted by symbiosis companies must pay less taxes-	[69, 34]
Social • Job creation • Education • Health • Improved local air quality	Education and consciousness on environment can be disseminate through field trip in IS plan Health and improved air quality are indirect benefit related to emission and energy requirement reduction	[69, 34]
Environmental • Resource extraction reduction • Water usage reduction • Emission reduction • Energy demand reduction • Waste reduction	More efficient use of resources improve the environmental sustainability of the industrial sector	[69, 34]

On one hand, economic returns and benefits of IS are measured by comparing the cash flow and costs of the IS configuration with the former configuration. However, the best way to compare scenarios is using the net present value that is computed as follows:

Equation 2. Net Present Value

$$Net\ Present\ Value\ (NPV) = \sum_{t=1}^{T} \frac{CF_t}{(1+i)^t} - I_0$$

$$CFt\ =\ Estimated\ net\ cash\ flow\ for\ period\ t$$

$$I\_0 =\ Initial\ investment$$

$$i =\ discounted\ rate$$

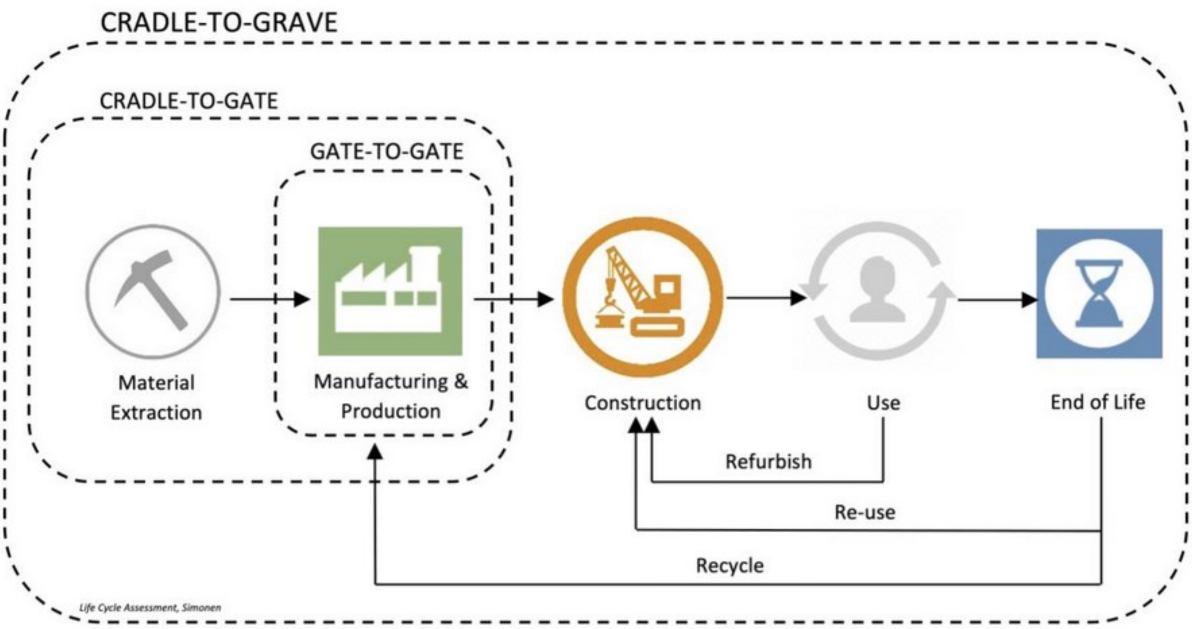

Figure 2-1 Boundaries life cycle assessment illustrated [82]

On the other hand, the most common tool to measure the environmental impacts and benefits of symbioses is the Life Cycle Assessment (LCA), an indicator that measures the total emissions generated by the production and use of a product, which can follow different approaches to assess the emission in function of the boundaries of the study. The rules and standards for this assessment are defined by the ISO 14040, and the figure above presents the most common boundaries considered for this kind of assessment.

2.5. Kalundborg the first case of Industrial Symbiosis

The model of industrial symbiosis was realized for the first time in the eco-industrial park at Kalundborg, Denmark. It is the result of the partnership between nine public and private companies in the Danish city that, since 1972, developed the world's first industrial symbiosis with a circular approach to production. It started from a traditional industrial cluster, but the challenges of water supply and interest in by-products economic return brings firms and public organizations together to find a solution. The symbioses evolved gradually and without a grand design over more than 50 years. It started as the firms sought to make economic use of their by-products and to minimize the cost of compliance with the new stricter environmental regulations of the 70s [61].

The partners of the Kalundborg Symbiosis have worked together since the 1960s, resulting in a collaborative approach and openness to new symbiosis opportunities [83]. However, only in the 1980s the partners realised that they had effectively "self-organised" into what is probably the best-known example of a working industrial ecosystem. In addition, it is believed that the very term industrial symbiosis was coined by the power station manager in Kalundborg, meaning "a cooperation between different industries by which the presence of each [...] increases the viability of the others, and by which the demands of society for resource savings and environmental protection are considered" [84].

The primary actors of the symbiosis were: an oil refinery, power station, a gypsum board facility, a pharmaceutical plant, and the City of Kalundborg. All of them literally shared groundwater, surface water and wastewater, steam and electricity, and also exchanged a variety of residues that become feedstocks in other processes [8].

Today, more than 20 different streams of surplus resources flow between the companies, that over the years have become 16, creating a symbiosis of resource exchange, adding more resilience and profit to the partners. Beyond material and resource surplus the symbiosis also creates trust and power of innovation within the community. It has positive impacts not only on the environment and economy, but also on the social level benefitting people such as employees, students, and researchers and the climate [83].

In *Figure 2-2* it can be observed the original resource flows of the Kalundborg Symbiosis in the year 2008.

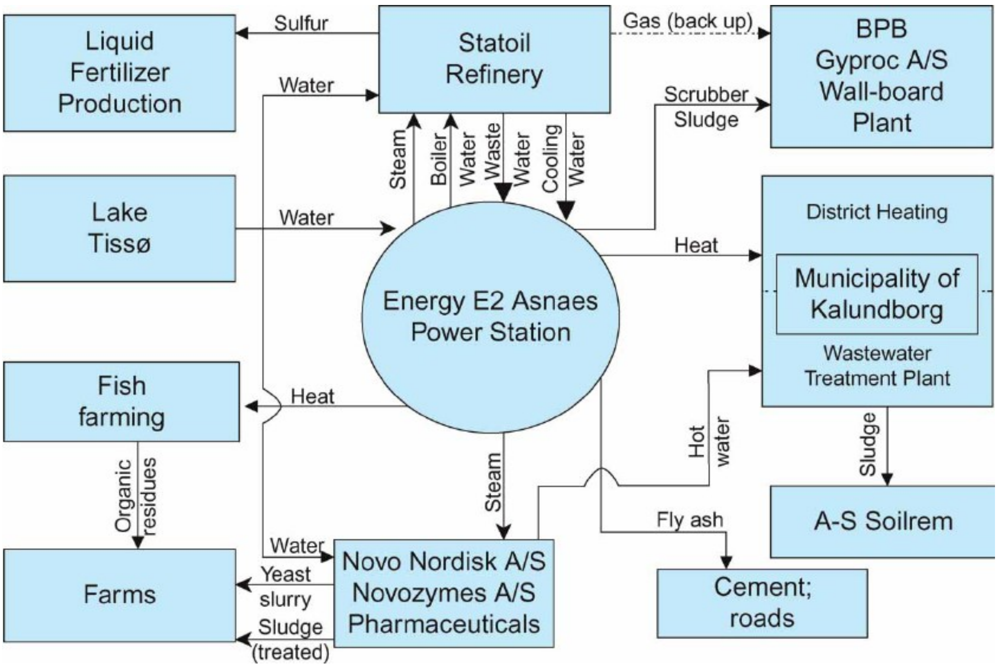

Figure 2-2. Industrial symbiosis in Kalundborg, Denmark [45, p. 1301]

The symbiosis has in its heart the Asnaes Power Station, the largest power plant in Denmark. The power plant exports part of the formerly wasted energy to its own fishing farm and to the municipality for domestic heating. Thank to this heat recovery Asnaes has reduced the fraction of available energy directly discarded by about 80%, and the town of Kalundborg has eliminated the use of 3,500 oil-fired residential furnaces by distributing heat from the power plant through a network of underground pipes. The sludge from the fishing farm is sold as fertilizer.

Asnaes also exchanges process steam to its neighbours, Novo Nordisk and Statoil Refinery. 40% of Statoil' steam requirements and all Novo Nordisk' steams come from the power station. The refinery also exchanges water and heating/cooling with the power plant.

The power station also provides feedstock containing gypsum to Gyproc, a neighbouring wallboard maker. The feedstock is the by-product of the scrubbing process and provides two-thirds of Gyproc's gypsum.

Fly ash and clinker, the remains of coal burning power generation, are sold by Asnaes for road building and cement production.

Every year symbiosis is assessed to save: 4 million cubic meters of groundwater substituted with surface water, 586.000 tons of CO_2, and 62.000 tons of residual materials recycled. In 2020 80% of the CO_2 emissions in the symbiosis has been reduced compared to 2015. The local energy supply is now CO_2-neutral [83]. The symbiosis was born to find economic use of by-products and to solve the challenge of freshwater scarcity, however, it resulted in a sustainable development that reached all the dimensions: economic, environmental and social.

3 Methodology

The aim of this research work is to better understand the diffusion and development of industrial symbiosis in the Italian context, the scope is to answer to 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?

The research followed a mixed approach to address these questions; the first phase of the research consisted of a literature review about industrial symbiosis to develop an understanding of the current academic landscape and to find the gaps in the literature. The second step was a quantitative research to create a database of industrial symbiosis cases in Italy consulting both academic literature and grey sources such as newspaper and public administration publications. Then a qualitative analysis was conducted on 5 case studies through interviews with the main stakeholders of each industrial symbiosis to gather insights on their development and inter-firm relationships. In addition, an interview with ENEA was performed to gain insights on their role of industrial symbiosis facilitator. A schematic description of the methodology adopted in this study can be seen in *Figure 3-1*.

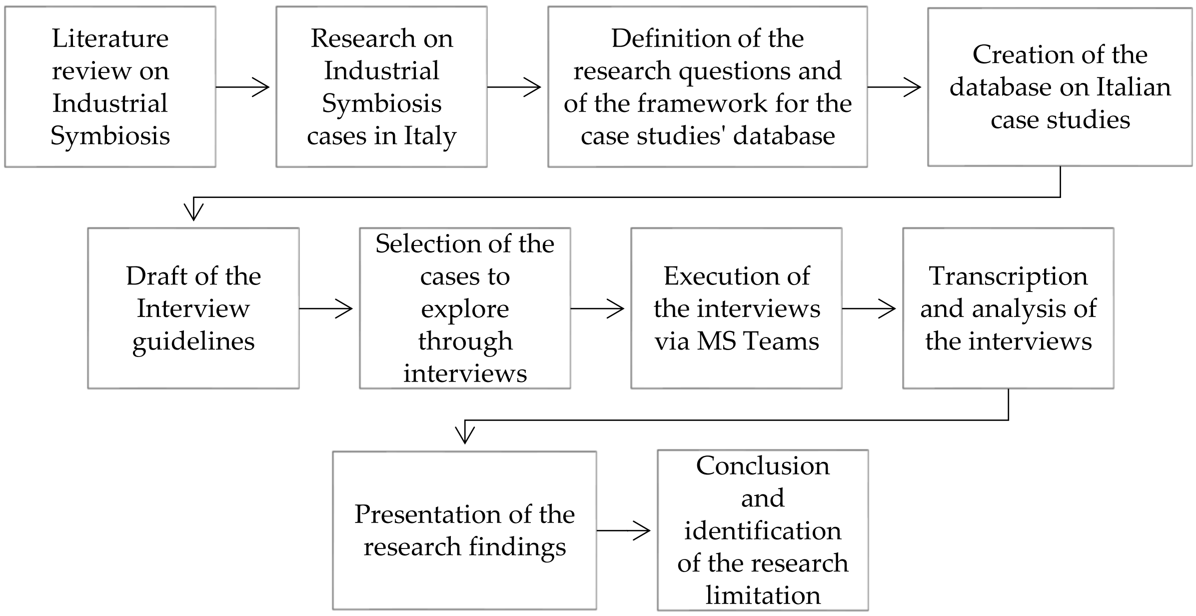

Figure 3-1 Methodology scheme

3.1. Literature review

The scope of the literature review was the understanding of the current state of the art in the research landscape on Industrial Symbiosis. The literature review was performed using as main sources Scopus, Google Scholars and Symbiosis Users Network (SUN), the website of the Italian network for industrial symbiosis, for the academic papers. The findings of the literature review can be seen in Chapter 2.

This research was performed using the snowball approach (Lecy & Beatty, 2012) starting from Chertow taxonomy on industrial symbiosis (Chertow, 2000). In Table 3-1, it can be seen the query used on Scopus to extract the articles and reviews used to define the state of the art of the academic and practitioner literature on Industrial Symbiosis

Table 3-1 Research query on Scopus for the initial literature review

```
REFEID ( 2-s2.0-0034497962 )
AND ( LIMIT-TO ( DOCTYPE , "ar" ) OR LIMIT-TO ( DOCTYPE , "re" ) )
AND ( LIMIT-TO ( LANGUAGE , "English" ) )
AND ( LIMIT-TO ( PUBSTAGE , "final" ) )
AND ( LIMIT-TO ( EXACTKEYWORD , "Industrial Symbiosis" )
OR LIMIT-TO ( EXACTKEYWORD , "Circular Economy" )
OR LIMIT-TO ( EXACTKEYWORD , "Eco-industrial Park" ) )
```

This research gave as output in July 2023 a list of 561 articles and reviews that were then analysed by title and abstract to check their pertinence to the research. The articles that contained urban symbiosis in the title, those that focused on the economic and environmental footprint assessment, and those that only presented case studies, meaning that they just described the exchanges and relationships in the symbiosis not adding analytical insight, were excluded. The literature on urban symbiosis was removed from the research due to its peculiarity and its focus on waste management in the form of waste to energy and recycling, these activities can be related to type I resource exchange according to Chertow's taxonomy that defines them as not aligned to the definition of industrial symbiosis [8]. The publications on economic and environmental assessment of individual symbiosis cases are excluded from the analysis as they did not provide information on the general context of industrial symbiosis but focused on specific contexts and applications.

After the cleaning of the search result the final output was a list of 347 articles and reviews, subdivided in 310 articles and 37 reviews. The main sources of the publications can be subdivided in: Journal of Cleaner Production, Sustainability Switzerland, Journal of Industrial Ecology, Resource Conservation and Recycling. However, as can be seen in *Figure 3-2* there are many different sources that covered the subject of industrial symbiosis both in the perspective of circular economy and sustainable development.

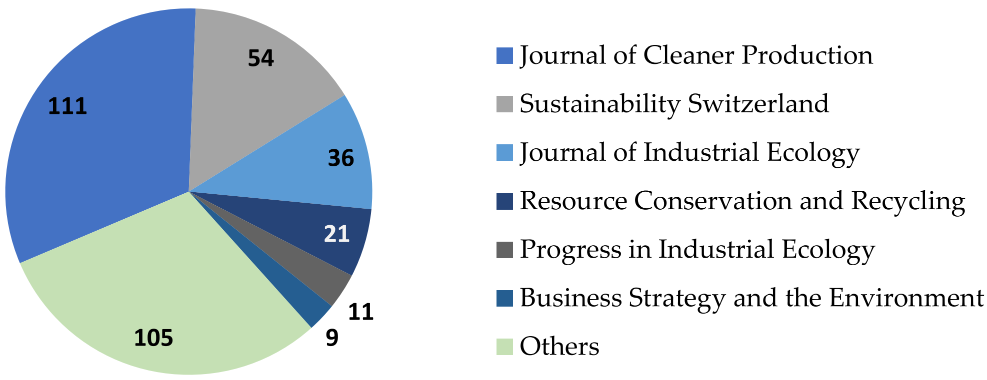

Figure 3-2 Sources of the literature review

Further analysing the sources it is possible to understand the historical development of IS research. The concept of industrial symbiosis emerged from the industrial ecology discipline in the late '90s, even if it was indirectly referenced even back to the late '70s. However, the publications on this topic steadily increased in the last two decades considering the year 2000 as the start of the trend. In *Figure 3-3* it is possible to have an overview on the spread of IS in academic publications, on the x axis are reported the years while on the y axis are reported the number of yearly publications.

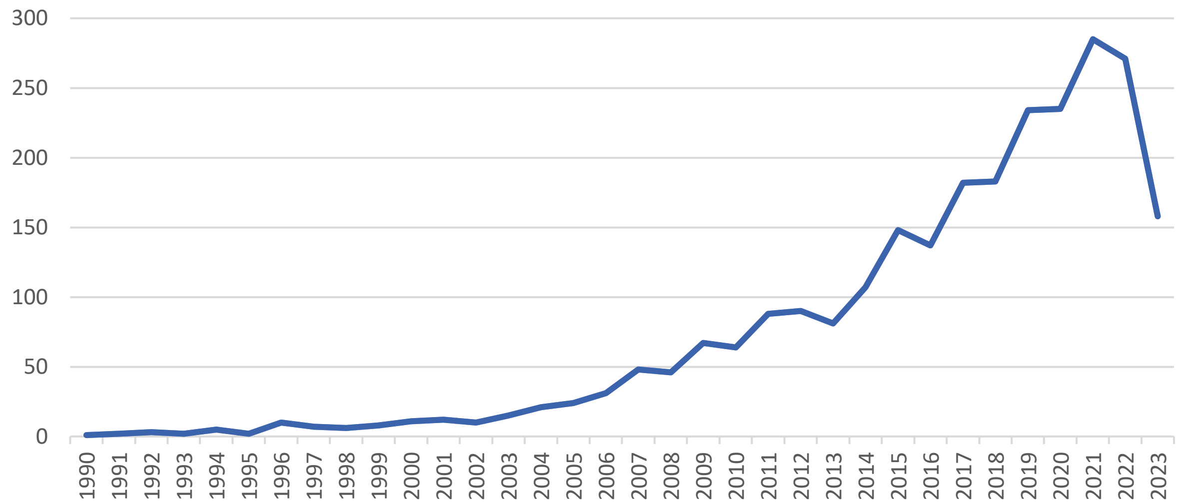

Figure 3-3 Number of yearly publications on Scopus about Industrial Symbiosis

The pieces of evidence gathered from the literature review were consulted and studied to create an overview on industrial symbiosis. In addition, the definition of the state of the art was the baseline to understand the gaps in the literature and therefore a tool to draft the right research questions and the framework designed for this thesis.

3.2. Database and quantitative analysis

The research for the Italian case studies on Industrial Symbiosis was performed using as main sources Scopus, Google Scholars and Symbiosis Users Network (SUN), the website of the Italian network for industrial symbiosis, for the academic papers while for grey literature the main source has been EcoCamere, the official website of the Italian Chambers of Commerce. In Table 3-2, it can be seen the query used on Scopus to extract the articles and reviews used to find the Italian case studies on IS.

Table 3-2 Research query on Scopus for the case studies in Italy

(TITLE-ABS-KEY (industrial AND symbiosis)
OR TITLE-ABS-KEY (eco-industrial AND park*)
AND TITLE-ABS-KEY (ital*))
AND (LIMIT-TO (PUBSTAGE, "final"))
AND (LIMIT-TO (DOCTYPE, "ar"))

This research gave as output in July 2023 a list of 52 articles that were analysed by title and abstract in order to check their pertinence to the research, from those publications only 22 were relevant to the creation of the database and the others were excluded from this part of the research. In addition, publications from the SUN and articles from EcoCamere were consulted to define the sources for the case studies database. The collected sources were then cleared giving as output a list of 22 articles extracted from Scopus, 9 publications from the proceedings of the yearly SUN conferences, and 19 articles from EcoCamere.

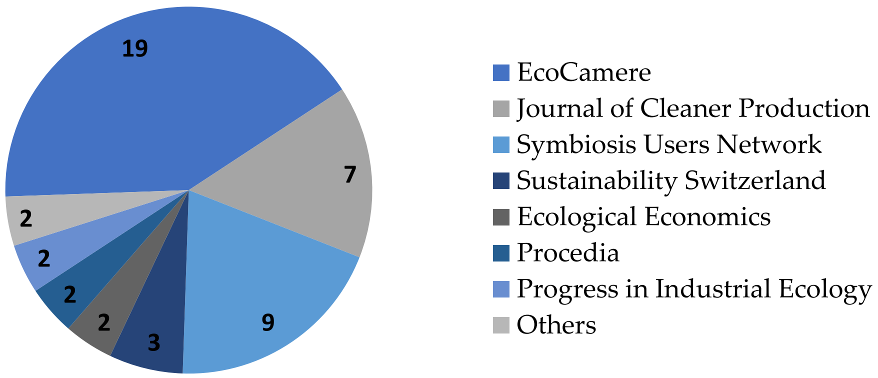

Figure 3-4 Sources of the case studies

The result of this literature review was the identification of Italian case studies of industrial symbiosis. From the 50 articles and publications 50 case studies were identified and collected in the database. Initially, the database was made on MS Excel, which is not a database tool, and then all the cases were described on a MS Word document using the following framework:

Table 3-3 Case Study Framework

Dimensions
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 dimensions of the database are the result of the literature review that gave as output an extensive understanding of the characteristics that are relevant to describe a case of industrial symbiosis, below will be presented all the dimensions.

Industrial symbiosis code is a number that univocally identify the case study in the database. The database consists of 50 cases of IS and symbiotic relationships in Italy, they were collected from academic literature (Scopus and Google Scholars) and publications of government agencies such as ENEA and EcoCamere (Italian Chamber of Commerce official website).

Geographic area refers to the Italian region where the IS takes place, further information will be recorded only if the symbiosis occurs in a single province or is an interregional symbiosis.

Productive sectors and *ATECO Code* are the dimensions of the analysis that describe the productive sectors involved in the symbiosis, the former focus on the macro dimension while the latter is more detailed and records the economic activities performed by the involved organizations using the Italian nomenclature. The ATECO code was adopted by ISTAT[5] in 2007 and updated in 2022; it is a numeric code from two to six digits that classifies the economic activities for statistical purposes.

[5] Istituto nazionale di statistica

The classification on *digital technologies* uses an extension of the industry 4.0 taxonomy that involve the following technologies: artificial intelligence, additive manufacturing, augmented reality, blockchain, big data analysis, cloud computing, cyber physical system, digital platform, digital twin, enterprise resource planning, internet of things, mobile computing applications, product lifecycle management systems, social media, simulation and virtual reality. The literature from which the industrial symbiosis' cases were collected rarely focused or disclosed this dimension. For these reasons some assumptions were done: Cloud Computing and Enterprise Resource Planning are well diffused technologies in the manufacturing industry therefore it was assumed that they are used for all the cases. In the interview phase of the research this assumptions have been validated.

Proximity among stakeholders, in this work this label is assigned in the case of an average distance between the organizations partaking in the IS of 30 km or less. According to the literature [86, 8] geographic proximity is not a necessary condition for the arise of IS but it is a driver. However, most of the cases in Italy take place in close proximity, where involved organizations are in a radius of less than 30 km, and in industrial clusters, a geographic concentration of firms operating in the same sector that is quite common in Italy; the latter are often turned from spontaneous industrial cluster into eco-industrial park.

The *taxonomy* used is the one developed by Chertow (2000) for material exchange among IS and EIPs that was previously defined in the literature review.

Shared or exchanged resources. From the literature review IS involves resources, infrastructure and information exchanges. Many resources can be shared in a symbiosis: material, energy, water and by-products are the physical exchanges [8], information and knowledge sharing [86], utility and service sharing [75].

The *involvement of the Public Administrations* (PA) -like municipality, provinces, regions, National Health Service (SSN), school and universities, and chambers of commerce- is recorded when it occurs.

EU or regional initiatives used for funding IS initiatives. Occasionally some symbiosis or exchanges are promoted and/or funded by European Commission project or regional funding, therefore they are recorded for cases where they have occurred.

Facilitator. In the implementation and development of an IS it is possible that an actor takes the role of facilitator, it can be a PA, a network for IS (e.g. SUN), a business association, or research institutes. According to Boons et al. (2017), the facilitator may play a wide range of roles from collecting technical data to organizing workshops or meetings, conducting feasibility studies, being involved in negotiation, decision making, and follow-up activities for operation of symbiosis [56].

The *current State of the IS* can be: research & planning, emerging, developed or declining. While the *emerging phase of IS* can be classified as: planned, self-organized (spontaneous) or facilitated [54, 87, 88]. Facilitated symbiosis can be both top-down and bottom-up, while planned symbiosis are always top-down.

In the literature there are several frameworks to classify Circular economy products and business model. The best known is the circular economy system diagram, also known as *butterfly diagram*, developed by Ellen MacArthur Foundation [89].The butterfly model together with the R10 models are very useful for classifying products, but in this work only the former will be used to describe the circular activities that are adopted in the different case studies. However, it is not enough to fully describe industrial symbiosis in the circular perspective.

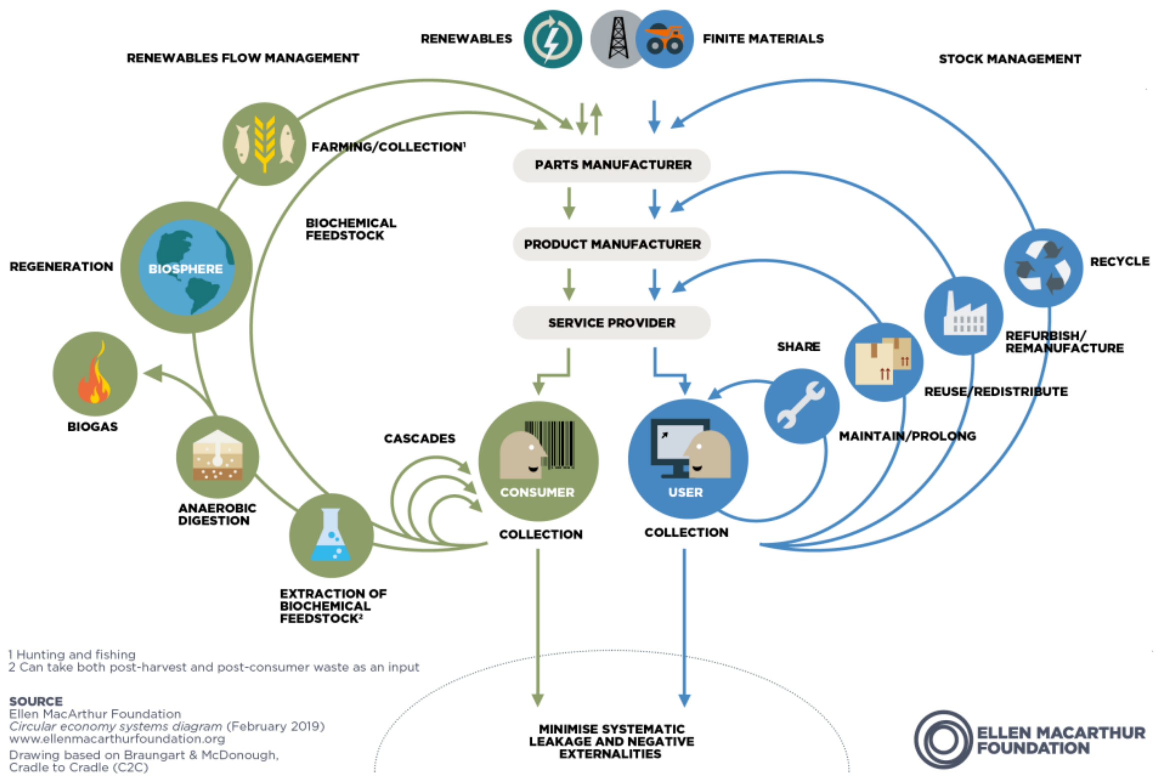

Figure 3-5 Butterfly Diagram [6]

As mentioned in the state of the art industrial symbiosis is one of the many circular economy business models, therefore, to describes the CE practices of the case studies the Circular Economy Matrix will be used [90]. The Matrix uses two dimensions to describe the company’s circular level of adoption, those dimensions are: the value network (suppliers and partners) and customer value proposition and interface.

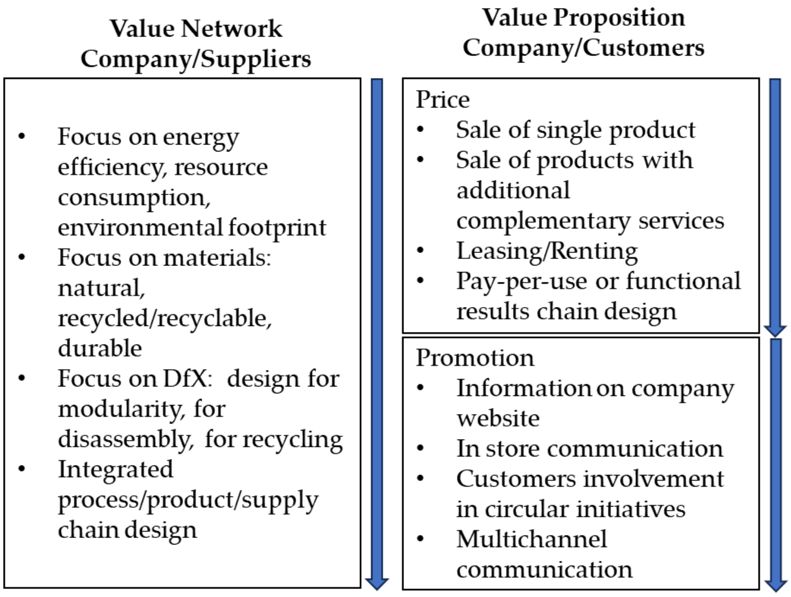

Figure 3-6 Circular Economy Matrix [90]

Beside the dimensions just described the framework also required information and research on number of involved companies and synthetic description of each case.

The framework used for the database enabled a quantitative analysis that provided information about the local distribution, the average number of companies involved, the most common sectors. These analyses were done using Excel due to the relatively small size of the database and the simplicity of the statistical analysis; however the limitation of this methodology will be presented in the concluding chapter.

3.3. Interviews and qualitative analysis

The research adopted a qualitative approach to explore and understand the phenomenon of industrial symbiosis in depth. Moving to the qualitative phase of the research, firstly the case studies to further investigate were selected from the database focusing on the cases that involved more organizations and seeking to gather data on different types of IS. From the literature review and the analysis of the selected case studies an interview guideline was defined drafting some questions to ask to all the companies and some only for facilitator and platforms, a series of open-ended questions were grouped in industrial symbiosis, organizational culture and trust, and digital technologies. The interview guideline can be seen in detail in *Annex A*.

The participants for the interviews have been purposefully selected to ensure diverse perspectives and experiences related to industrial symbiosis in Italy. For each selected case the main companies were identified and contacted. Each company was contacted via e-mail or phone to schedule an interview. However, we didn't receive replies from all companies contacted, but we planned and executed 10 interviews. Each interview was done online using the software MS Teams between the months of May and July 2023. In table 3-4 can be seen an overview of the interviews.

At the beginning of each interview, the interviewees were provided with a clear explanation of the research and were asked for permission to record the interview and to be able to report the company name in this thesis. Informed consent has been obtained prior to conducting the interviews. The recordings were used to transcribe the interviews and for further research and to facilitate data analysis.

The data collected was then analysed and elaborated to deepen the case studies and detect some information to answer the research questions. The collected data enabled the identification of recurring patterns, themes, and categories within the various cases of industrial symbiosis in Italy. The findings of the interview' qualitative research will be presented in chapter 5, about the case studies, and chapter 6, about ENEA's role of facilitator and its occurrence in the database.

Adopting a combined methodology, using quantitative analysis in the database and qualitative analysis with the semi-structured interviews, this study aims to gain a comprehensive understanding of the Italian context about industrial symbiosis dissemination in order to answer the research questions.

The expected results will contribute to a deeper the understanding of the subject matter and provide valuable recommendations for promoting and implementing industrial symbiosis practices. A summary collection of the findings, future research and recommendations, and the limitations of this study will be presented in the final chapter of this work.

Table 3-4. Overview of the interviews

Industrial Symbiosis code and company	**Interviewee(s) role**	**Interview date**	**Interview length**
017_Agroittica Lombarda	Head of Special Projects & Scientific External Relations	15th May 2023	90 min
017_Feralpi	Head of Environmental Management System Employee Environment Office	09th June 2023	65 min
022_Molhelix	Chief Executive Officer	15th May 2023	60 min
035_Cuoiodepur	Technical director	10th May 2023	60 min
035_Lapi Group	Chief Executive Officer	05th June 2023	55 min

042_Bioenergia	Chief Executive Officer	19th May 2023	60 min
042_MCF la Segheria	Technical director	25th May 2023	45 min
048_Alfa Acciai	Environment manager	14th June 2023	75 min
048_A2a Calore e Servizi	Project Management Engineer – process specialist District heating-communication	16th May 2023	45 min
ENEA	ENEA's research scientist of the Laboratory Resources valorisation	26th July 2023	60 min

4 Database on industrial Symbiosis

The analysis of the database of 50 Italian case studies of industrial symbiosis will be presented in this chapter as factual as possible, for comments and extrapolation of the results refer to the final chapter of this thesis. The database is the result of the updating and editing of a preexisting database that counted 31 cases that was integrated using the literature review described in the previous chapter.

4.1. General analysis

In this paragraph the information that wasn't deepened in the *Case Studies Framework* will be presented. The analysis of the framework dimensions will be done in paragraph 4.2.

Comparing the case studies that emerged in an industrial district with the others it emerged that the former usually involve more companies than the latter, this can be justified with the fact that companies in industrial district usually are small and medium enterprise specialized in one or few phases of the supply chain; therefore, to reach economic feasibility and process optimization about resource exchange more companies are needed and also the proximity among the firms in the district and their specialized activities favour the creation of a bigger network of organizations. However, as can be observed in the table 4-1 most of the cases of symbiosis take place outside of industrial districts.

Table 4-1. Comparison between number of involved organizations

	From industrial district	**Not from industrial district**
N° of cases	7	43
Average involved organizations	260	5

In the cases some companies were cited explicitly, particularly there are 92 organizations such as enterprises, municipalities, universities and business associations that are named, while there are some businesses that are left anonymous, therefore it is not possible to clearly identify the total number of organizations involved in industrial symbiosis activities.

In the database, the innovation level and the capital intensiveness of each company were reported. On one hand, capital intensive refers to business processes or industries that require large amounts of investment to operate, the assets are often fixed, and the initial investment is high, therefore this dimension is strongly related to the industrial sector of each company. On the other hand, innovation level refers to the level of novelty in the process and products of the company compared with the companies in the same sector. The two dimensions used the following scale: Low, medium-Low, Medium-High and High. In the table below is possible to see the relationship between innovation level and capital intensive.

Table 4-2. Capital intensiveness and innovation level relations.

		Innovation level			
		Low	Medium-Low	Medium-High	High
Capital intensive	Low	3	0	10	8
	Medium-Low	42	24	7	7
	Medium-High	8	22	43	1
	High	3	7	3	1

From the literature review not a lot of companies result to be both capital intensive and high in innovation level, however through the interviews emerged that often the most recent innovations of a company are not disclosed publicly for competitive and strategic reasons. Therefore, it is plausible that the real number of companies with high innovation levels could be higher than reported.

The last dimension analysed in the database and not in the framework is the distinction between input and output actors, in the existing database and therefore in this work those words have the following meanings:

- Output actors are those that can offer or share resources, they supply materials, by-products, water, energy, infrastructure and skills.
- Input actors are those that can use and demand the resources, they can exploit the resources supplied by the output actors through direct use or transformation.

An organization can be both an output and an input actor, and from the literature it emerged that companies are more often exclusively output providers rather than input receivers. Considering the definition of IS in any case there are at least two actors who play the two distinct roles, although in some cases where the symbiosis is within the boundaries of a vertical integrated organization or in a group both the roles can be played by the same actor.

4.2. Analysis of the database dimensions

In this paragraph, the dimensions of the case studies framework will be elaborated and deepened to provide an overview on the Italian landscape of industrial symbiosis.

A relevant finding from the database is the analysis of the dimension *geographic area* that provides interesting insight on the geographic distribution of the case studies in Italy. The analysis of the literature shows that not all Italian regions have cases of symbiosis, the regions of Basilicata, Campania, Liguria and Val d'Aosta don't have any reported case of industrial symbiosis according to our literature review.

Other interesting information on the geographic context can be observed in *Figure 4-1*. Beyond expectations, there are many cases of symbiosis in Umbria and Sicilia, those can be explained by two ENEA's projects Ecoinnovazione Sicilia (2011-2015) and Simbiosi Industriale Umbria (2017-2018). While for the cases in Calabria they are all in the agri-food industrial, and 2 of them were facilitated by the Mediterranean University of Reggio Calabria and one by a European project (Porem Project LIFE ENV/IT/ 333).

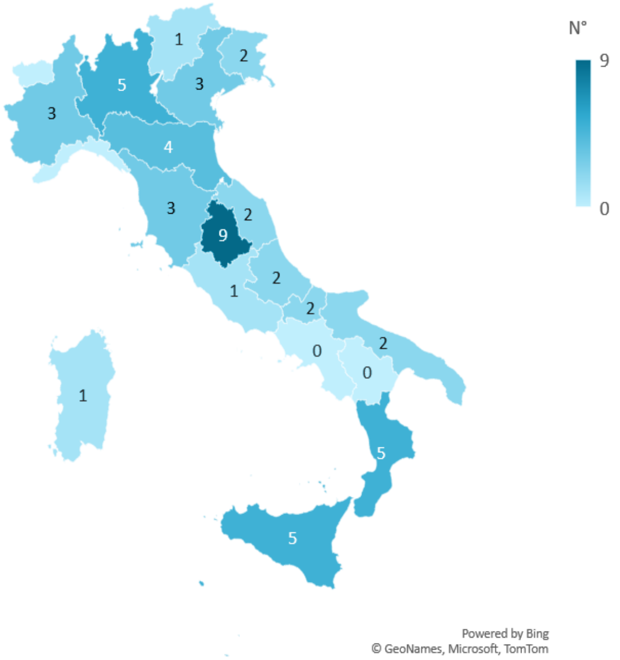

Figure 4-1. Number of IS cases for each Italian region.

It is relevant to investigate the dimensions of *productive sectors* and *ATECO Code*, according to the ISTAT all the code referring to the specific economic and industrial activities, ATECO code, can be grouped into 14 macro productive sectors. In *figure 4-2* it can be observed in how many cases of industrial symbiosis a sector is involved; it is important to highlight that most of the cases are cross-sectoral meaning that stakeholders from different sectors collaborated for the IS. For further level of detail on the ATECO codes pairing with productive sector see *Annex A.2.*

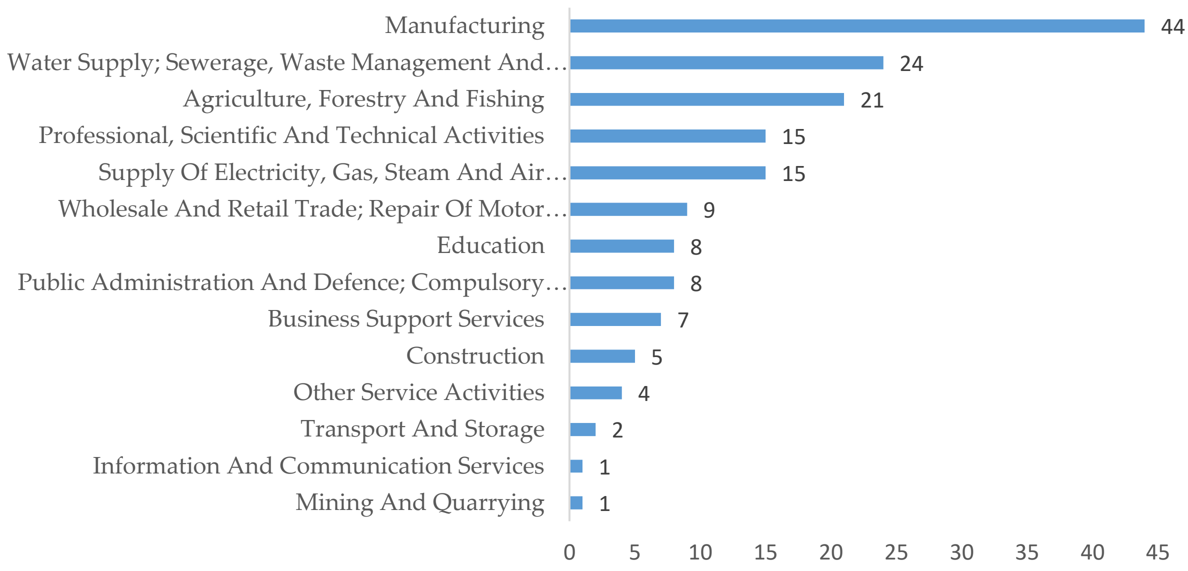

Figure 4-2. Bar chart of the productive sectors included in the cases.

Most of the cases of industrial symbiosis involve manufacturing, agriculture, water, sewage and waste management. Those three sectors are the ones that most frequently participate in symbiosis, particularly shared industrial environmental services are the base of the cases of symbiosis that emerged from industrial district. Other relevant sectors are professional, scientific and technical activities, education, and public sector. Those are the sectors of the stakeholders that cover the role of industrial symbiosis facilitators in the form of coordinator or research and developing actor.

Regarding the *digital technologies* dimension, the literature review on the case studies didn't give back many data, it has been assumed that most of the companies participating in the symbiosis, which are medium or big enterprises, follow industry standards regarding digital technologies, meaning that they use: cloud computing, enterprise resource planning, and internet of things through industry 4.0 sensors. While small enterprises could use digital technologies with a smaller extent, due to the costs of cloud solution and of industry 4.0 technologies. In addition, this dimension has been deepened mostly during the interviews, therefore the results will be presented in the next chapter.

Considering the dimension of *proximity* most cases are labelled as close, in fact 34 cases are characterized by a distance between the involved companies lower than 30 km. While the other 16 cases are characterized by an average distance higher than 30km. Considering that as mentioned some cases didn't report the name of the companies involved in the symbiosis some of this data are the result of assumption based on the information available in each paper.

Table 4-3. Proximity dimension.

	Proximity	**Not Proximity**
N° of cases	34	16

Chertow *taxonomy* was applied to the case studies of the database, all the five types of resource exchanges were identified. The most common types are the fourth and third ones, this is aligned with the average number of involved organizations and to the fact that most of the cases are characterized by close proximity.

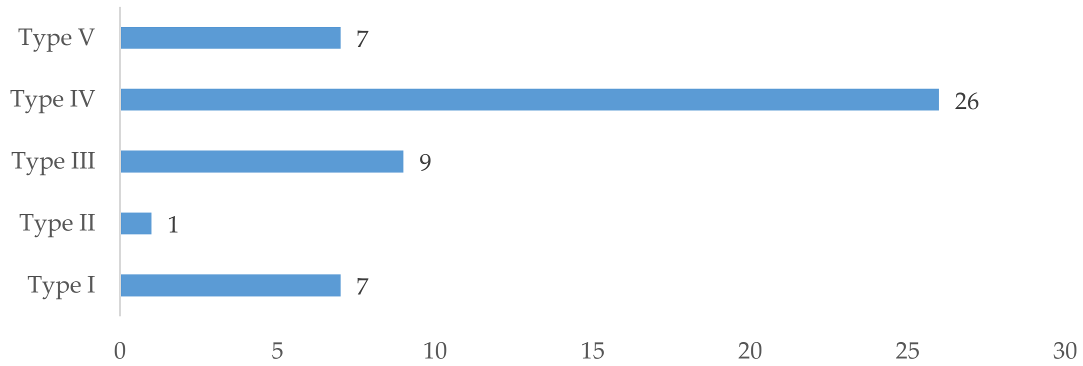

Figure 4-3. Chertow taxonomy applied to the database.

The resources that companies can share or exchange in symbiosis are of many types: by-products, material, water, energy, infrastructure, service and knowledge. In figure 4-4 can be observed all the combinations of resource exchange in the 50 cases of industrial symbiosis. 19 cases rely on by-product exchange and the other 24 share a combination of resources that include by-products. Those results are reinforced by the literature that positions the exchange of by-products and materials as the most common form of industrial symbiosis. The database also highlights the rarity of information and knowledge sharing in IS, the literature recognizes those resources as difficult to share due to lack of trust among players and to the complexity of managing information among different actors.

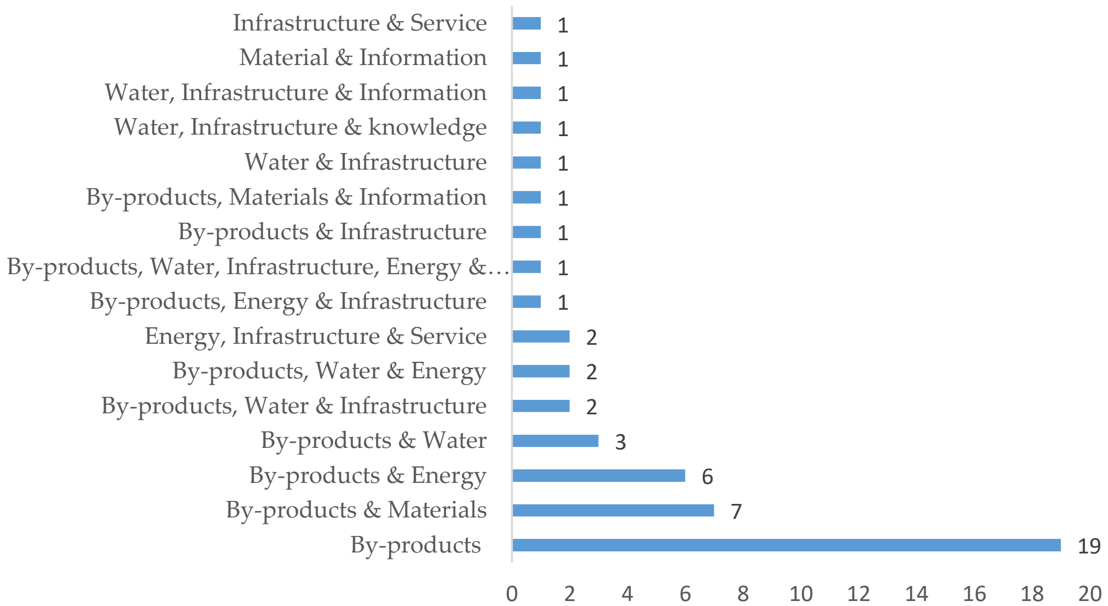

Figure 4-4. shared or exchanged resources in the symbioses.

Considering the classification in top-down and bottom-up, the database corroborated the literature regarding the dominance of bottom-up approaches in the west; the Italian landscape on symbiosis is aligned with the data from other European and American countries. In summary, there are 15 cases of top-down symbiosis and 35 of bottom-up. Some of the top-down cases are related to industrial districts that, due to changes in the national or regional policies, had to develop centralized environmental services and change their practices.

The presence of a *facilitator* in the case studies often overlaps with the involvement of a public administration. In this thesis the term public administration (PA) refers to actors such as municipality, provinces, regions, national health service (SSN), school and universities, and chambers of commerce and national agencies such as ENEA.

Table 4-4. Comparison between cases with and without facilitator.

	With Facilitator	**Without facilitator**
N° of cases	23	27
N° of cases where PA is involved	21	2
N° of cases where a platform is used	2	0

It can be said that among the analysed cases the majority doesn't involve a facilitator or a coordinator of the IS, however, as can be seen in table 4-4 the number of facilitated symbiosis is not that smaller than the number of self-organized symbiosis. However, it can be highlighted that most of the facilitators are *public administrations* in the form of national agencies, universities and municipalities. Universities, research centres and national agencies acted as facilitators in the emerging phase of many cases providing support in gathering information and opportunities to recover material surplus and in the assessment of the environmental and economic impact. Furthermore, the use of platforms to manage the symbioses is quite scarce, it could lead to further research.

Regarding the possible funding of the symbioses, 40 cases do not disclose if any *regional or European initiatives* were employed, while 10 cases explicitly declare the use of regional or European funds. The name of the initiatives or funds adopted are reported in Figure 4-5.

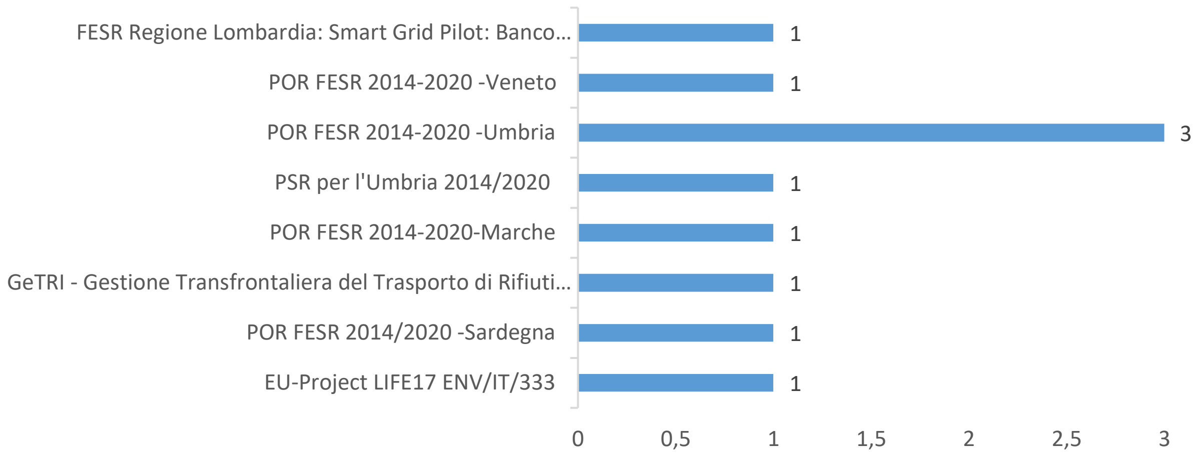

Figure 4-5. European and Regional initiatives used for funding IS initiatives.

POR FESR are the Regional Operational Programmes financed by the European Regional Development Fund for financing actions on regional territory and are therefore owned by the Regions or the Autonomous Provinces [91]. As can be seen in Figure 4-5, POR FESR are the most commonly applied programmes to support the development of industrial symbiosis.

For each case it was identified the *current state* of the symbiosis and how it *emerged*, meaning how it was born. On one hand, the scale used for the current state dimension is research and planning, emerging, developed, and declining. On the other hand, the scale for the emerging phase is: planned, self-organized, and facilitated. The combinations of those dimensions can be seen in Table 4-5.

Table 4-5. Emerging phase and Current state comparison

		Current state			
		Research & Planning	Emerging	Developed	Declining
Emerging phase	Planned	4	1	7	2
	Self-organized (spontaneous)			26	1
	Facilitated	2	1	6	

The term research & planning in this thesis refers to the activities of research performed before the emergence of the symbiosis, including the analysis of the potential resource exchanges, the preliminary communication among the stakeholders and the discussions preceding the first operational activities and the definition of contracts or pilot projects. The emerging phase refer to the initial exchanges and to possible pilot projects before the consolidation of the symbiosis. The fact that there are no spontaneous cases in the planning and emerging phase is linked to the fact that this type of symbioses can be recognized only ex-post as shown in the example of

Kalundborg. In a specular way, only planned and facilitated cases can be labelled as in the emerging and planning phase.

The last dimensions to analyse are the two related to circular economy: butterfly diagram and circular economy matrix. The butterfly diagram, designed by the Ellen MacArthur Foundation in 2019, focuses on the circular economy approaches and practices and how resources are managed to extend their life cycle.

On one hand, the cases involving the manufacturing sector mostly follow the circular practices of the technical cycle that is relevant to products that are used and not consumed; considering that the focus of industrial symbiosis is the production and manufacturing the most common circular practices are: reuse and redistribute, and recycling.

On the other hand, the cases involving environmental service and agri-food follow more the biological cycle that works for biodegradable materials; the most common practices identified in these cases are: farming, composting and anaerobic digestion, cascades and the extraction of biochemical feedstock.

The last dimension is the one on Circular economy matrix that showed to be not very aligned with the concept of industrial symbiosis, meaning that studying and analysing this strategy the focus is on the production that is described by the dimension value network without any information on the value proposition dimension. The dimension value proposition is made by price and promotion, which will be represented as price-promotion in the table below, and the value N/A means that there are no data on the subject.

Table 4-6 CE Matrix values

		Value Network			
		Low	Medium-Low	Medium-High	High
Value Propositi	N/A	3	4		
	N/A-Low		2		
	Low-Low	2	17	2	8
	Low-Medium				4
	Low-High	1	6		1

5 Industrial Symbiosis case studies

In this chapter will be presented the five case studies that were further explored through interviews with one or more members of the involved companies. Except for the last case, two companies per case were interviewed about the history of the symbiosis focusing on description of the resource exchanges, challenges and drivers, on the kind of relationships and collaboration among the stakeholders, employed manufacturing and communication technologies.

Each case is presented in a descriptive way according to three dimensions: information on the industrial symbiosis to portrait the current and emerging phases, relationships inside the network and trust focusing on the inter-firm communications and level of formalization of the inter-firm collaboration and employed digital technologies.

As support to the text, a flow chart of the resource exchanges in the symbiosis will be reported for each case. In figure 5-1 is reported the legend to read the flow chart: in the boxes are reported the organizations involved in the exchanges, rhombuses represent internal processes that the company upstream has to execute to transform by-products, circles represent intermediaries for resource collection, arrows show the exchanged resource the ones in blue represent raw material exchanges or final products while those in blacks represent by-products or scrap exchange.

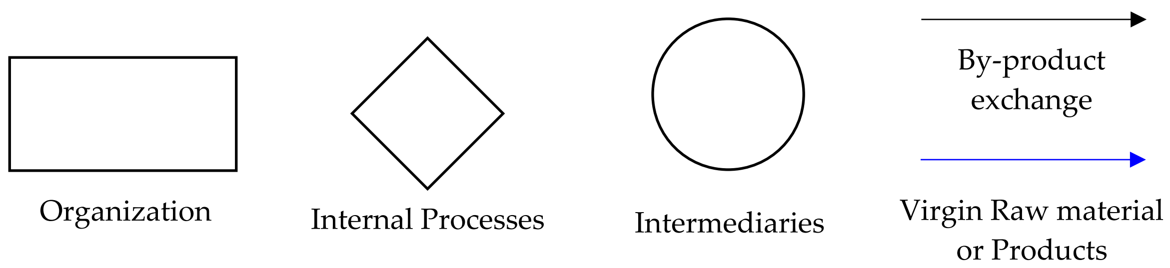

Figure 5-1 Legend on the flow charts.

5.1. Agroittica Lombarda and Feralpi

Table 5-1 Overview of Case 017 interviews

	Agroittica Lombarda Spa	**Feralpi Siderurgica Spa**
Interviewees per companies	1	2
Interviewees' role	• Head of Special Projects & Scientific External Relations	• Head of Environmental Management System • Employee Environment Office

The sources consulted for this paragraph are the websites of the companies involved [92, 93], the transcriptions of the interviews conducted and a scientific article [94].

Industrial Symbiosis history

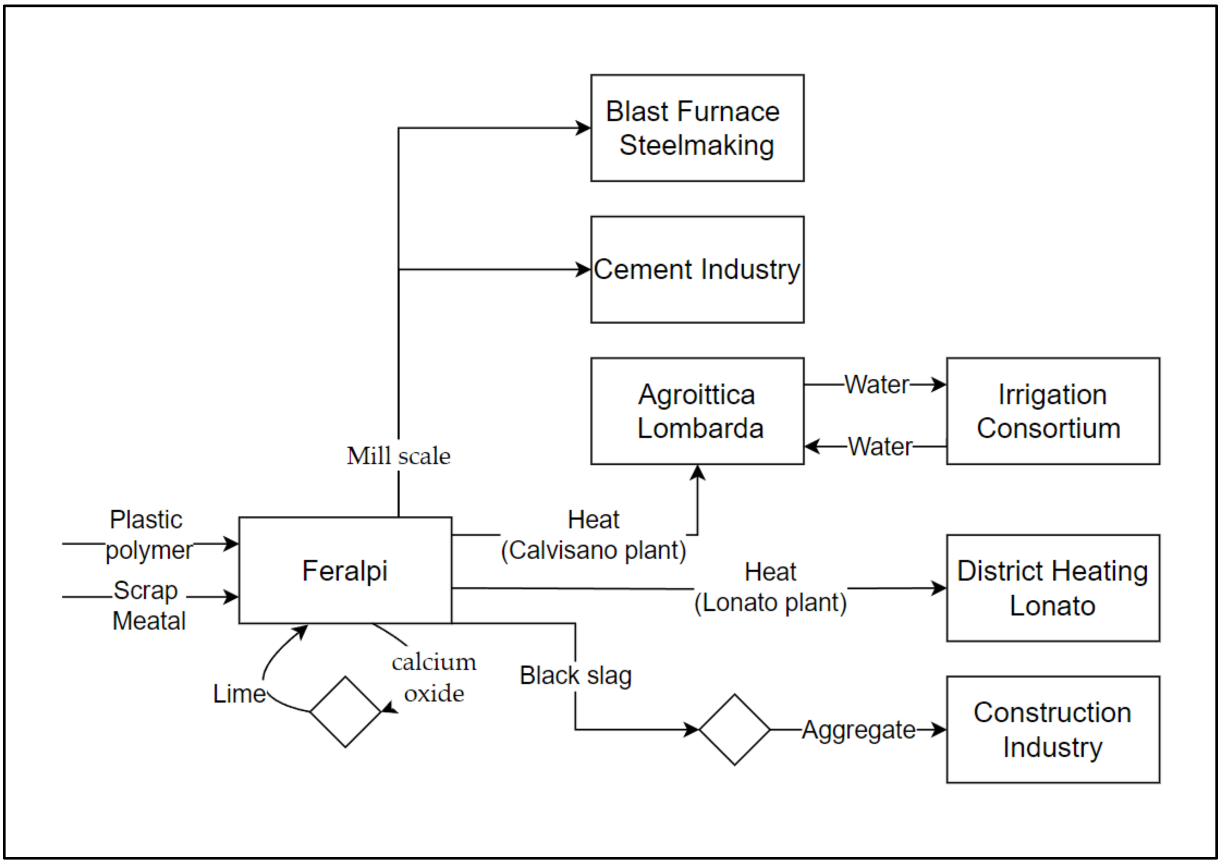

Figure 5-2 Feralpi IS flow chart

The symbiosis between Feralpi and Agroittica nowadays is recognised by involved companies and institutions as a case of self-organized symbiosis, however when the collaboration between the two companies was born the concept of industrial symbiosis had not yet emerged.

The symbiosis takes place in Lombardy, particularly in the province of Brescia. The steel plant of Calvisano, that processes scrap steel trough electric arc furnace, and the aquaculture plant were designed and developed together with the scope of saving costs and finding additional profit sources.

"In 1972 Gino Ravagnan and Giovanni Tolettini imagined using the heat of the steel mill, recovering it through a heat exchanger, to farm fish of high commercial profile."

In 1972 the Calvisano steelworks were founded, the founder of the steel mill realized that it was possible to exploit the local availability of water and great availability of heat from the production process to venture a new business. In 1973, in collaboration with the then suppliers of the water treatment plant, Feralpi decided to embark on the adventure to create a fish farm; the species of fish have changed over the years. Agroittica initially farmed eel which was a popular food between the 70s and the 80s, but when the fashion changed so did the farm, in the 90s through research and collaboration with international universities the production switched to sturgeon for meat and caviar production. Since the beginning the two companies have been formally separated but under the control of the Feralpi Group. However, the management changed completely in 1998, when Agroittica began to employ people with specialised technical knowledge as managers.

The steel plant was initially designed and built without cooling towers, by design the cooling of refrigerant fluids was done through a heat exchanger that transferred the excess heat to the water of the fish farm. However, in recent year some cooling towers were installed in the steel plant due to an increase of the production and global warming.

It is important to highlight that there is no water exchange between the steel mill and the fish farm. However, both the steel mill and the aquaculture plan draw water from groundwater through wells, the latter supplies the water to the irrigation network downstream of the breeding tanks. Local farmers have several benefits from the water from fish farm, which is a regularly checked and shows to be of excellent quality. Agricultures save energy not needing to extract water from the groundwater, use a water that is thermally more suitable and richer of microalgae improving the soil structure.

The virtuous cycle between the steel plant and the aquaculture farm was initially favoured by the Government by funding, however in most recent years the Italian normative on by-products and wastes limited some opportunities for further resource exchanges on both companies. Let's see some practical examples, on one hand, the fish farm is interested in farming insects using by-products or waste from internal production as feedstock to recover food resources, however, the current regulation on the use and farming of insects doesn't allow it. On the other hand, the steelmaker due to the regional limitation of some by-product's regulations cannot exchange their by-products, such as white and black slag, outside the regional borders.

In the table below are summarised the benefits and challenges faced by the two interviewed companies.

Table 5-2. Benefits and challenges of Agroittica-Feralpi IS.

	Agroittica Lombarda Spa	**Feralpi Siderurgica Spa.**
	Benefit	
Economic benefits	• Operational costs saving (Heating and energy consumption) • Business opportunities	• Operational costs saving (cooling and energy consumption) • Tax reduction
Environmental benefit	• Emission reduction • Improvement of water quality for agriculture • Reduction of water volumes extracted from groundwater	• Emission reduction • Raw material extraction reduction (metal and lime)
Social benefit	• Job creation • Territorial development • Environmental education during farm visits	• Job creation • Territorial development
	Challenges	
Social challenge	• Reputation of the product	
Normative challenge	• Uncertainty in regulations for research • High complicate bureaucratic procedures	• Uncertainty in regulations • High complicate bureaucratic procedures

Beyond the symbiosis between Calvisano steel plant and Agroittica, the Feralpi group has sustainability and circular economy in its hearth, the group produces steel recovering ferrous scrap through electric arc furnace, that it is more sustainable than producing steel from mineral through blast furnace.

Feralpi group has always been active in the field of resource recovery, circular economy and sustainability. Everything started from the already mentioned activities in Calvisano in the 70s, then in 2004 the plant in Lonato implemented an environmental management system according to ISO 14.001 and EMAS, the same plant provides heat for the district heating of the municipality of Lonato. In addition, Feralpi is an international group that applies heat recovery in its production plant in Germany, in which case the heat is supplied to a nearby tyre plant.

Feralpi Group recovers more than 90% of its production residues and is working to increase this percentage even more. The province of Brescia authorized Feralpi to recover the refractory residues; for example, calcium oxide is recovered within the production process allowing the company to buy less lime from the external market.

The steelmaker recovers all the mill scales from the rolling plants, the scale is the surface part of the finished or semi-finished product that is mostly made of iron oxide. The recovered scales can be used in cement production processes, in the process of producing steel in the blast furnace in replacement of iron or reused to make counterweights.

Since the 2010s the group classified black slag, the main production residue of the electric furnace, as a by-product and no more as a waste. The black slag is then sold to companies that manufacture concrete or to road construction sites.

Feralpi was the first to replace the coal powder with a mixture of polymers as a reducing agent in the production process of the foam slag inside the electric furnace. Through a research project, which lasted several years, the steelmaker succeeds in building a plant that allows the use of polymer mixture, that come from unrecoverable part of separate collection of plastic, as additive to produce foam slag. Therefore, Feralpi is very active in recycling and recovering all its by-products, ranging from slag to heat.

Relationships in the network and trust

The management of heat and water in the symbiosis is defined via contracts, in the contracts are defined the responsibility of the parties for the infrastructure and the kind of resource provision. Also the symbiotic exchanges about black slags, ferrous scraps, mill scales, and plastic polymer are regulated via traditional contracts.

The relationships between the organizations involved in the main symbiosis, heat recovery for sturgeon farming, are built on trust and a long history of collaboration, the sharing of information is not regulated but based on mutual request. There were some small challenges in the sharing of information and communication between the parties due to employee turnover, the sharing of information is based on personal relationships and informal agreements, therefore it is possible that this is lost when a role is covered by a new person without a complete training.

Both Feralpi and Agroittica partnered with universities, business associations and used platforms for further their research and innovation. The initial symbiosis was spontaneous, however, it was partially funded by PA.

In recent years, the steelmaker took part in the CORALIS project involving companies from different sectors to create pathways for the decarbonisation of resource and energy intensive sector such as steelmaking. This project also has the ideal characteristics to be financed as a choral project and to provide support in the authorization of research processes.

Therefore there was some facilitator in this symbiosis, public fundings, university support in the selection of the most suitable fish to farm, and lastly a project to find the right approaches to reduce emissions.

Digital technologies

Both Agroittica and Feralpi use digital technologies in their production processes; however, the symbiosis does not require the use of digital technologies, everything is defined by contract and through coordination meetings that give as output the maintenance schedule of the heat exchanger, while in case of unscheduled block of the heat exchanger the companies communicate via telephone.

However, it is pertinent to briefly describe the digital technologies that the interviewed companies use in their processes. On one hand, Agroittica employs agriculture 4.0 technologies, such as sensors on agriculture vehicles and in the fish tanks, and electronic scales for weighting fish feed. In addition, the aquaculture is signed into platforms for research and innovation fundings.

On the other hand, Feralpi employs some industry 4.0 technologies both on the electric furnace and in handling inside the production plant. Sensors are used to continuously control gas emissions in the electric furnace, and to safely manage the access to the furnace and the casting area. An internal management system is used to have greater control and higher performance in the production process. The steelmaker uses digital technologies to control its production processes and its output, without measurement is impossible to control, and control over the processes and knowledge about outputs are necessary to take part in an industrial symbiosis.

5.2. Tuscany tannery district: San Miniato

Table 5-3 Overview of Case 035 interviews

	Consorzio Cuoiodepur Spa	Lapi Gelatine Spa
Interviewees per companies	1	1
Interviewees' role	• Technical director	• Chief Executive Officer of Lapi Group

The sources consulted for this paragraph are the transcriptions of the interviews conducted and some scientific articles [95, 96].

Industrial Symbiosis history

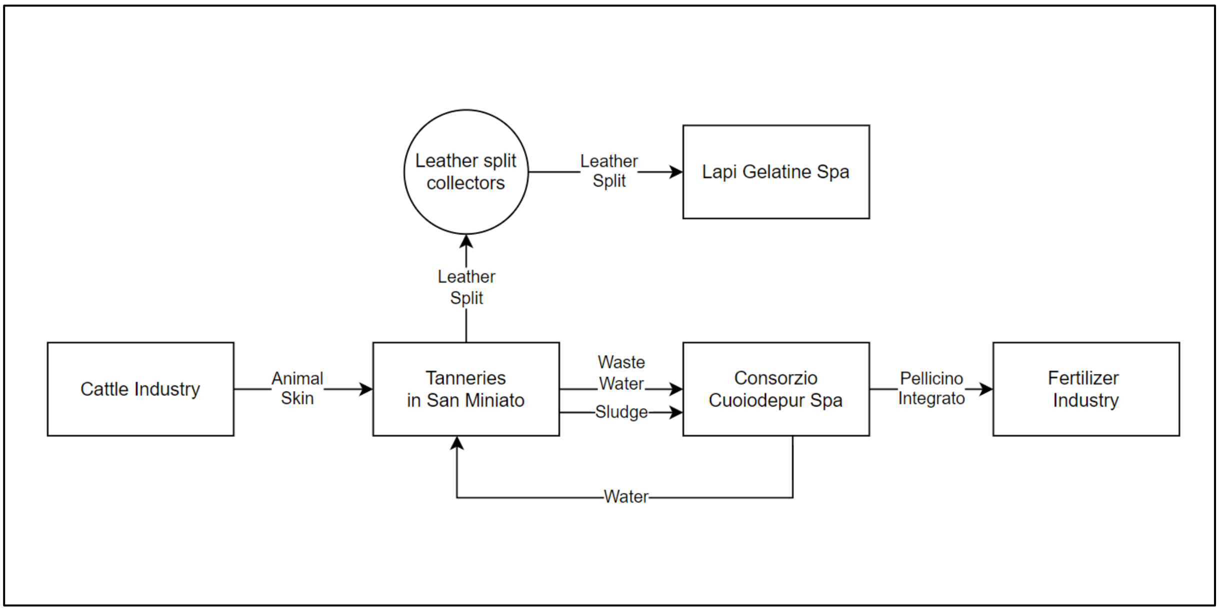

Figure 5-3 San Miniato tannery IS flow chart

The Tuscan tannery district is famous for its long history and circular practices, it must be specified that it is subdivided into two areas, the industrial area of Santa Croce on the right and the industrial area of San Miniato in the left side of the Arno River.

The tanning industry is intrinsically characterised 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 interviewed companies are part of the left bank of the Tuscany tannery district. The symbiosis that will be described in this paragraph focuses on the companies of the tanning consortium of San Miniato, in the province of Pisa, particularly on a gelatine manufacturer and the consortium for sewage treatment plant Cuoiodepur.

The symbiotic activities related to material and by-product exchanges can be dated back to the 1960, while the service and infrastructure sharing can be dated back to the 1980. It is a case of spontaneous symbiosis regarding the material and by-products exchange, while for the management and treatment of industrial water it can be said that it has been pushed by environmental regulations. Particularly, the birth of the water treatment plant was enforced by Merli law approved the 10th of May 1976, the first Italian law to make the treatment of wastewater mandatory, before this event companies discharged the wastewater directly into the rivers and seas (Merli L. , 1976). In 1980, the consortium Cuoiodepur was founded and financed by local companies aiming to implement and manage industrial water and liquid discharges to be compliant with environmental regulations. The consortium sewage plant developed according to specific purposes that have allowed the survival of companies within the tannery industrial district, practically without the sewage treatment plant this would not have been possible because regulations made wastewater treatment mandatory. Therefore, the branch of industrial symbiosis related to water treatment is a case of planned symbiosis in which the consortium played the role of management body and coordinator.

From the interviews it emerged that in the whole tannery district the awareness about industrial symbiosis and circular economy practices is high and well consolidated. The district and the symbiosis involve hundreds of companies that operate in different sectors: vegetable tannery, water and waste management, chemical and pharmaceutical. However, due to the long history of the symbiosis some of the companies have difficulties in assessing the benefit and challenges of the IS, for them it is difficult to imagine a by-products and water management different from the current one.

In summary the symbiosis and resource exchanges are the following: cattle skin a by-product of meat industry is collected and used as input of the tannery industry that transforms it in leather, then protein byproducts are recovered in the production of glue and gelatine while the sludge is recovered to produce fertilizer.

First of all, the raw animal skin is collected from the cattle industries, this by-product is processed separating the hairs and the fat layer from the raw leather. The central layer of the animal skin is used to produce leather, the hair and fat layers are classified as by-products: organic by-products from the tannery are used as raw material to produce organic or liquid fertilizer, other protein by-products are collected by intermediaries and used to produce gelatine for the food and pharmaceutical sectors.

Leather splits (spaccature) are collected by specialized companies from the tanneries in the district, this by product is then supplied to gelatine and glue manufacturers. The thin layer of dermis containing collagen that is located between the epidermis and the subcutaneous layer, which is a section of the leather split, is used as a raw material to produce gelatine. Through an alkaline hydrolysis treatment, the collagen protein is extracted with the sole use of water. Subsequently, this protein is purified through filtration, demineralization and sterilization treatments. The concentrated solution is then dried and made in granule of collagen. The final product, bovine gelatine, is a pure, high-quality protein. It is possible to produce gelatine for the food industry because animal skin is a by-product of the meat industry that if managed carefully maintain a food-grade quality.

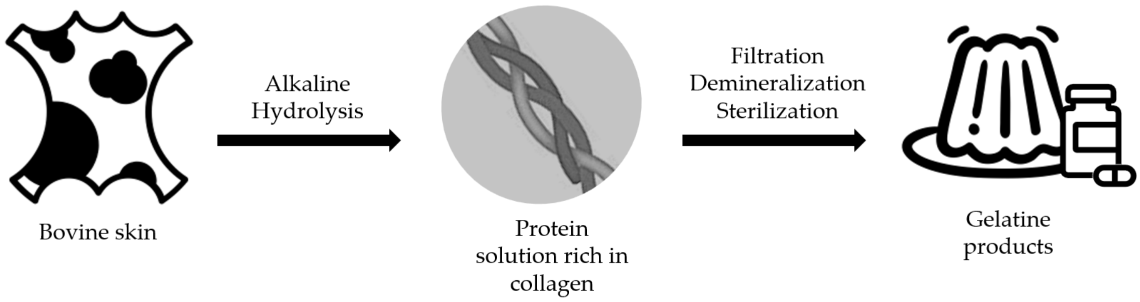

Figure 5-4 Schematic view of bovine gelatine manufacturing

The symbiosis related to the shared industrial sewage treatment plant has evolved since the 1980s. Initially, the symbiosis and resource exchange were limited to the shared service and infrastructure to depurate the industrial sludge of the tannery district. Since the 2000s, applying circular economy practices Cuoiodepur transforms the sewage sludge from the district into a fertilizer product adding a new resource to those exchanged in the symbiosis. The consortium produces pellicino integrato a nitrogen organic fertilizer from the tanning sludge and provides it as raw material to fertilizer companies.

The municipality of San Miniato is the owner of the treatment plant managed by Cuoiodepur, which is a no profit organization funded mainly by private companies but with some public actors in the board of director. The involvement of public administration is not limited to the ownership of the treatment plant, for more than forty years universities, institutions and agencies were involved in a series of very important research and development activities to get the formulation of fertilizer from the tannery sludge. The sludge comes from two main sources, tanneries internal collection and Cuoiodepur collection, and they are both processed in the sewage plant to be turned into fertilizer.

An interesting example of the strategic relevance of the district and its symbiosis emerged during the years of the mad cow disease (MCD), for sanitary and health reasons the production of gelatine and glue from the cattle farming by-products had been stopped in all the plant in Italy, but the municipality of Empoli allowed the tannery district to continue those activities to avoid the disposal of those by-products and to prevent a supply crisis.

In the table below can be find a summary of the benefits and challenges faced in the symbiosis. The benefits and challenges from the tanneries' perspective were inferred by the two interviews with the treatment plant and the gelatine manufacturing.

Table 5-4. Benefits and challenges of Tuscany tannery IS.

	Cuoiodepur Spa	**Tannery**	**Lapi Gelatine Spa**
Benefit			
Economic benefits	• Operational costs saving (avoided sludge disposal) • New business opportunities	• Operational costs saving (avoided sludge disposal, centralized water treatment)	• Operational costs saving (cheaper procurement and logistics) • New business opportunities
Environmental benefit	• No landfill disposal • Lower resource extraction • Emission reduction • Better water quality	• No landfill disposal • Emission reduction • Better water quality	• Resource lifecycle extension • Emission reduction
Social benefit	• Job creation	• Job creation	• Job creation
Challenges			
Normative challenge	• High complicate bureaucratic procedures • Lengthy and complex authorization path		• Normative and regulation on animal by-products
Economic and Financial challenge	• Complexity in accessing funding		

The treatment plant currently collects and treats only industrial wastewater from the tannery district, but by 2025 the plant should treat also urban wastewater, that come from neighbouring and further areas. The scope of the treatment of these waters would be the recovery and reuse of them in tanning companies through an industrial aqueduct. The main objective of this project is to dramatically reduce the withdrawal of water from the aquifer.

Relationships in the network and trust

The network is made of more than 300 organizations, involving both public administrations and private companies. In the history of the symbiosis there were some facilitators: the public administration and the regional authorities though policies and regulation create the necessary and sufficient conditions for the development of the symbiosis. The consortium Cuoiodepur supports and directs the companies of the district toward the recovery of tanning wastewater and is the management body of this phat of the symbiosis, while the tannery association support the companies at a business and normative level.

The effort to find a use for the sludge of the tanneries was pushed by the Tuscany region. Since the 90s, the region wanted to recover these sludges to end the allocation in landfill with all the correlated environmental impacts.

The industrial district of San Minato, where the IS took place, is an APEA (Environmental Equipped Production Area). The Italian legislation defines APEA as an industrial or productive area equipped with the necessary infrastructure and systems to ensure the protection of health, safety and the environment. The tanneries and the water treatment plant are all part of the APEA.

Beside the participation of the public administration for the research and development of the fertilizer, most of the relationships in the symbiosis are spontaneous and each company finds the right exchanges for its interest. The material exchanges are defined with traditional contracts, while the distribution of the benefits of the consortium and of the association are defined by the organizations' statute.

Digital technologies

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. However, the development of the IS in the tannery district promoted the rise of specialized skill and know-how, the most relevant ones are the technologies for management of sewage treatment plants. The concentration and specialization of the companies in the area have led to the emergence of design and engineering companies specialised in sewage treatment and air treatment plants.

However, it is pertinent to briefly describe the digital technologies that the companies in the symbiosis use in their processes. The environmental treatment plants, both the one of the consortium and those of the companies that are not part of the consortium, use industry 4.0 technologies, mostly sensors and system integration.

The gelatine manufacture greatly uses digital technologies to control its processes and the quality of the input. The suppliers of the by-product that the gelatine maker uses don’t provide data on the product quality and characteristics, therefore the plant need to control the input to define and schedule its production processes.

The water treatment plant is equipped with intranet and sensors to measure and control the processes. All the data are collected automatically and controlled by operators in the control room inside the plant. The plant also implemented over the years more advanced monitoring system using big data analysis, this technology was developed in the context of projects co-financed by European funding and regional funding such as POR Creo 2014-2020.

5.3. Magnifica comunità e BioEnergia di Fiemme

Table 5-5 Overview of Case 042 interviews

	BioEnergia Fiemme Spa	**Magnifica Comunità di Fiemme La Segheria Spa**
Interviewees per companies	1	1
Interviewees' role	• Chief Executive Officer	• Technical director

The sources consulted for this paragraph are the websites of the two organizations [98], the transcriptions of the interviews conducted and scientific paper [99].

Industrial Symbiosis history

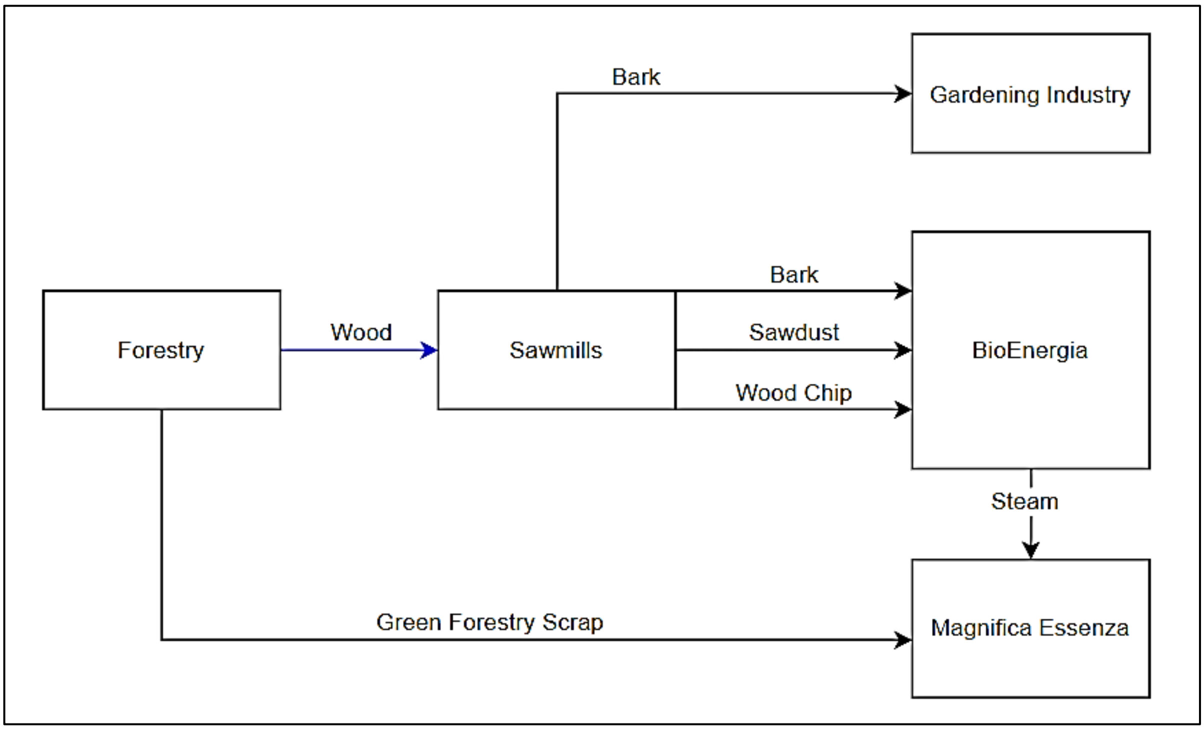

Figure 5-5. Fiemme Vally IS flow chart.

The industrial symbiosis that takes place in Val di Fiemme, in the region of Trentino-Alto Adige in the province of Trento, involves about 10 organizations between the Magnifica Comunità di Fiemme, Bioenergia, some local municipalities, forestry companies and family-owned sawmills. The symbiosis began in 1999 when Bioenergia opened its plant to recover the scrap and by-products of the wood supply chain to produce energy and heat.

The forests in the Fiemme valley are managed and owned since the XII century by the Magnifica Comunità di Fiemme (MCF), that has legal personality as a representative of the universality of the neighbours and it is attributed the ownership of the collective heritage. The neighbours are all the persons that lived in the area of the community for more than 25 years.

The MCF owns and manages 12.000 hectares of forests certified FSC[6] and PEFC[7], the neighbours can log and harvest from the forest of the Community. Some sawmills operate in the forests of the MCF, one of theme is owned and controlled by the Community and provides its production scrap, small logs and kindling, at a discounted price to neighbours who are not able to make wood themselves.

The sawmill of the MCF was interviewed and provides its insight on the partnership with Bioenergia. The sawmill is a stakeholder and partner of the utility supplier. The sawmill is controlled completely by the MCF that is also a stakeholder of Bioenergia. Clearly the symbiosis and the resource recovery is an important and felt matter in Fiemme Valley represented by the Magnifica Comunità.

The sawmill produces many by-products of the wood supply chain, woodchip, bark and sawdust are supplied to Bioenergia and another utility provider for energy recovery, most of the bark is sold to produce gardening mulch, while the sawmill recovers some of its by-products internally with a biomass boiler that produce heat and electricity. The MCF sawmill supplies to Bioenergia 700 steres of wood by-products each week, a stere is a unit of volume equal to one cubic metre that is typically used for measuring large quantities of firewood and cut wood.

Bioenergia is an energy and heat provider, it recovers and exploits forestry's by-products from local sawmills and logging activities. Its plant in the village of Cavalese produces heat for the urban district heating burning wood chip in a boiler. It also produces electricity through a cogeneration plant and promotes the installation of PV panels in the villages. Bioenergia is the actor in charge of the collection of the by-products, they do so through local logistics providers that collect from the sawmills the scrap.

In 2010 Bioenergia funded a new company with the aim of recovering energy and matter from organic waste collected in Trentino, the activities of this company spread in the whole Trento province. The plant is in the Municipality of Faedo and treats 60.000 tons of urban greenery and wet waste to produce 14.000 tons per year of high quality compost that is used in the agricultural of the Adige valley. In addition, the plant produces about 8.000.000 electric KWh that are fed into the power grid of Faedo.

Since 2016, Bioenergia recovers sawdust from the local wood supply chain. The sawdust becomes the raw material to produce pellet. The raw material is processed and dried through the use of heat from the district heating network.

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[6] Forest Stewardship Council
[7] Programme for Endorsement of Forest Certification schemes

In 2019 the energy provider joined a new business to further exploit the local resources, it launched a new activity to produce essential oil using, on the one hand, the excess vapours produced by the district heating plant and, on the other, using the green part of the plant that should be discarded.

The sawmills of the area provide wood chips and sawdust to Bioenergia, while the bark derived from the debarking of the trunks is a by-product conferred both to Bioenergia for energy and heat production and to companies that produce mulch for gardening.

This can be considered a case of planned symbiosis that involved public administrations, the MCF and the municipality of Cavalese are partners of Bioenergia since the beginning, and private organizations to find a way to exploit and give value to all the material and by-products of the forestry industry and the territory. The involvement of the public administration at the beginning of the symbiosis was a necessity due to the characteristic of the project, however it slowed and limited the symbiosis.

In the table below can be seen the benefits and barriers identified by the companies interviewed.

Table 5-6 . Benefits and challenges of Fiemme Valley IS.

	Bioenergia Fiemme Spa	**MCF La Segheria Spa**
	Benefits	
Economic benefits	• Operational costs saving (short supply chain,) • New business opportunities	• Operational costs saving (reduced waste disposal costs) • New business opportunities
Environmental benefit	• Waste reduction • Resource lifecycle extension • Emission reduction	• Waste reduction • Resource lifecycle extension
Social benefit	• Job creation • Territory protection and growth • Affordable electricity and heating for the territory	• Job creation • Territory protection and growth • Creation of specialized skills

Challenges	
Normative challenge	• High complicate bureaucratic procedures • Lack of policies in favour of short supply chain and circular practices
Economic and Financial challenge	• Public tenders that do not reward local development

In the symbiosis there is a strong interest toward the research of new opportunities to recover and give value to the territory resources. In fact the interviewed sawmill stated to be a supplier of woodchips for another utility company, in the form of public tender, that operates in the region but outside the boundaries of the province of Trento. However, the commitment toward a sustainable and conscious use of the by-products is very strong in the sawmills, the fear that their waste will be misused leads them to seek new collaboration for the use of by-products with great caution. They favour companies that they already known and trust with great attention to geographical proximity.

Relationships in the network and trust

The network is facilitated and regulated by Bioenergia, the energy and heat provider that created the network of sawmills and logistics providers to collect and exploit forestry's by-products of the Fiemme Valley. The involved actors are very conscious of the collaborations and circular economy practices that took place thanks to Bioenergia. However, the concept of industrial symbiosis is not well known by the small family sawmills that take part in the partnership aiming to give value to all their resources including scrap and by-products.

The relationships among Bioenergia and the sawmills are based on contracts that define the quantity and quality of the supply of forestry's by-products. The network is well established and built on mutual trust and interpersonal relationships, the vicinity of the actors and the strong territory identity is identified as strength of the symbiosis. The communication between the companies in the symbiosis are via e-mail or in person, periodically the owners of the sawmills and the management of Bioenergia meet to redefine the contractual agreements.

Another relevant factor that characterises the symbiosis is the organizational structure of Bioenergia, as stated before, is that the MCF and the municipally of Calvisano are shareholders and members of the board of director of the utility provider, in addition also the sawmill of the MCF is a shareholder of Bioenergia. It can be said that the symbiosis is reinforced by the fact that some suppliers and stakeholders are also shareholders of Bioenergia.

A challenge that emerged from the interviews are the generational handover of a family business, as stated the relationships between Bioenergia and its suppliers are based on trust and at the personal level, therefore when the person in charge of a family business change also the contractual mechanism and trust face a challenge.

Digital technologies

Both the interviewed companies used incentives for Industry 4.0 to update and equip their plants with technologies to support the production processes and quality controls. However none of the applied technologies were identified as necessary for the symbiosis.

Here are summarised the digital technologies employed by the interviewed companies. On one hand, The MCF sawmill employs digital technologies mostly in its manufacturing process and quality control: debarked trunks are measured digitally using camera and sensors, the cutting plan is defined to maximize yield and minimize waste, a stacker machine assemblies the box of wood, in the furnace they use sensors to measure temperatures and humidity, a scanner is used to check the quality of WIP and to define the cutting plan.

On the other hand, Bioenergia plants uses sensors to remotely control its production processes and to gather information; they have real time remote control on the plants and can also operate them from mobile devices. The heat and energy providers employ digital technologies not only in its production but also at the client level. Users of the urban district heating can control their consumption and manage their utilities online.

5.4. Steel mill and heat recovery: BANCO energETICO

Table 5-7 Overview of Case 048 interviews

	Alfa Acciai Spa	A2A Calore e Servizi
Interviewees per company	1	2
Interviewees' role	• Environment manager	• Project Management Engineer – process specialist • District heating-communication

The sources consulted for this paragraph are the transcriptions of the interviews and some official documents of the project [100] .

Industrial Symbiosis history

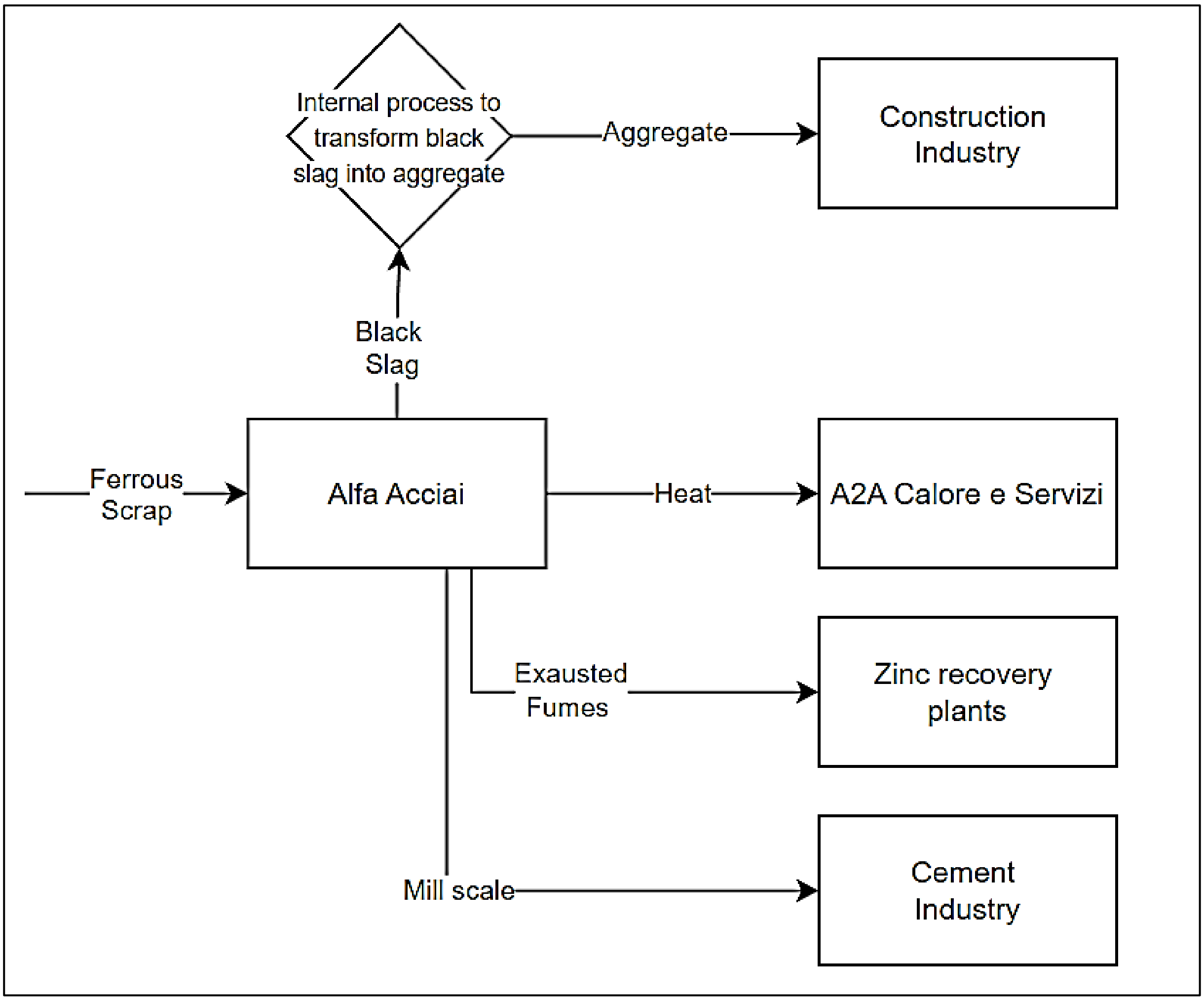

Figure 5-6 Alfa Acciai and A2A IS flow chart

The symbiosis between Alfa Acciai, a steelmaker, and A2A Calore e Servizi, a multiutilities provider, is a planned and facilitated symbiosis, it is the result of SMART GRID PILOT: BANCO energETICO a public call for the research and development of an energy recovery from production plan. The project was launched and co-financed by Lombardy Region that used FESR funds, the call was open to everyone and was won by the partnership among A2A, Alfa Acciai, University of Brescia and DHPlanet.

The project was born as a pilot and today operates at full capacity. The pilot and research project went on from 2018 to 2021. The project was led by A2A Calore e Servizi partnering with Alfa Acciai, Università degli studi di Brescia and DHPlanet for the common goal of creating an innovative and efficient system to recover energy from industrial thermal waste. In the project A2A Calore e Servizi recovers waste heat from the production site of Alfa Acciai and supplies it to the district heating serving the city of Brescia. Within the project the university of Brescia launched research activities on a new system to increase the efficiency of large heat accumulators, on the method of energy allocation for district heating utility and the use of thermal energy currently dissipated in evaporative towers. DHPlanet was involved in the research and development of the thermal recovery system and developed an air-preheating system complementary to the electric one for district heating pipes. The pilot plant enables to recover energy for 27.000 MWh/year, equivalent to 2.340 tonnes of oil not consumed.

Briefly the symbiosis is the following: the heat waste resulting from 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 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.

Beside the environmental and economic benefits, the project has also a social scope: to support vulnerable groups and users in need in Lombardy, the project leader A2A Calore e Servizi committed to making donations to Banco dell'Energia Onlus, that is part of the A2A group, based on the amount of heat fed into the network. The onlus provides funds to local public administrations to support economically people in need.

The project was planned and developed in four years, the last two overlap with the years of the covid-19 pandemic that had a big impact in Lombardy region, particularly in the province of Bergamo and Brescia. The pandemic and the lookdowns had an impact on the project, the resulting supply chain crisis caused some procurement challenges that slowed down the building of the pilot plant.

Table 5-8 . Benefits and challenges of Alfa Acciai-A2A Calore e Servizi IS.

	Alfa Acciai Spa	**A2A Calore e Servizi**
	Benefits	
Economic benefits	• Operational costs reduction (cooling costs, water consumption) • Increased reputation • FERS fund	• Operational costs reduction (fossil fuel reduction) • Emission tax reduction • FERS fund
Environmental benefit	• Reduction of heat dissipated into the atmosphere • Reduction of energy consumption • Fewer water withdrawal from the aquifer • Emission reduction	• Lower use of fossil fuel • Emission reduction
Social benefit	• Increase of technical skills and dissemination in the Lombardy region • Job creation	• Job Creation • Know- how development
	Challenges	
Normative challenge	• Different regional normative on black slag in Italy • Lengthy authorization and bureaucratic processes	• Lengthy authorization and bureaucratic processes
Complex challenge	• Covid 19 pandemic	• Covid 19 pandemic

Alfa Acciai and A2A Calore e Servizi are involved also in other symbioses. Both electric furnace steel making, and district heating sector have energy and material recovery in their hearts.

Electro-steel industry is historically characterised by resource recovery and exchange, upstream with the collection and selection of scrap metal for re-melting in an electric furnace to produce steel and downstream with by-products exchange and energy recovery that is a novelty for Alfa Acciai. We can date the first symbiotic exchange with the foundation of the steel mill in the 1950s, but the exchange of production scrap and by-products is more recent, about the end of the 1990s. In summary, the steelmaker recovers: black slag, exhausted fumes dust, and mil scale. Black slag is used to replace natural aggregate from quarry, the use of this resource is in function of its dimension and characteristics: coarse aggregates are used as draining, while finer aggregates are used instead of gravel and sands in concrete and bitumen. Exhausted fumes dusts are collected to extract zinc, while mill scale is recovered in the cement industry as iron-based additive for cement clinker production.
Currently Alfa Acciai is collaborating with other steelworks on a research and development project on the recovery of white slag, this by-product is rich in calcium, alumina, silica, and can have future in cement production.

In the sector of district heating network, the trend is toward energy recovery from production plant, from glassmaking to steel making with all in between, to reduce the dependence on fossil fuels.

The interviewed companies acknowledge that involving more and more sector in a symbiosis is a strength, diversifying the recovery and valorisation of resources lead to competitive advantages and support the continuity of a business.

“The symbioses are really more than strengths, are the very constraints of survival for steel manufacturing “

Therefore, diversification and continuous research of new ways to recover resource is a strength, however research and development require continuous investment, partnership with university and research institute, and a deep knowledge of the local policy on resource recovery, those factors can lead to some complexity.

Relationships in the network and trust

As stated, the symbiosis between Alfa Acciai and A2A is a case of planned and facilitated symbiosis, Lombardy Region facilitated the development of the symbiosis that was planned and proposed to the public call banco energETICO by the four partners, in addition the municipality of Brescia facilitated the development of the energy exchange. The communication and the exchanges among the partners in the planning and development phase were run by firm external to the symbiosis. The firm allowed the coordination between the four partners and the Lombardy Region and verified compliance with the timing and technical requirements.

However, the other material exchange and energy recovery of symbiotic type do not involve mediators or platforms. The steel producer manages and relates with its suppliers and clients for resource recovery with simple commercial contracts where quantity and quality are defined. The multiutility operates with both public actors, especially municipalities for district heating, and private companies.

Digital technologies

A2A and Alfa Acciai use a dedicated platform to control and share data on the heat recovery, the digital platform was developed for the smart grid and funded by A2A. The platform is a safe communication channel between the PLCs of the two companies where only the data in read mode are shared.

Considering that a smart grid is defined as energy network that use digital technologies, sensors and software to better match the supply and demand of energy in real time while minimizing costs and maintaining the stability and reliability of the grid, it can be said that the implementation of digital technologies such as sensors, shared information system and so on was a necessity for the implementation of this kind of symbiosis.

The symbiosis is based on a heat recovery plant that is built with its own Programmable Logic Controller (PLC), that is a ruggedized computer used for industrial automation, that enable the plant to operate without staff and the system is completely automated. For cybersecurity reason the plant operates and share data only with the intranet of A2A.

Outside of the symbiosis both the companies employ industry 4.0 technologies, the complexity of the production plant requires the use of sensors and remote control system. The steel maker identifies as a competitive requirement a strong use of digital technologies, to control increasingly complex systems and to stay competitive it is fundamental to map processes and gather data with a high level of detail. To be able to take part in the numerous symbioses Alfa Acciai need to control the quality of its processes and by-products, without the control guaranteed by the use of digital technologies the quality of the material will be unknown, and they couldn’t find client for their by-products.

Some dedicated plants and technologies were implemented by Alfa Acciai for the material by-products exchanges: dedicated crushing and selection plant for the creation of the aggregates from the black slag.

5.5. Molhelix

Table 5-9 Overview of Case 022 interviews

	Molhelix
Interviewees per companies	1
Interviewees' role	• Chief Executive officer

The sources consulted for this chapter are the transcription of the interview with Molhelix, its websites and a short article on the website of Chamber of Commerce [101].

Industrial Symbiosis history

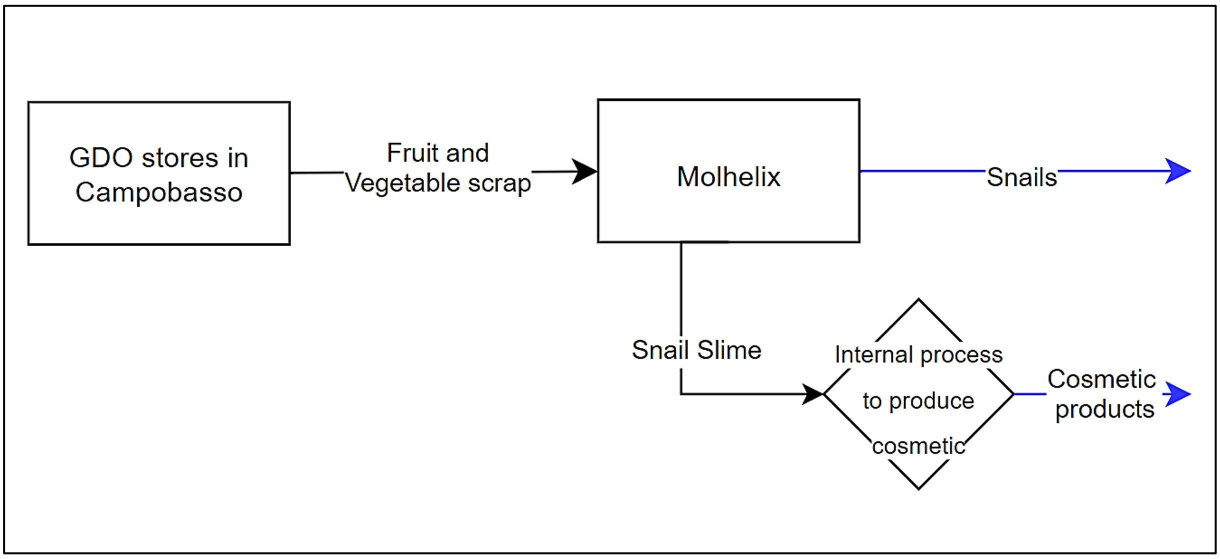

Figure 5-7 Molhelix IS flow chart

This case was classified as industrial symbiosis on the website of the Chambers of Commerce (EcoCamere) but during the interview the founder of Molhelix told us that they consider themselves to be an example of circular economy in the agri-food sector and not a case of industrial symbiosis.

Molhelix is a snail farm that produce snails and cosmetic products using snail secretion. The farm collects fruit and vegetable by-products from five grocery stores in the city of Campobasso and uses them to feed the snails. The company opened in 2020, just after the first covid-19 national lockdown, in the province of Campobasso, in Molise region, involving some local grocery stores in the recovery of vegetable organic produce as feedstock. The founders identified and managed the selection and regulation of the by-products used as food for the animals autonomously.

The funders initially contacted many GDO players in the province of Campobasso to start a partnership for recovering fruit and vegetable by-products, however only one player was interested in the collaboration. From the beginning the retailer showed to be very motivated and interested in the collaboration. The founders of the farm supported the retailer to follow the normative process to enter in the register of animal feed producers; the two companies work together to find the right trade-off between the farm's needs, in the form of materials characteristics and logistics, and the retailer's needs, such small time and complexity tasks for the operator.

At the beginning of the collaboration, the retail group that own the five grocery stores required the founder of Molhelix to hold training sessions for the operators responsible for the fruit and vegetable departments, in those training the operators learnt what products are good for the snails and how to pick and assemble the collection unit.

To be able to recover what once were fruit and vegetable waste Molhelix and the GDO group had to follow the regulations of the region, therefore the retailer had to sign in in the register of animal feed producers, thank to this action the grocery stores of the group can provide vegetable scrap in the form of by-products to the snail farm. Without this action the exchange between the firms would have been impossible according to the Italian regulation, in fact it is illegal to use a waste as feed for farming for sanitary reason, however if the same product with the same characteristics is classified as by-products and not as waste it can be used as animal feed.

Regarding the benefits and challenges faced by the two companies the ones about the GDO group were inferred from the insight collected in the interview with Molhelix. In the interview it emerged that the GDO actor currently is not gaining any reputation or economic benefits from the partnership due to their reluctance in advertising their practice and to the waste regulation and policy in Molise.

Table 5-10 Benefits and challenges of Molhelix IS.

	Molhelix	**GDO of Campobasso**
	Benefit	
Economic benefits	• Operational costs saving (no need to cultivate snail feed, lower time dedicated to the farm) • Good reputation for circular practices	• Potential reduction of waste disposal costs • Reputation
Environmental benefit	• Fewer fields to farm animal feed	• Waste reduction
Social benefit	• Education of children about sustainability	

Challenges		
Normative challenge	• Lack of support from the chamber of commerce • Lack of regional regulation to favour circular practices • High complicate bureaucratic procedures	• Uncertainty in regulations on waste management • High complicate bureaucratic procedures
Economic and Financial challenge	• Lack of financial support for circular startup	
Organizational and Motivation challenge		• Trust among stakeholders • Organizational structure and trust in the workforce
Operational challenge		• Selection of the grocery stores to involve • Definition of the collection procedures

In addition to the resource recovery from the grocery stores Molhelix is also a partner in a project funded by a Gal del Molise and Coldiretti to educate children on healthy eating through several laboratory activities. The farm participates in the project with farming laboratory focused on circular economy, they provide workshops on snails and mushrooms cultivation from coffee grounds.

Relationships in the network and trust

The relationship and communication methods between Molhelix and the GDO group changed with time. Initially, the collections and communications were managed via phone calls and e-mail, but once the collection's schedule and the relationship consolidated, they moved to a mobile group chat. The founders and the managers of the various points of sale use the group chat to manage quickly and easily resource collection, the logistics and the weekly schedule.

At the beginning of the partnership the relationship between the companies was formal and at the administrative level, while today the relationship is at the operational level. The GDO group performed a review of its points of sale to identify those that were suited for this kind of activity, only the grocery stores where the staff were considered trustworthy were selected for the partnership with Molhelix. This required internal action to prevent risk by the GDO to identify the points of sale suited for the resource exchange.

In the interview, it emerged that a common worry of the GDO regarding the recovery of by-products from the point of sale is the possibility that the recovery could be used to hide embezzlement through the collection process. Therefore, it is a real risk if the employees are not trustworthy, and the stock is not punctually controlled.

Digital technologies

Molhelix is a small farm that involves only two employees, the two founders, in the farming and selling of the products. To manage a snail production with few manpower and time the founders implemented some agriculture 4.0 practices, such as soil humidity sensors that are used to automate the irrigation. The data on humidity is accessible by remote and the system is automated, meaning that the irrigation starts when the humidity is lower than a set threshold.
The selling of cosmetics and snails took place on social media and is managed manually, and their sales are mainly local in the province of Campobasso.

The GDO certainly uses an ERP to manage their resources and to schedule its inbound and outbound logistics. However, regarding the symbiosis no particular digital technologies are utilized.

6 ENEA: Industrial Symbiosis facilitator

In this chapter the origin and the development of ENEA as a facilitator for industrial symbiosis will be presented, the sources consulted for this chapter are an interview with Tiziana Beltrani (ENEA's research scientist of the Laboratory Resources valorisation), the thesis's database, and the websites of the Symbiosis Users Network, Symbiosis Platform and ENEA.

ENEA, the Italian Agency for New Technologies, Energy and the Environment, is organized in four departments: Energy technologies and Renewable Sources, Fusion and technologies for nuclear safety, Sustainability of production and territorial systems (SSPT), and Energy efficiency. However, the department that is mostly involved in industrial symbiosis is the SSPT that is subdivided into six divisions: Efficient resource use and cycle closure (USER[8]), Technologies and Materials Processes for Sustainability, Models and Technologies for the reduction of anthropogenic impacts and natural risks, Protection and enhancement of the territory and natural capital, Biotechnology and Agroindustry, Technologies and methodologies for health protection.

Within the USER division there are three laboratories: water technologies, waste, and exploitation of resources in production and territorial systems (RISE). The latter deals with various activities, including industrial ecology, and is particularly involved in the dissemination of industrial symbiosis. RISE's activities started around 2010, and since then they operate in the field of environmental certifications, environmental labels, social costs, impact assessment, and life cycle assessment.

ENEA initiated its activities to favour industrial symbiosis in 2011 with the project Eco-innovazione Sicilia and the launch of the Symbiosis platform. As presented in the introduction chapter, ENEA is playing the role of industrial symbiosis facilitator in Italy. It is doing so through a series of projects, a clearly defined methodology, a platform and an industrial symbiosis network (SUN).

To promote industrial ecology and symbiosis, the agency does not operate alone, ENEA involves in the SUN companies and organization of different kind, from universities to businesses. For the projects that are at regional or local dimensions, the agency needs to involve actors at the territorial level, such as territorial agencies, local authorities, chambers of commerce, universities and private companies.

In *Figure 6-1* is possible to see the tools that the agency uses to enhance industrial symbiosis, those will be deepened in the following paragraphs.

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[8] Uso efficiente delle risorse e chiusura dei cicli

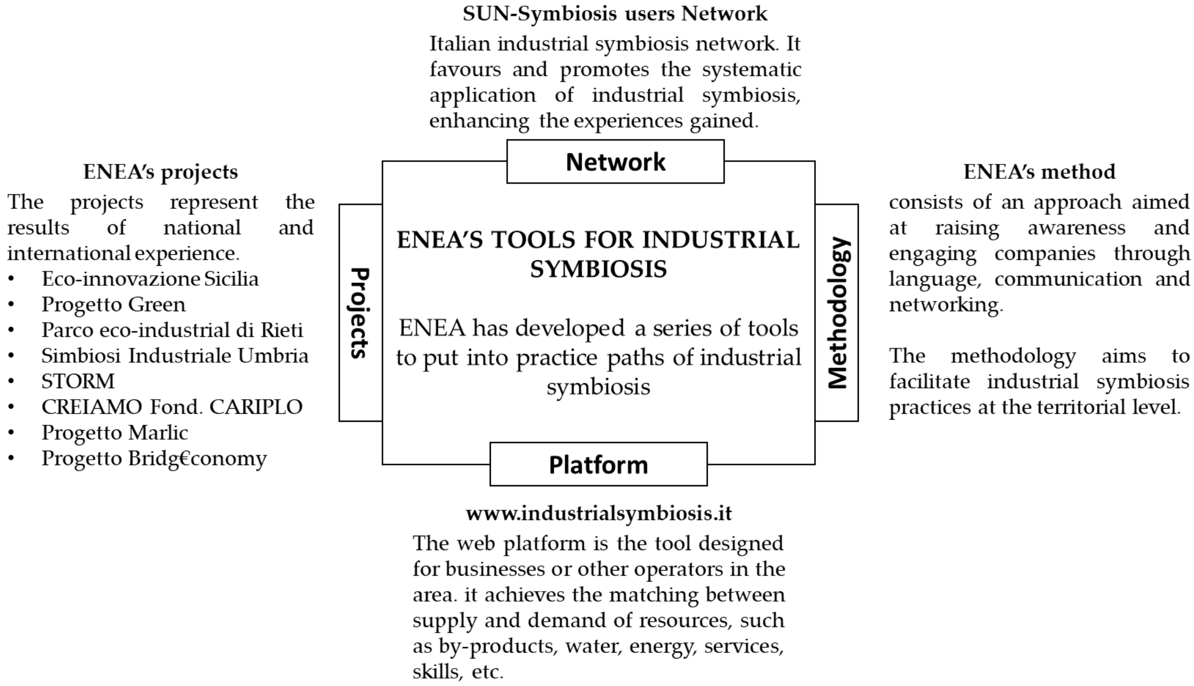
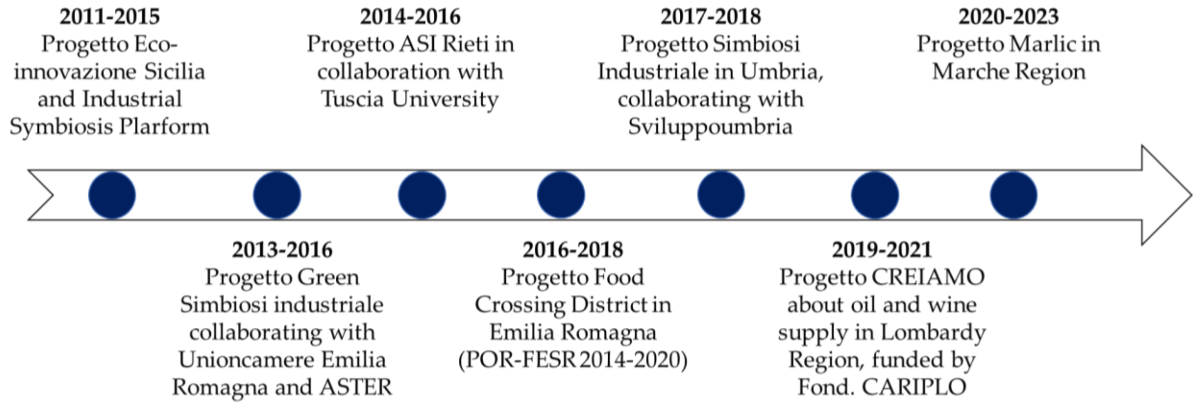


Figure 6-1. ENEA'S Tools for IS [102]

6.1. ENEA's Projects

The agency has completed many projects since 2011. It already worked in 6 regions: Sicily, Emilia Romagna, Lazio, Umbria, Lombardy and Marche. Currently it is working on a project in region Campania partnering with the consortium Bridg€conomy of the Enterprise Europe Network [103], the scope of this project is to facilitate the implementation of industrial symbiosis in the region to find a solution to the problem of waste and byproducts disposal, focusing on the management of the end of life of products and components in composite material, which are the most challenging when speaking about resource recovery in the form of recycling.

Figure 6-2. ENEA's projects on IS.



The timeline of the completed projects of ENEA can be seen in In *Figure 6-2*, in all those projects ENEA played the role of facilitator providing technical and legal support to companies in the planning and research phase of industrial symbiosis, the final output of each project was an operative manual with guidelines and best practices to follow in the main potential symbioses identified during the working table. Let briefly summarize the objectives of the various projects:

- Eco-innovazione Sicilia began in 2011 and was completed in 2015. The project operated in Sicily and promoted sustainable practices in significant productive sectors of the region and collaboration among firms to promote competitiveness. Through the implementation of a series of actions of research, development, implementation of technological and methodological tools to promote environmentally friendly business strategies that foster competitiveness. The productive sectors on which the project focused are electronic equipment and plastics, with a pilot intervention for the energy enhancement and recovery of valuable raw materials from waste from these sectors. The project involved more than 90 companies that partake in some working tables where almost 600 symbiosis, meaning kernel of symbiosis or more complex exchanges, were identified. The development and first use of the symbiosis platform is the second output of this project [104].

- The project Green Simbiosi Industriale began in 2013 and was concluded in 2016. It operated in region Emilia Romagna and ENEA collaborated with ASTER and Unioncamere Emilia-Romagna. The project's activities concerned the development of regional industrial symbioses aimed at the treatment and exploitation of agro-industrial waste and by-products, with interest in solutions to produce high value-added bioproducts (biopolymers, resins, solvents, building blocks). Such choice is correlated to the importance of the possible repercussions that these paths could have on the economy and the regional entrepreneurial tissue. The activities of the project enabled the identification of 8 main resource flows, 28 possible destinations of productive use and a total of 90 potential synergies. In addition, ENEA developed three operative manuals on the following symbiotic processes: production of biopolymers from food scrap, nutraceutical substances from food scrap, energy recovery from agri-food by-products [10, 105].

- From 2014 to 2016 ENEA collaborated with ASI Rieti-Cittaducale and Tuscia University to analyse and assess the possible symbioses in that specific area of Lazio region. Through two working tables the project involved 27 companies of the territory and 146 different resources were identified as available for symbiotic exchanges. ENEA and its partners defined 5 possible symbioses analysing the data of the working tables, four of these symbiotic scenarios focused on the reuse of wood and cardboard packaging, while the fifth scenario concerned improving the management of woody biomass in the industrial area aimed at recycling [106].

- The Food Crossing District project involved ENEA and Alma Mater University of Bologna and focused on the agri-food sector, it went on from 2016 to 2018 and was co-funded by POR FESR 2014-2020 of Region Emilia-Romagna. The project focused on the exploitation and recovery of tomato peels and seeds, and bran and middlings from wheat. The Food Crossing District focused on the definition and optimization of industrial symbiosis paths and delivered a geo-referenced tool to collect and process data from companies [107].

- In the biennium from 2017 to 2018 ENEA and Sviluppoumbria collaborated to identify possibilities of industrial symbiosis in the regional territory. 30 companies of various productive sectors joined the organizers in a working table, they shared information on their resources and operational knowledge. Many resources were identified as available for sharing, 95 as output and 32 as input, and the project identified 100 potential symbioses [108].

- The CREIAMO project was carried out by University of Brescia, ENEA and University Bicocca, and funded by Foundation Cariplo. The project went on from 2019 to 2021 and its scope was to find use and valorisation for residues of wine and oil production. The project focused on the province of Brescia and pushed for industrial symbiosis to find new solutions to reuse agriculture residues. The solution to exploit residues of olive oil and wine identified in the project are: production of bio-surfactants, treatment of contaminated soil by using bio-surfactants produced from residues of olive oil and wine sectors and cross-sectorial valorisation via industrial symbiosis [109, 110]. Two operative manuals were delivered as output for this project.

- ENEA took part in the MARLIC project from 2020 to 2023 which worked with companies in Marche region to give value to industrial residues and surplus. 31 companies from different sectors join ENEA and the other project planners in a working table, in which 199 sharable resources and 86 potential cross-sectoral synergies were identified [111, 112].

As emerged from these summaries the final scope of ENEA is to identify the potential synergies in the territory and provide companies with operative manuals to follow to achieve them. In addition to the creation of the symbiosis platform that will be deepened in paragraph 6.3, this gives a general overview on how the national agency facilitates the development and dissemination of IS practices in Italy.

6.2. ENEA Methodology

The agency's methodology follows a horizontal approach to create a network. Its objective is to close the loop through the creation of synergies between resources demand and supply. It is an approach that uses a specific language, that companies and other actors need to learn to be able to enter and use the network. A detailed step by step description of the methodology can be found in *Figure 6-5.*

All the projects took place in a limited geographic area going from regional level down to provincial level, the reasons beyond this strategy are the easiness to gathers local actors to make them collaborate, and flow optimization. Resource recovery efficiency and its environmental sustainability is strongly related to the distances and the mode of transportation used to close the loop. It is easier and more efficient to share and recover resources at the local level rather than at the national one. However, it is fundamental to be compliant to local regulation and specialized competencies and skills are required.

Let's overview how the ENEA operates to facilitate the development of IS. Everything starts with the identification of the local stakeholders to get involved, ENEA contacts companies, associations and local authorities. Then the agency sends invitations to the stakeholders and asks them to fill out forms on the resources that they can supply or need, the output of the second step is the creation of a preliminary database and the preparation of the working table.

The third step is the hosting of the working table where ENEA and the other possible facilitators, such as foundations and universities, gather all the companies and associations to further collect data on resources, while companies share their data on resource sharing ENEA and its partners look for synergies and for resources matching. Companies are identified with codes to maintain privacy while the resources are explicated in symbiosis schemes. The companies are georeferenced in order to define the distances and optimize the resource path.

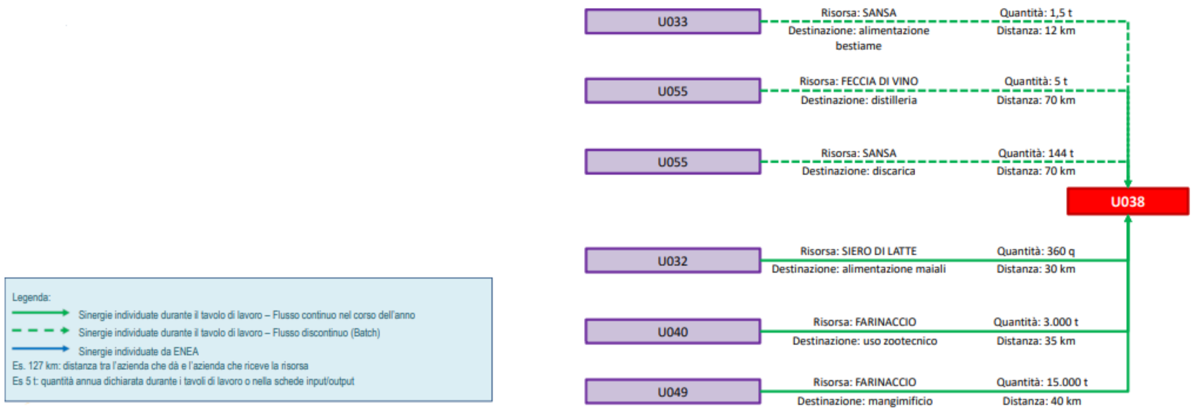


Figure 6-3 example of ENEA preliminary synergies scheme [113]

After the working table ENEA analyses and elaborates the collected data to identify the possible synergies and the resource loops that can be closed. The agency analyses and processes the collected data to identify what are the most significant resource flows in quantitative and economic terms. ENEA provides to each company involved in the programmes a company report, a document that highlight all the companies with which the company can share and exchange resources, this deliverable support companies in identifying the possible symbioses. However, it is the responsibility of the firms to develop them.

In the fifth step, ENEA then evaluates the technical feasibility, assesses the economic and environmental impacts, and checks if the synergies can be realized verifying the normative and the technical standards.

Lastly, ENEA publishes one or more operating manuals highlighting the findings from the working table and the proposed best practices. In the manual there are the synergies scheme and the localization of the companies, synoptic schemes where each resource stream is identified and analysed according to normative standards, technical, logistic, economic and other. Each aspect of the analysis is then colour coded: no barrier in green, to be explored in yellow, and barriers in red.

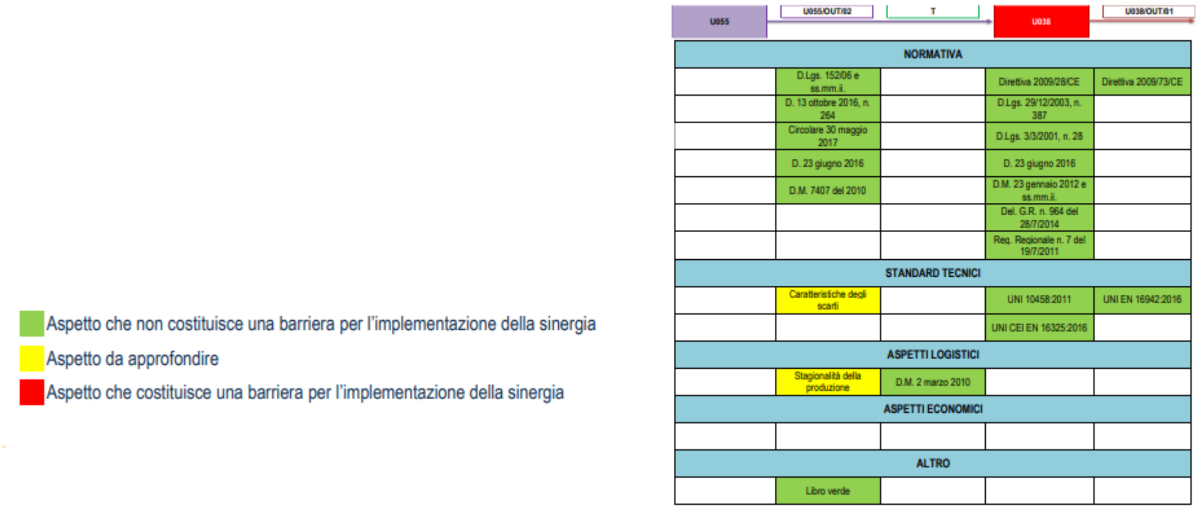


Figure 6-4 example of ENEA synoptic panel [113]

Another part of the operating manual is the technical dossier containing the community, national and regional regulations, characteristics of the by-products, and the valorisation processes. The final output of each project should be one or more technical manuals to guide companies in the implementation of the identified symbiosis. Therefore, it can be said that ENEA participates as facilitator only in the planning and research phase and then exit the symbiosis, leaving the actual implementation to the operating actors.

Figures 6-3 and 6-4 were extracted from the presentation that ENEA used during the interview and that is available online [113].

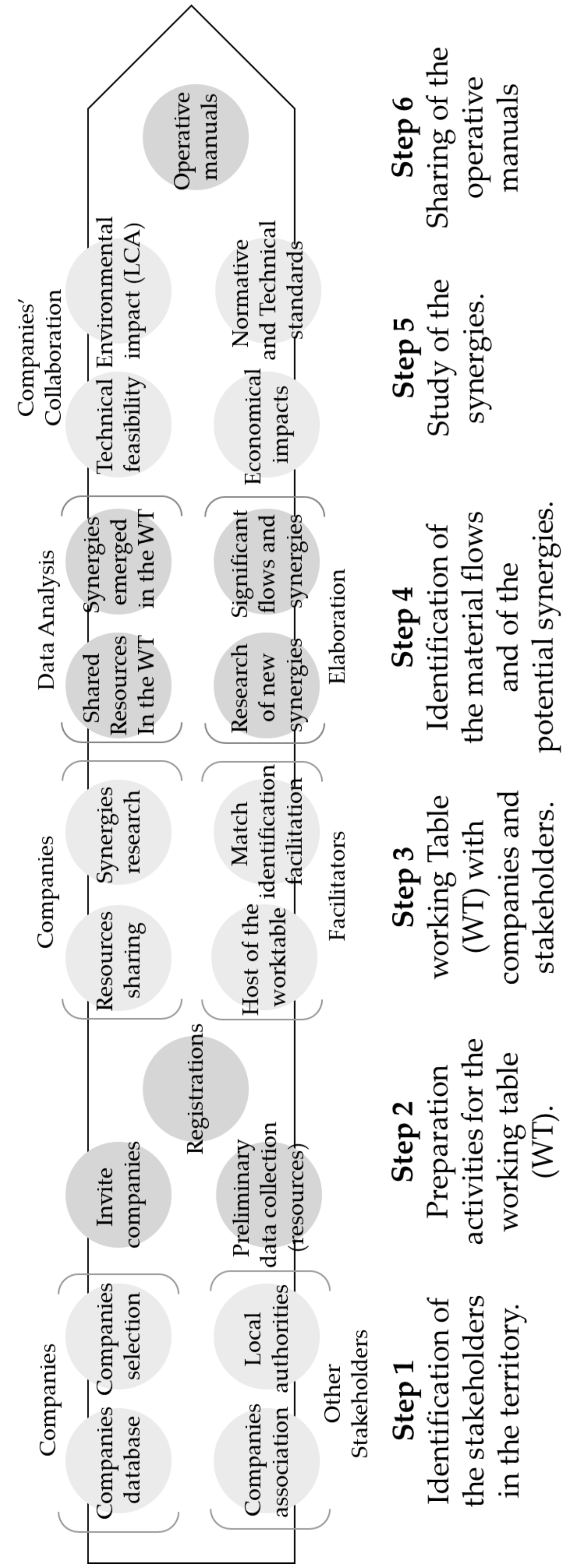


Figure 6-5. ENEA's methodology for working table.

6.3. Symbiosis Platform

The Symbiosis Platform is one of the outputs of ENEA's project Ecoinnovazione Sicilia (2011-2015), initially it was financed by the MIUR[9] and with the Food Crossing District project it was optimized thanks to the funds of the POR-FESR 2014-2020 of the Emilia Romagna region.

The aim of the Platform is to create networks and mechanisms of industrial symbiosis in a functional and simple way. It was born as a tool for resource matching at the service of companies and operators in the territory. The function of the Platform is to match supply and demand, to enable the transfer of resources, and support the birth of relationships between companies.

Currently 290 companies and 2672 resources are registered on the platform, and 1946 potential symbioses are identified. All the users can: geo-referencing their organization, update the information regarding their production site, insert, update and manage resources by fill in input/output forms, share resources, and search for possible symbiosis within the network.

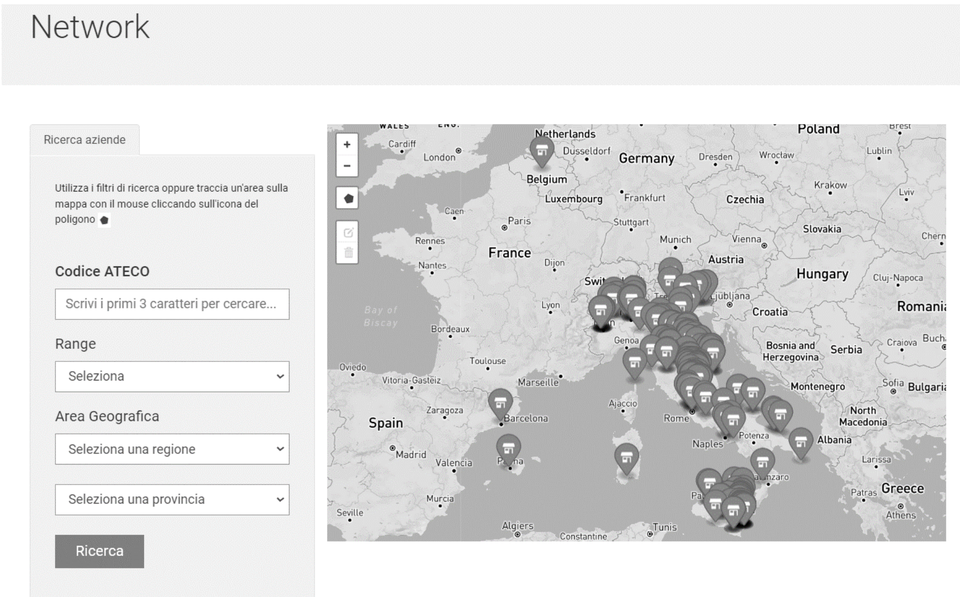


Figure 6-6. Symbiosis Platform organizations network in August 2023.

Companies easily register on the platform and publish the resources that they want to share or need. The term resource in the platform refers to all kinds of things: material by-products, water, energy, services, skills and so on. The shared resources are subdivided in input and output and are linked through a logical mechanism called origin-destination arcs. There are two categories of origin-destination arcs: direct and technological. The former directly connects two companies, meaning that the output of company A is the requested input of company B. While the latter requires a

[9] Ministero dell'Istruzione, dell'Università e della Ricerca

transformation, a technology is used to change the output of A in the input requested by B. The more technologies there are within the platform, the more interactions can be created in the future.

After each project, or working table, the platform is updated with the technologies and matches identified. The platform supports its users in the identification of possible synergies with other companies, and in the resource diagnosis: a tool to visually represent the processes of resource exchange and transformation.

On the platform a company can identify the matches and the contact information of the potential partners. Then it has to establish a collaboration contract independently, without any support from the platform, with the actors it is interested in. Therefore, the platform is a tool to inform companies and to highlight the potential symbiosis and resource sharing, but it is not a place where companies can make agreements or directly manage the resource flows.

6.4. Symbiosis Users Network

ENEA launched the first Italian network of industrial symbiosis the Symbiosis Users Network (SUN) in 2017, which currently involves 43 partners among universities, public institutions, research bodies, private companies, technology networks and local authorities. The SUN is the Italian landmark for operators who want to apply industrial symbiosis at an industrial, research and territorial level.

The network is organized into six working groups, that were defined by the coordination committee in the foundation year according to the most relevant subject on industrial symbiosis.

1. Working Group 1: mapping of the state of the art. Assessment of the current situation to capitalize on the results of the experiences both on success and failure.
2. Working Group 2: regional policies and action for industrial symbiosis. Analysis and possible implementation of regional policies and actions.
3. Working Group 3: assessment of the economic and social impact of industrial symbiosis. Evaluation of the economic and social impacts of the industrial symbiosis on the Italian production system.
4. Working Group 4: standards and certification for industrial symbiosis. Mapping and monitoring of measurement systems, certification and standardization of industrial symbiosis.
5. Working Group 5: working on normative deepening legislative acts, programmatic documents, devices. They work to favour a functional transition toward circular economy with reference to industrial symbiosis.

6. Working Group 6: communication and dissemination. They carry out communication and dissemination actions of the SUN network to promote more effective internal and external communication of the activities and of the state of the art.

In the figure below it is possible to find the partners and the coordinators of each working group, it is important to highlight that ENEA is working to involve more and more companies and organizations in the working groups.

Denominazione Gruppo di Lavoro	Coordinatori	Partecipanti
Mappatura dello stato dell'arte	Assocarta, Confindustria, Politecnico di Bari	ENEA, LazioInnova, Università di Catania, Politecnico di Bari, ASSOCARTA, Sistene, SAPIENZA, Università di Roma, Amici della Terra, ASTER, Sviluppumbria, Università di Brescia, Federacciai, Dintec, EURAC, UniBa, Catalyst
Politiche e azioni regionali per la simbiosi industriale	Agenzia per la Coesione Territoriale, ASTER, ENEA, Sviluppumbria	ENEA, ASTER, Sviluppumbria, Agenzia per la coesione Territoriale, MATTM, LazioInnova, Consorzio Dragona, Università di Bologna, Università di Messina, Ecoinnovazione, UniTuscia, Camera di Commercio del Molise, ASM Rieti, Fondazione Cluster Marche
Valutazione economica e sociale della simbiosi industriale	Università di Catania, Università di Roma Tre	ENEA, Università di Roma 3, Università di Catania, Università D'Annunzio, Politecnico di Bari, CNR, Università di Messina, Sistene, SAPIENZA, Università di Brescia, Consorzio Dragona, Ecoinnovazione, UniBicocca, UniTuscia , Novamont
Certificazione e standard per la simbiosi industriale	CNR, ENEA	CNR, ENEA, Università di Bologna, Politecnico di Milano, Università di Messina, Novamont, Dintec, Università di Brescia, UniBA
Normativa	ENEA, MiSE	MiSE, ENEA, MATTM, Politecnico di Milano, ASSOCARTA, Consorzio Dragona, Università di Bologna, Amici della terra, UniBicocca, LEAP, Federacciai, Confindustria
Comunicazione, Diffusione e Formazione	Amici della Terra, ENEA	Amici della Terra, ENEA, EnergoClub, Confindustria

Figure 6-7. Coordinators and partners of the SUN working tables [114]

The scope of the SUN is to gather together relevant stakeholders to discuss industrial symbiosis, to find solutions to existing problems and overcome barriers to its development. It is not only a tool to disseminate the concept of industrial symbiosis but also a network that is working to foster the development of this manufacturing strategy in an active way, changing rules and solving conflicts.

6.5. Facilitating industrial symbiosis

The previous sections of this chapter presented the methodology and formal actions that ENEA is pursuing to foster industrial symbiosis, while in this section will be presented the actual cases in which the national agency contributed to the development of a symbiosis. The sources for this chapter are the database on industrial symbiosis and the publications of the SUN.

ENEA participated as facilitator and coordinator in many initial stage of industrial symbiosis especially in the context of the projects presented in the previous paragraphs, however from the analysis of the database it emerged that not a lot of cases reported the agency as a partner or active stakeholders, this is related to the nature of the facilitating activities of the national agency.

In summary, ENEA partners with local organizations, such as universities, foundations, and associations, to know the local stakeholders that can be involved in the projects, then it collects information on input and output resource that the stakeholders want to share, plans and executes working tables to gather more data and educates about the concept of industrial symbiosis, identifies all the potential symbiotic exchanges and then focuses on the most relevant ones. The national agency develops operative manuals, practical dossiers to support companies in the development of the symbiosis. These dossiers are operative handbooks presenting material flows, regulation from the European to the regional level, guidelines, technical standards, logistic and economical aspects useful for supporting companies in the development of the symbioses [114]. Therefore, ENEA is an industrial symbiosis facilitator, but only in the research and planning phase, after which the responsibility for the execution of the symbiosis has passed to the operating companies that need to plan and manage the exchanges autonomously.

Moving to the activities of the SUN, it can be said that some of the working tables act as facilitator fostering normative and policy changes to favour IS. The Symbiosis Users Network is a case of ISNs, a network of organizations that with relational and knowledge tools support the resource matching between demand and supply among partners who, by economic and social activity, have no other opportunity to meet.

With its projects and the network the public agency shown to be committed to the With its projects and the network the public agency shown to be committed to the identification of potential industrial symbiosis through operative manuals, company reports and the symbiosis platform, and in the presentation of success story and best practices on the subject through the management of SUN conference and the publication of its proceedings. However, in the literature is missing a critical analysis of the actual developed symbioses that emerged from ENEA's activities, the literature mostly focuses on the planning and research phase and fail to present the developed symbioses, this is strongly related to the nature of the activities of ENEA that operate as a facilitator with dissemination initiatives and guidelines, and not as a facilitator in the operative and execution phase. The national agency considers the development, the execution of the identified symbiosis, outside of the scope of its projects, they provide guidelines and the symbiosis platform to support companies in the matchmaking, however the formalization of the exchange with contracts and pilot are in charge of the operative companies.

To be able to understand how many of the symbioses identified during ENEA's projects were actually developed the national agency should develop a post project assessment, such as running surveys after the closing of the projects to measure how many of the potential symbiosis were developed and what challenges or barriers occurred. However, currently ENEA does not assess its project in this way.

In the database only four cases presented ENEA clearly as a coordinator or facilitator, however during the interview with the national agency it emerged that some of the companies that are reported as stakeholders in industrial symbiosis case were involved in the industrial symbiosis projects, however not knowing if they were hosted to promote pre-existing symbiosis or as companies to educate on the subject it is impossible for us to assess if ENEA played the role of facilitator in those symbioses.

ENEA in the form of the proceedings from the Symbiosis User Network conference is the source of 9 articles from which 11 cases were found; in addition the national agency is recognised as a facilitator in four cases emerged from industrial symbiosis dissemination projects or from European project on resource recovery and valorisation.

Table 6-1 Number of cases reported by ENEA and its role as facilitator.

	With facilitator			
	ENEA	**Other PA**	**Private organization**	**Self-Organized**
ENEA as primary source	3	3	1	4
ENEA not as primary source	1	7	8	23

To complete the presentation of the activities of the public agency as industrial symbiosis facilitator, it is pertinent to briefly review the four cases where ENEA is recognized as facilitator to better understand if they were implemented and which sectors are involved, a synthetic version of the database framework will be used.

Table 6-2. Case 001

Description	Planning and research for potential IS between the steel and chemical-plastic industries. It is one of the many research project supported by ENEA. In the project the by-products, slag, of electric arc furnace are used as filler to produce polymer components such as vulcanized plastic.
Involved Companies	• ASONEXT S.p.A. • Novotema S.p.A. • ENEA • Unspecified company
Number of involved organizations	4
Geographic Area	Lombardy
Productive sectors	Manufacturing Professional, Scientific And Technical Activities
Digital Technology	Unmentioned, the following are assumptions: • Cloud Computing • ERP • Internet of Thing
Proximity	Less than 30 km
Taxonomy	Type IV
Shared or exchanged resources	By-products (EAF slag)
Top-down o bottom-up	Top-down
Public administration involvement	Yes, ENEA
EU or regional initiatives used for funding IS initiatives	N/A
Facilitator	ENEA for the planning and resource flow analysis
Current State of IS	Research and Planning
Emerging Phase	Planned
Sources	[115, 116]

Table 6-3 Case 002

Description	Planning and research for a potential IS between agri-food and chemical sector. Through biotechnology vitamin B9 (folic acid) can be synthesized from sugarcane processing by-products. Glucose and xylose are the main sugars released during the processes of pre-treatment and hydrolysis of various lignocellulosic biomass residues.
Involved Companies	• CoProB • ENEA • Unspecified company
Number of involved organizations	3
Geographic Area	Emilia-Romagna
Productive sectors	Agriculture, forestry and fishing Manufacturing Professional, Scientific And Technical Activities
Digital technology	Unmentioned, the following are assumptions: • Cloud Computing • Digital Platform through ENEA's symbiosis network
Proximity	More than 30 km
Taxonomy	Type IV
Shared or exchanged resources	By-product
Top-down o bottom-up	Top-down
Public administration involvement	Yes, ENEA
EU or regional initiatives used for funding IS initiatives	N/A
Facilitator	ENEA in the research and planning
Current State of IS	Research and Planning
Emerging Phase	Planned
Sources	[117, 118]

Table 6-4 Case 006

Description	The European project promotes the biological cycle of circular economy. To do so they developed a poultry manure based bioactivator for better soil management through bioremediation. Poultry manure is collected from a poultry farm in Calabria and is used as a raw material for creating a fertiliser, the bioactivator is then used in agriculture.
Involved Companies	• Unspecified agri-food companies • European Commission • Gruppo Soldano • ENEA
Number of involved organizations	4
Geographic Area	Calabria
Productive sectors	Agriculture, Forestry And Fishing. Manufacturing. Professional, Scientific And Technical Activities.
Digital technologies	Unmentioned, the following are assumptions: • Cloud Computing • ERP • Internet of Things
Proximity	More than 30 km
Taxonomy	Type IV
Shared or exchanged resources	By-products
Top-down o bottom-up	Top-down
Public administration involvement	Yes, European Commission and ENEA
EU or regional initiatives used for funding IS initiatives	Yes, European Commission LIFE POREM
Facilitator	ENEA as coordinator of the project
Current State of IS	Developed
Emerging Phase	Planned
Sources	[119]

Table 6-5 Case 043

Description	The Green- Simbiosi Industriale project involves 13 companies and has as management bodies ENEA and ASTER. It is a top-down experiment of a brownfield approach, recovery and renewal of industrial areas, in the Emilia Romagna region, the objective of the project is to spread EIP practices among companies, research and development centres and other regional actors. It is primarily a network for industrial symbiosis. The symbiotic network defines some main flows with their main potential synergies sectors as: food waste, sludge, packaging, waste from construction and demolition, textile waste, wastes from petroleum refining and natural gas purification, waste wood processing and biochar.
Involved Companies	• ENEA • ASTER • Unspecified companies
Number of involved organizations	13
Geographic Area	Emilia Romagna
Productive sectors	Agriculture, Forestry And Fishing. Manufacturing. Supply Of Electricity, Gas, Steam And Air Conditioning. Water Supply; Sewerage, Waste Management And Sanitation Activities.
Digital Technologies	• Digital Platform Unspecified, the following are assumptions: • Cloud Computing • ERP • Internet of Things
Proximity	More than 30 km
Taxonomy	Type V
Shared or exchanged resources	By-products and energy
Top-down o bottom-up	Top-down

Public administration involvement	Yes, ENEA and ASTER
EU or regional initiatives used for funding IS initiatives	N/A
Facilitator	ENEA and ASTER as project coordinators
Current State of IS	Developed
Emerging Phase	Facilitated
Sources	[120, 121, 10]

Considering these cases, all of them were planned and facilitated by ENEA and occasionally a partner. Half of these cases, according to the most recent source, were developed or are in the developing phase, while the others are still in the planning and research phase.

In cases 001 and 002 ENEA supported the involved companies in the identification and assessment of the resource available for sharing; particularly in the former ENEA partnered with Bicocca University to test the feasibility of the use of black slag in vulcanized polymer and in the latter supported the companies in the assessment of the environmental impact of the potential symbiosis.

Focusing on case 006, the POREM project was planned during a European project that was guided in the execution by a manufacturing company, ENEA acted as a facilitator in the planning and research phase assessing the environmental impact of the activities but didn't support the private company in the execution.

Moving to the project that ENEA developed in Emilia Romagna partnering with ASTER, among the symbioses identified three were formalized before the conclusion of the project while the others according to the most recent sources were not developed yet. These findings reinforce what was stated before, ENEA supports and facilitates the planning and research of industrial symbiosis but is not the actor that develops or manages them.

In summary, the national agency is a facilitator for industrial symbiosis mostly at the planning and research phase, supporting companies in the identification of the possible symbiosis and exchanges and assessing its projects with the number of involved companies, the number of resources available to share and the number of technical manuals developed during the project. Placing a critical analysis, it can be said that this methodology, as it is currently, does not assess in any way the number of implemented symbiosis among the potential ones identified and communicated, therefore, it should be defined as an indicator to measure the implementation rate of the potential symbiosis to measure the actual number of industrial symbiosis emerged thanks to ENEA's activities.

7 Findings discussion

In this concluding chapter the results of the research will be discussed and commented in order to highlight their significance and novelty to the current knowledge on industrial symbiosis in the Italian and European context. Additionally, these finding will be used to try to answer the research questions of this thesis.

Further research and the implications of the study in terms of contribution to theory would be briefly presented together with tips for the practitioner that would perform a study similar to this one.

Limitations of the research and of the findings will be presented in this chapter, and lastly the most relevant discoveries of the thesis will be summarised in the conclusions.

7.1. Research findings

Going by order, let's analyse and comment the data on the database. From the database emerged that there are more companies interested in sharing and exploiting their by-products than companies interested in using by-products as raw material or that can transform them. That's because typically a by-product must undergo some technological processes to make it suitable for further use, occasionally making them more costly than virgin raw materials and increasing the complexity of the material flow. Some of these transformation processes for material recovery need specialized machinery and processes that must be outsourced to companies that have expertise in that field. In addition, companies know their outputs and by-products, can label them clearly, and make them available even if they don't always know in which sector they can be employed. However, they will request by-products as input for their processes only if they recognize them as suitable.

This finding confirms what is disclosed by ENEA during its projects. The public agency identified more output resources available for symbiosis than inputs. This can be related to the economic drivers, that are the most common ones behind the origin of an industrial symbiosis: most of the companies that decide to undertake this strategy do so to find new market opportunities and to reduce their operating costs. In addition, ENEA also distinguishes the arcs between companies in a symbiosis in technical and direct, the latter are more common and easier to achieve than the former that require to work on the by-product to make it suitable for material recovery.

Moving to the analysis of the data on the geographic distribution of the Italian case studies it can be observed that they are not present in all regions. While there are regions without any case there are some with more occurrences than the average. On one hand, the regions of Basilicata, Campania, Liguria and Val d'Aosta do not have any reported case of IS, on the other hand Umbria, Sicilia, Calabria and Lombardy have more than 4 cases. Region Calabria didn't host ENEA's project yet, but the university of Reggio Calabria is pursuing many initiatives to foster symbiosis and circular economy and is acting as facilitator in the form of disseminator and research support in the planning and research phase of many cases. Umbria, Sicilia and Lombardy hosted ENEA's symbiosis projects and it can be assumed that especially in Sicilia, where the Ecoinnovazione project took place between 2011 and 2015, most of the symbiosis are the result of dissemination activities of the public agency, the working tables, technical manuals and the symbiosis platform foster the planning of some IS cases. There is a partial overlap between the regions that hosted ENEA industrial symbiosis projects and the regions that have more than average cases of IS, this can be used as a qualitative evidence of the relevance of facilitators and research institutes to disseminate and uncover industrial symbiosis cases.

Most of the case studies in Italy involve companies operating in manufacturing, environmental service, agriculture and energy production sectors. There are some symbiosis thar involve only companies of the manufacturing sector that simply exchange material resources in the form of scrap or by-products, but most of the identified symbioses are cross-sectoral where the most common combinations are: manufacturing-environmental service, manufacturing-energy production, agriculture-energy production in the form of waste to energy, and agriculture-environmental service. The dominant presence of firms operating in manufacturing, especially steelmaking, cement production and power generation confirms what the literature states about IS diffusion in productive sectors [69, 11]. The number of firms operating in the agriculture, forestry and fishery sector partaking in IS are consistent, there are at least 24 cases in the database that involve those kind of industry, this is related to the big volume of organic by-products generated by these activities that are collected and recovered commonly in composting and as biomass feedstock in anaerobic digestion [122, 123].

Materials, by-products, energy, water, service, infrastructure, information and knowledge are all the possible resources that can be exchanged in a symbiosis. The database showed that the most common resources exchanged are by-products and materials, followed by energy and water while the others are less common. On one hand, for companies it is easier to manage material exchange that can be regulated easily with contracts and transferred via road transportation and traditional logistics, on the other hand energy and water transportation require dedicated infrastructure and proximity between companies to be affordable, these kind of symbiosis are not always feasible without public projects and funding due to the entity of the initial investment. The rarity of symbiosis where information and knowledge are shared is tied to the numerous difficulties that companies have in regulating and defining these kind of exchanges, moreover, companies fear and avoid the sharing of their data and know-how for competitive reasons; the few cases where information and knowledge sharing take place are the result of multi partners projects that were facilitated or funded by Regions or European Union, such as the project banco energETICO presented in the previous chapter or CORALIS project, and employed the use of digital technologies for collecting and managing information.

Another relevant dimension related to information sharing is the trust among the stakeholders, considering the interviews with Agroittica and Bioenergia it emerged that the creation of a long lasting and trustworthy partnerships was the base for this kind of exchange. In the former the trust among the two companies is related to the long history of the partnership and to the fact that the two companies are part of the same group. For the latter, the case of the Magnifica Comunità di Fiemme, the trust among the utilities provider and the local sawmills was enforced via personal relationships and to the socio-geographic characteristics of the area; most of the sawmills are small and family businesses and they supply their by-products to the utility provider because they trust that they will be used in way that is compliant to their values and will give back to their community.

As shown in Chapter 4, proximity between IS stakeholders is a common occurrence in Italian case studies, from interviews with ENEA and some companies, it emerged that this trend is related to cost reduction and material flow optimization. The economic value of by-products and waste is low, so handling them is not convenient unless talking about large volumes or short distances. Therefore, to optimize resource flows and reduce logistics costs companies need to be close one to another in other to make IS economically sustainable.

Before answering the research questions it is important to highlight that during the companies contacting and in two interviews it emerged that not all the parties of a symbiosis are aware that they are part of it or are familiar with the concept. This was occurred mostly with small and medium enterprises, which shown to be familiar with the general concept of circular economy that is part of everyday language but don’t know the strategies available to achieve it. This lack of knowledge and dissemination of industrial symbiosis outside large companies has led to some difficulties during the interviews and can be assumed to be the cause behind the limited number of companies that answered to the contact email.

7.2. Answers to the research questions

The interviews provided important insight to answer the research questions of this thesis. For brevity from now on I will refer to the five cases as follow: Agroittica-Feralpi as S1, San Miniato tannery district as T1, MCF-Bioenergia as M1, AlfaAcciai-A2A as S2 and lastly Molhelix as A1. In the table below are reported the most relevant findings from the interview with the companies in the industrial symbioses.

Table 7-1 Summary of the interviews findings

	S1	T1	M1	S2	A1
Year of emergence	**1973** (energy) **1990** (material and by-products)	**1960** (by-products) **1980** (water and service)	**1999** (energy and material)	**1990** (material and by-products) **2021** (energy)	**2020** (by-products)
Kind of emergence	Self-organized	Self-organized (by-products) Planned (water)	Planned	Self-organized (by-products) Planned and facilitated (energy)	Self-organized
Resource exchanges	Material By-products Energy Water	Material By-products Water Service Infrastructure	By-products Energy	Material By-products Energy	By-products
Relationships among the organizations	Contractual agreement Mutual information exchange	Contractual agreement Intermediaries for resource collection Consortium and associations	Contractual agreement Mutual trust Shareholder mechanism Public tender	Contractual agreement Public tender	Contractual agreement
Digital technologies for the IS	Digital communication	Digital communication	Digital Communication	Digital Platform Digital communication	Digital communication
Digital technologies used by the	ERP Internet of Things	ERP Internet of Things	ERP Internet of Things	ERP Internet of Things	Mobile Computing Applications

companies in the IS	Digital platform Cyber Physical System	Big Data Analysis		Cyber Physical System	Social Media

The research work, especially the interviews, has provided interesting insights into the benefits and challenges that individual firms can face in IS. Economic benefits such as cost reductions and new market opportunities, followed by environmental benefits like emission reduction and resource efficiencies are the most common benefits identified by the participants, the social benefits are rarely identified and take form in job creation and education activities. The most common challenges disclosed by companies are lengthy bureaucracy processes and difficulties in gaining funding.

In the figure below, the five case studies are positioned according to two dimensions that are particularly relevant for this study: formal inter-firm collaboration and kind of emergence of the symbiotic exchange. Case T1 and S2 are presented with two distinct points to make explicit the different emergence of the resources exchange.

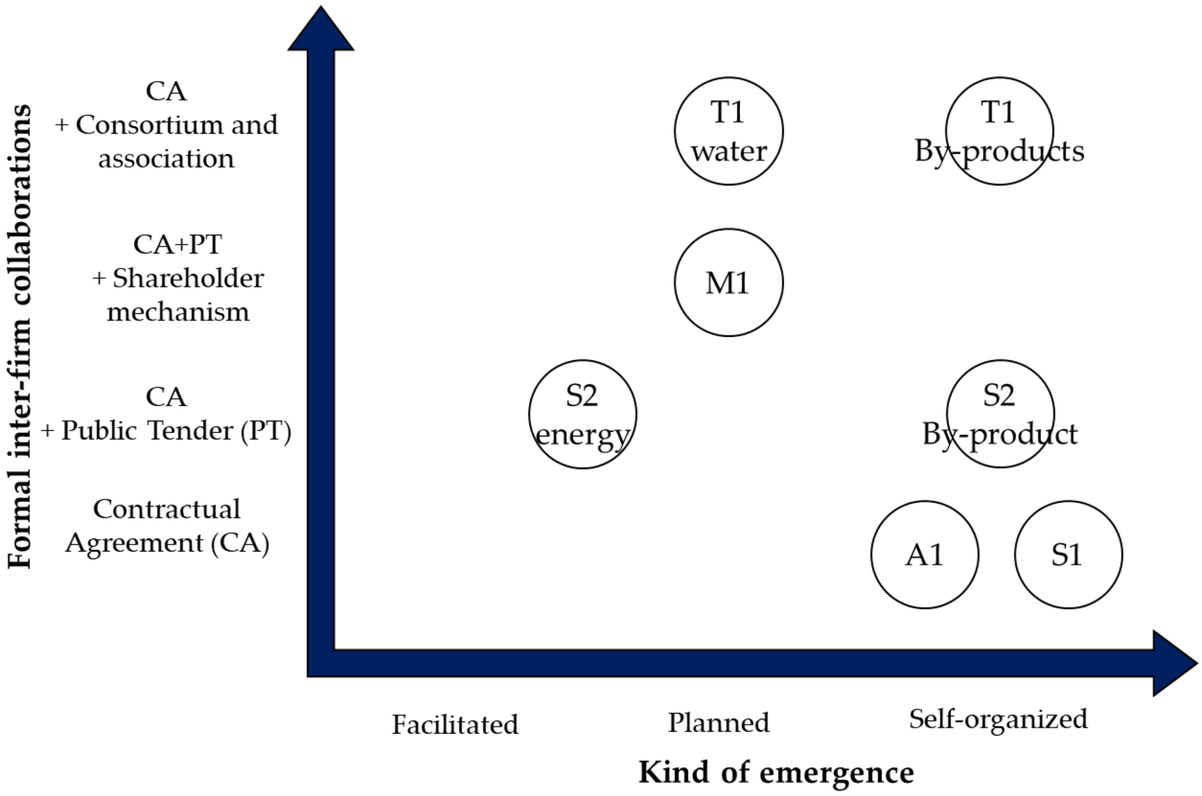


Figure 7-1 Positioning of the case studies on the collaboration - emergence matrix

To answer the research questions of this thesis three key sources of information are particularly relevant: data extracted from the database, insight from the interviews with ENEA on its role of facilitator, and insights from the interviews with companies within symbiosis. The *table 7-1* highlights the main findings of the interviews that will be used to answer the research question of this thesis. In the following pages the research questions will be addressed, and answers proposed.

7.2.1. How and when industrial symbiosis cases emerged in Italy?

Most of the cases of industrial symbiosis identified in Italy emerged and developed spontaneously and without a conscious intention to develop an IS strategy, especially for the cases that can be dated before the 2010s. From the interviews and the literature review emerged that the most common reasons and drivers for symbiotic exchange are economic ones like operating costs reduction and new market opportunities.

The total number of planned and facilitated cases is 23, in which 15 are in the emerging and developed phase, 6 in the research and planning and the remaining are in the declining phase. In fact, only facilitated and planned symbiosis can be identified in before the emergence phase. Changes and development projects are the most common drivers for this kind of symbioses, for example in case T1 the change of mandatory water treatment pushed the development of the consortium for the management of tannery wastewater while in case S2 the regional project funded the pilot project that led to the development of the symbiosis between the steelmaker and the utility company.

Thanks to the interviews it was possible to discover that a case of symbiosis can be both spontaneous and facilitated, meaning that different 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. This can be explained better using cases T1 and S2 as examples: in the former businesses spontaneously exchanged and shared by-products and material resources, while the water and service exchange was planned by Cuoiodepur and partially pushed by the normative about water treatment; while in the latter by-products exchanges were spontaneous while the energy recovery is the result of a regional project that enabled the exchange with fundings for the infrastructure development and research activities.

Regarding when industrial symbiosis cases emerged or were planned the literature doesn't have an answer and the result of the interviews are quite diverse. This was predictable considering that the occurrence of partnerships among companies and the kind of relationship among them is influenced by the maturity and strength of each company and by their strategies. To answer to this question it is important to highlight one limitation of the methodology: only some companies were contacted and even fewer answered and agreed to partake in interviews. Furthermore, two of the cases analysed with the interviews are about symbiosis among steelmaker and energy recovery in the province of Brescia, in Lombardy region, that therefore pushed the research to be focused on that sector.

From the database analysis and the interviews emerged that there is not a clear period when most of the IS cases emerged, the readiness for the development of this kind of strategy is in function of the context of each company. In four of the five interviews it emerged that the economic drivers of operating cost reduction and new market opportunities are recognized by all the interviewed actors, therefore, it can be assumed that those drivers are particularly strong for the development of industrial symbiosis. Without economic convenience no company would undertake this strategy. However, an organizational culture oriented toward sustainability and efficient resource exploitation, together with interest in finding new commercial opportunities guide companies toward symbiotic exchanges.

Moreover, from the interviews and the database it emerged that sectors like agriculture, electric arc furnace steel making, tanneries and forestry have a long history of symbiotic exchanges that only in recent year were identified and labelled as industrial symbiosis. While in manufacturing industry, such as machinery and food production, this kind of exchanges and practices developed symbiosis in more recent year.

Concluding this answer, it is important to show what was gathered from the interview with ENEA, which provided an important insight on the timeline of the consciousness and dissemination about IS in Italy. The interest on this topic has increased since 2010, the year when the project eco innovazione Sicilia began, thanks to the projects of the national agency which informed and made many companies aware of this strategy with working tables and developing operative manuals. However as emerged from two interviews and from casual talks the subject of industrial symbiosis is unknown to most.

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

To gather information on the relationships among industrial symbiosis' stakeholders the interviews with ENEA and companies involved in the case studies have been a necessity. This combined approach, involving both expert insights and practical experiences, has significantly enhanced the depth and breadth of our research findings. Without these interviews, it would not have been possible to deepen this topic on the Italian context. Briefly, most of symbiotic relationships are defined and guided by traditional business contracts, the parties of the contract 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.

The kind of relationships among companies partaking in a symbiosis can be facilitated and managed by consortium and enterprise association, especially in the context of industrial district where enterprises are generally small and specialized in only one phase of the supply chain, as emerged from case T1.

In some cases the companies involved in the symbiosis are stakeholders of other organization partaking in the symbiosis, providing additional control on the relationship. This emerged from case M1 where a sawmill and the Magnifica

Comunità are minority shareholders of Bioenergia, the utility firm, and in case S1 where the fish farm and the steel mill are in the same corporate group.

The database analysis didn't provide insight about relationships in the symbioses but gives back relevant information on resource exchanges. Material and by-products are the most common resources exchanged, followed by water and energy, and lastly by services, infrastructure, knowledge and information. However, regarding the last two items in the list it is possible that those exchanges can be difficult to detect and are rarely publicly reported meaning that they are underreported.

The sharing of information between the involved parties is a relatively infrequent occurrence beyond the scope of formal contractual agreements. However, within long-lasting and well-established symbiotic relationships, occasionally a scenario emerges where the exchange of information 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. For example this occurred in cases S1 and M1.

7.2.3. What are the digital technologies used in industrial symbiosis?

The research work provided an insight on the digital technologies employed by the companies in the symbiosis, it gave a portrait of the digital technologies used in manufacturing activities, such as sensors and internet of things used both on cloud or with organizational intranet, and in information systems. In summary, the most used technologies among the interviewed companies and according to the few papers that reported on this dimension are: information system, digital communication such as e-mail and collaboration tools such as Microsoft or Google suits, sensors and digital quality control of the input and output.

However, the most relevant digital technologies for this strategy are the one related to communication and information management, manufacturing technologies were reported only in few cases and the interviewees stated that those technologies were related to the core activities and not implemented for the symbiosis. Only in one case, S2, a digital platform to control the smart grid was specifically designed for the symbiosis even if this kind of internet of thing and energy flow platforms are the best practice for this kind of solution, all the smart grids are managed in similar way (Tuballa & Abundo, 2016).

Companies and organizations need data and information on their processes and outputs to be able to share and exchange resources, without information and knowledge on these topics it is impossible to find a use or a market for by-products and surplus resources. For this reason it is common among companies that take part in IS to employ internet of things, cyber physical system and ERP. The complexity of the employed information technologies is related to the size and sector of each company. For example, on one hand, big data analysis is a sophisticated and expensive digital technology that only big companies, that have historic data on the processes that they want to control, can use only after an ex-ante process assessment and measurements. On the other hand, cloud computing and especially ERP are common technologies in today's organizations, they require medium-low investments and are solutions that don't need a long time to be implemented and adapted to each company and process.

Also communication technologies have shown to be important to coordinate and control symbiosis. E-mails are the most common medium used to communicate among companies, phone calls are used for extraordinary communication when something does not go according to schedule, in small and young companies mobile messaging applications are sometime used to coordinate material flows. Digital revolution in the form of mobile computing and remote control technologies are reshaping manufacturing and service systems.

From the interviews and the database analysis, it emerged that platforms are rarely used to manage material and resource exchange, particularly it is important to highlight the use of ENEA's symbiosis platform, which is used to collect data on resources available for exchange classified as input or output, for dissemination of the subject of industrial symbiosis and to provide to the users a tool to identify and contact potential partners to implement the potential symbiosis identified using ENEA's operative manuals. However, its objective is to identify and connect, according to the principles of industrial symbiosis, companies and operators at local level to stimulate resource exchanges and closing loops. This platform provides a place where companies can access to data and information that can lead to industrial symbiosis, but it acts as a guidelines not an operating tool.

7.3. Limitations

This work, like any research, inevitably presents some limitations that arise from several factors: time constraints, companies' awareness and knowledge on industrial symbiosis, availability of participants to the interviews that could have led to a sampling bias favouring big companies rather than small enterprises.

The time allocated for the execution of this master thesis was of nine months, from March to November 2023, the research timeline was the following, literature review, definition of the research framework and questions, creation of the database, identification of the case studies for the interviews, contacting the organizations and interview scheduling, conduction of the interviews and transcription, results analysis and finding, and lastly the analysis of the obtained results. It is important to highlight that the interviews were planned and conducted before August to avoid potential availability problems that could arise due to the summer holidays of each company. This enabled the critical analysis of the findings to be performed in late summer and during autumn months.

During the case studies research and analysis, in particular those identified by the chamber of commerce, has emerged that sometimes any practice of circular economy is labelled as industrial symbiosis even if it takes place within the boundaries of a single company or is limited to separate waste collection. In addition to this, during the companies contacting and in two interviews it emerged that not all the parties of a symbiosis are aware that they are part of it or are familiar with the concept. This lack of knowledge and dissemination of industrial symbiosis outside large companies has led to some difficulties during the interviews and can be assumed that lead also to the limited number of companies that answered to the contact email.

Moving to the research tools, both the database and the interviews showed to have some limitations. A noteworthy limitation of the database is its reliance on manual update, a way to collect the required data automatically from each new publication on the subject is not possible, to keep the database up to date on Italian cases of IS the only way is to read and extract the data manually, therefore it is a very time-consuming process to keep the database up to date. For this reason, it is possible that the database may not portrait the complete and more recent situation in Italy, therefore, to further develop research it is needed to make new surveys and inquiries the literature source.

The software used for the database creation and analysis, MS Excel, is not recognized as a database management system. It showed to be suitable for the dimension of the database and to perform small calculation and data filtering. However, if the database will be expanded in the future, it should be turned into an actual database to be managed with a database management system, such as MS Access and MySQL, that are designed for large, complex, or multi-user environments that characterise a database.

Additionally, there are some limitations related to the research findings. Even if there was a strong effort in capturing a diverse range of industrial symbiosis cases there may still be some inherent biases in the sample selection process. It is noteworthy that it was not possible to interview all the organizations within the cases due to the time and availabilities of the involved stakeholders. In fact initially more or less 20 companies were contacted for the interviews but only 10 answered and were available.

It is important to acknowledge the limitations of the sample size of the organizations that were interviewed, which may influence data collection and the completeness of the study. Furthermore, casually the study ended to be mostly focused on the north and centre of Italy, meaning that the geographic focus may limit the generalizability of the results. As emerged with the interviews with Feralpi and Molhelix the normative and regulations regarding waste and by-products management are regional and could significantly impact the practices and approaches observed in this study.

Remaining on the matter of the limited variety of the sample of case, the figure below shows that almost all the cases involve a utility provider or an environmental service provider, therefore it can be said that our study unintentionally focused on the symbiosis between manufacturing and environmental/utility service sectors.

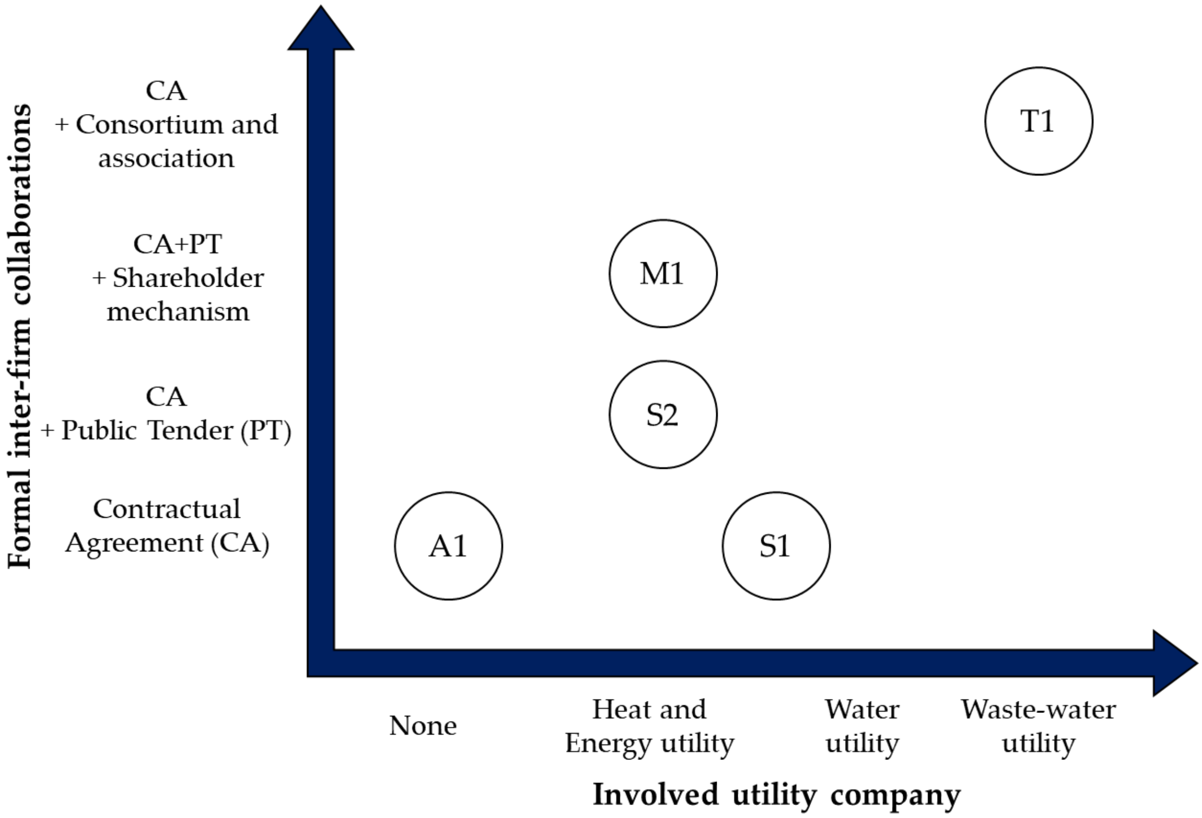


Figure 7-2 Positioning of the case studies on the collaboration - utility matrix

Despite these limitations, it is important to highlight that the insights gained from the interviewed organizations provide valuable and meaningful contributions for the understanding of industrial symbiosis development in Italy, the analysis of these studies provide an insightful qualitative view and a foundation from which develop further research.

7.4. Future research

Considering the limitations of this research, particularly regarding the number of companies and case studies deepened, I believe that is important to continue this research with further interviews with practitioners and organizations. Essentially, it is important to update and review the database to make it more relevant and robust for the understanding of the Italian application of industrial symbiosis practices and dissemination. This will serve to keep the repository relevant and robust, developing further understanding of the developed industrial symbioses in Italy and distinguishing among operative and simple dissemination projects.

In the literature there are numerous publications about projects and industrial symbiosis networks to promote industrial symbiosis. However, these works are often limited to the presentation and analysis of the deliverables and timeline analysis of these initiatives not providing structured post-project assessment. There is a gap in terms of long-term results of those projects, for example the publications about ENEA's projects often present the new technologies and processes to develop industrial symbiosis, and in the deliverables are identified the number of potential symbioses and the resources that are available for the exchange, but it is never reviewed what and how many of those are developed after the conclusion of the project. In essence, if something is not measured it is not possible to know its real impact; therefore, I believe that this aspect deserves further research attention and investigation.

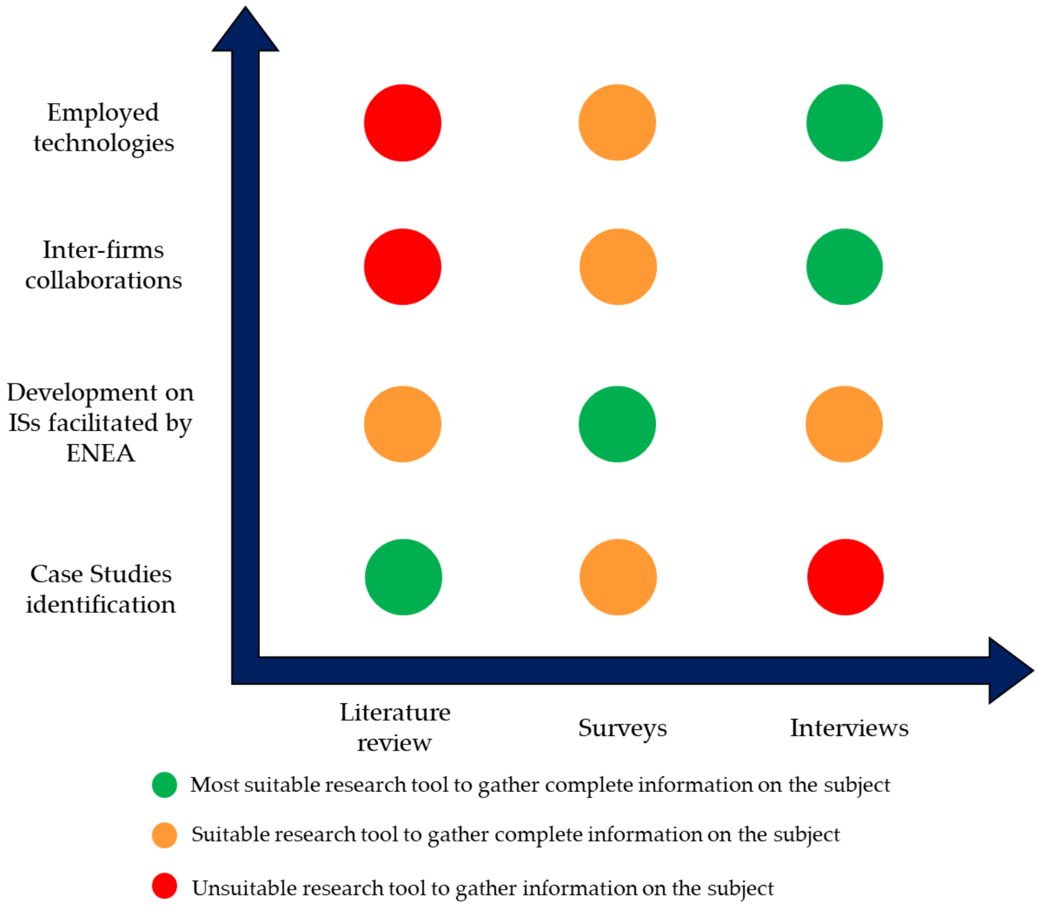


Figure 7-3. Recommended research framework for future research

In the figure above is presented a summary of the possible strategies and tool to use to undertake further research to deepen the knowledge on the current development of symbiosis.

7.5. Conclusions

In conclusion, this research provided new insights about the diffusion of industrial symbiosis practices in the Italian context providing new insights: on the timeline and methodology of the dissemination of the strategy, on the relationships and exchanges among the organization that partake in the symbiosis, on the technologies employed and providing a detailed analysis of the activities of ENEA, the Italian agency for sustainable development, as industrial symbiosis facilitator.

The most evident contribution was the identification of new cases of industrial symbiosis in Italy, but also with the presentation of a new case study that involves the forestry and service sector in the region of Trentino Alto-Adige, which wasn't yet described under the lens of industrial symbiosis in the academic literature. These additions enriched the understanding about industrial symbiosis in the country providing a wider knowledge on geographical distribution and the sectors that partakes in this strategy.

It emerged that most of the case of industrial symbiosis in Italy are self-organized and spontaneous, and that the cases in the planning and execution phase that are recognized by the literature, both academic and grey, are facilitated and planned. In addition it was bring up that each symbiotic exchanges, also known as industrial symbiosis kernel, could emerge differently from the others already present in the symbiosis. It is possible that a kind of resource exchange developed spontaneously in the symbiosis and that another arise from a planning or normative enforcement in a different time and manner. This shows that an industrial symbiosis, which is considered as a natural environment, evolves with the changing needs of the parts that compose it. A symbiosis is always evolving, immobility can lead to the decay of a symbiosis or even of an industrial district.

The analysis of the interviews provided interesting insights about relationships among stakeholders, the kind of exchanged resources, the employed digital technologies and undercover the activities of ENEA as industrial symbiosis facilitator. Starting with the inter-firm relationships some recurring pattern were observed; the most common relationships in industrial symbioses are traditional contractual agreement, which can be of different kinds from spot to blanket order (contratti quadro). However, in some cases the relationship and management of the symbiosis involves associations and shareholder control.

To exchange resources organizations need to define common understanding and mutual commitment through contracts. The findings about resource exchange corroborated the existing literature on the matter, showing that by-products and waste exchange are the most common, followed by energy and water exchanges and lastly by service, infrastructure and information sharing.

This research did not provide novelty on the subject of digital technologies adopted in industrial symbiosis and corroborated, with empirical evidence, the existing literature on the matter. The dissertation concluded that digital communication and information system are necessary tools to support the creation and management of symbiosis [14, 15, 126]. However, no evidence was found regarding industry 4.0 manufacturing technologies, such as internet of things and 3D printing, as necessary or auxiliary conditions for the development of IS strategy.

Lastly, the research on ENEA as an industrial symbiosis facilitator provided important insights on its methodology and projects and led to the conclusion that the national agency is very active in the collection of success stories and best practices and uses them to provide guidelines and operating manuals to companies that partake in its projects or are users of its platform to disseminate industrial symbiosis practices.

In summary, this research work provided an overview of industrial symbiosis state of the art, described the current development and diffusion of the strategy in the Italian landscape, provided an in-depth description of five case studies on industrial symbiosis in the Italian context and gave a critical analysis of the activities of ENEA. Additionally, it described the critical role of ENEA as a facilitator, the national agency supports organizations in the planning and research phase of the symbiosis and provides operative manuals for the development of them.

We can conclude that there are many cases in the research and planning phase showing growing interest in this strategy. There is a commitment from the Italian national agency for sustainable development to foster this resource valorisation strategy. However, it is fundamental to be able to continue the development of those symbiosis to reach the emerging and developed phase. To achieve sustainable development and circular economy more symbiotic exchanges are needed and ENEA and its partners need to foster them not only via education but also with practical and operating activities.

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A Appendix A

A.1. Interview guidelines

The aim of the interviews is to better understand the emergence and development of industrial symbiosis in the Italian field. For each case some of the involved actors have been interviewed to have a well-rounded comprehension of the relationship and shared services in the symbiosis. The interviews will be done in Italian.

Industrial Symbiosis macro information

1. Following the definition of industrial Symbiosis (Chertow 2000). Are you aware of being part of an Industrial Symbiosis?
2. Are you a user of the Symbiosis Platform[10] or of other platform for sharing extra resources like material, by-products, infrastructure, and services (Sfridoo etc)?
3. When did the symbiotic relationship start? Was it born as a classic business transaction or as a strategic partnership for sustainability?
4. Who started the industrial symbiosis? Was it the result of a project developed by a public administration or of private partnership?
5. Is the public administration, also considering universities, involved in the symbiosis? If so, how it is involved in the symbiosis? What is its role?
6. Is there a **facilitator** or **management body** in this symbiosis?
   - If there is a facilitator, who is the facilitator? Is it a platform, a private or public organization? According to you, what is the role of the facilitator, which are its competences and activities? Did its role or relevance change in the years?
   - If there is a management body, what organization is the management body? Is it a public or private organization? According to you, what is the role of the management body, which are its competences and activities? Did its role or relevance change in the years?
7. Which are the kind of **benefits** that you have from the symbiosis?
   - Focusing on the economic ones, are they mostly cost reduction or profit increase?

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[10] http://www.industrialsymbiosis.it/

- What are the environmental one? (Reduction of: CO_2e emission, water consumption, virgin raw material required input, fuel)
- Did the IS cause some social benefits like talent attraction, local community engagement, new job opportunities?

8. What do you think about the current normative on industrial symbiosis and circular economy? Would you like some normative changes? If yes, what changes would you like?
9. **For the companies that share infrastructure:** Were the shared infrastructure build especially for the symbiosis or symbiosis' relationships emerged thank to the presence of the infrastructure?
10. **For the management/coordinator actors only:** Your company is the management body/coordinator actor of the symbiosis/eco-industrial park, can you explain to us what is your role and how do you coordinate all the involved organizations?

Organizational culture and trust

1. Did joining the Industrial Symbiosis cause some organizational changes? Like organization chart, creation of a new business unit, need for new skill and employees?
2. How would you describe the relationships in the symbiosis? Did you face some challenges? Is trust an issue?
3. How do you communicate with the other actors of the symbiosis? About resource management, do you have a shared system/platform or do you use traditional methods?
4. Are the limited number of sector in the symbiosis a constraint or a strength of the symbiosis? Do you believe that a diversified symbiosis is more circular than one that involves only few sectors?

Digital Technologies

1. Which are the digital technologies implemented in the company?
2. Are there some digital solutions implemented specifically to support the circular economy and the Industrial Symbiosis (e.g. to favour data sharing with suppliers and customer, to optimize resource management)?
3. Which is the function performed by these digital technologies (I.e. why is the digital technology used)?
4. Where/for what is the digital technology used (e.g. to implement which technical cycle/in which product lifecycle stage)?
5. Focusing on the IS, how do you manage data in the symbiosis? Do you have a shared information System for the shared resources, or each company manage their data independently? What technical challenges did you face?

A.2. Productive sectors and ATECO Code table

The table below reports all the ATECO codes of the companies involved in cases of industrial symbiosis. All the ATECO codes are paired with a productive sector according to the definition of ISTAT.

Table A-1. 7.2. Productive sectors and ATECO Codes

Productive sector		**ATECO Codes**
A	Agriculture, Forestry And Fishing	• 01.11.2 <Coltivazione Di Semi Oleosi> • 01.11.10 <Coltivazione Di Cereali> • 01.13.30 <Coltivazione Di Barbabietola Da Zucchero> • 01.23.00 <Coltivazione Di Agrumi> • 01.26.00 <Coltivazione Di Frutti Oleosi> • 01.41 <allevamento Di Bovini Da Latte> • 01.47.0 <Allevamento Di Pollame> • 01.49.9 <Allevamento Di Altri Animali Nca> • 01.50.00 <Coltivazioni Agricole Associate All'allevamento Di Animali: Attività Mista> • 01.61.00 <Attività Di Supporto Alla Produzione Vegetale> • 01.50.00 <Coltivazioni Agricole Associate All'allevamento Di Animali: Attività Mista> • 02.1 <Silvicoltura Ed Altre Attività Forestali>
B	Mining And Quarrying	• 08.12.00 <Estrazione Di Pietre Ornamentali E Da Costruzione, Calcare, Pietra Da Gesso, Creta E Ardesia>
C	Manufacturing	• 10.2 <Lavorazione E Conservazione Di Pesce, Crostacei E Molluschi> • 10.32.00 <Produzione Di Succhi Di Frutta E Di Ortaggi> • 10.39 < Altra Lavorazione E Conservazione Di Frutta E Di Ortaggi> • 10.51.20 <Produzione Dei Derivati Del Latte> • 10.61.4 < Altre Lavora • zioni Di Semi E Granaglie> • 10.71.10 <Produzione Di Prodotti Di Panetteria Freschi> • 10.72 <Produzione Di Fette Biscottate E Di Biscotti; Produzione Di Prodotti Di Pasticceria Conservati> • 10.73 < Produzione Di Paste Alimentari, Di Cuscus E Di Prodotti Farinacei Simili> • 10.81.00<produzione Di Zucchero> • 10.91.00 <Produzione Di Mangimi Per L'alimentazione Degli Animali Da Allevamento> • 11.02 <Produzione Di Vini Da Uve> • 11.05.00 <Produzione Di Birra> • 12 <Industria Del Tabacco> • 13.20.00 <Tessitura> • 13.30.0 <Finissaggio Dei Tessili, Degli Articoli Di Vestiario E Attività Similari> • 13.92.10 <Confezionamento Di Biancheria Da Letto, Da Tavola E Per L'arredamento>

		• 14.13.1 <Confezione In Serie Di Abbigliamento Esterno> • 14.13.2 <Sartoria E Confezione Su Misura Di Abbigliamento Esterno> • 15.11.00 <Preparazione E Concia Del Cuoio E Pelle; Preparazione E Tintura Di Pellicce> • 16.1 <Taglio E Piallatura Del Legno> • 17.12.00 <Fabbricazione Di Carta E Cartone> • 19.20.1 <Raffinerie Di Petrolio> • 19.20.4 <Fabbricazione Di Emulsioni Di Bitume, Di Catrame E Di Leganti Per Uso Stradale> • 20.15.00 <Fabbricazione Di Fertilizzanti E Composti Azotati (Esclusa La Fabbricazione Di Compost)> • 20.16 <Fabbricazione Di Materie Plastiche In Forme Primarie> • 20.42 <Fabbricazione Di Profumi E Cosmetici> • 22.19.09 < Fabbricazione Di Altri Prodotti In Gomma Nca> • 20.13.09 <Fabbricazione Di Altri Prodotti Chimici Di Base Inorganici> • 20.42.00 <Fabbricazione Di Prodotti Per Toletta: Profumi, Cosmetici, Saponi E Simil> • 20.53 <Fabbricazione Di Oli Essenziali> • 22.23.01 <Fabbricazione Di Rivestimenti Elastici Per Pavimenti (Vinile, Linoleum Eccetera)> • 22.23.09 <Fabbricazione Di Altri Articoli In Plastica Per L'edilizia> • 23.42 <Fabbricazione Di Articoli Sanitari In Ceramica> • 23.51 <Produzione Di Cemento> • 23.52.2 <Produzione Di Gesso> • 23.61 <Fabbricazione Di Prodotti In Calcestruzzo Per L'edilizia> • 24.10.00 <Siderurgia - Fabbricazione Di Ferro, Acciaio E Ferroleghe> • 25.11 < Fabbricazione Di Strutture Metalliche E Di Parti Di Strutture> • 27.90.09 <fabbricazione Di Altre Apparecchiature Elettriche Nca> • 28.93 <Fabbricazione Di Macchine Per L'industria Alimentare, Delle Bevande E Del Tabacco> • 29.10.00 <Fabbricazione Di Autoveicoli> • 30.12.00 <Costruzione Di Imbarcazioni Da Diporto E Sportive>
D	Supply Of Electricity, Gas, Steam And Air Conditioning	• 33.3 <Fornitura Di Vapore E Aria Condizionata> • 35.11.00 <Produzione Di Energia Elettrica> • 35.14 <Commercio Di Energia Elettrica>
E	Water Supply; Sewerage, Waste Management And Sanitation Activities	• 36 <Raccolta, Trattamento E Fornitura Di Acqua> • 37 <Gestione Delle Reti Fognarie> • 38 <Attività Di Raccolta, Trattamento E Smaltimento Dei Rifiuti; Recupero Dei Materiali> • 38.11 < Raccolta Di Rifiuti Non Pericolosi>

		• 38.21.01 <Produzione Di Compost> • 38.21.09 <Trattamento E Smaltimento Di Altri Rifiuti Non Pericolo> • 38.32.30 <Recupero E Preparazione Per Il Riciclaggio Dei Rifiuti Solidi Urbani, Industriali E Biomassa> • 39.00.09 <Altre Attività Di Risanamento E Altri Servizi Di Gestione Dei Rifiuti>
F	Construction	• 41.2 <Costruzione Di Edifici Residenziali E Non Residenziali> • 43.1 <Demolizione E Preparazione Del Cantiere Edile> • 43.22.01 < Installazione Di Impianti Idraulici, Di Riscaldamento E Di Condizionamento Dell'aria (Inclusa Manutenzione E Riparazione) In Edifici O In Altre Opere Di Costruzione>
G	Wholesale And Retail Trade; Repair Of Motor Vehicles And Motorcycles	• 45.32.00 <Commercio Al Dettaglio Di Parti E Accessori Di Autoveicoli> • 46.38.9 <Commercio All'ingrosso Di Altri Prodotti Alimentari>
H	Transport And Storage	• 49.20.00 <Trasporto Ferroviario Di Merci> • 49.41 <Trasporto Di Merci Su Strada>
J	Information And Communication Services	• 62.01 <Produzione Di Software Non Connesso All'edizione>
M	Professional, Scientific And Technical Activities	• 71.12 <attività Degli Studi D'ingegneria Ed Altri Studi Tecnici> • 71.12.5 <Attività Di Studio Geologico E Di Prospezione Geognostica E Mineraria> • 72 <Ricerca Scientifica E Sviluppo> • 72.19.09 <Ricerca E Sviluppo Sperimentale Nel Campo Delle Altre Scienze Naturali E Dell'ingegneria> • 74.9 <Altre Attività Professionali, Scientifiche E Tecniche Nca> • 74.90.99 <Altre Attività Professionali Nca>
N	Rental, Travel Agencies, Business Support Services	• 77.4 <Concessione Dei Diritti Di Sfruttamento Di Proprietà Intellettuale E Prodotti Simili (Escluse Le Opere Protette Dal Copyright)> • 82.92.10 <Imballaggio E Confezionamento Di Generi Alimentari> • 82.99.99 <Altri Servizi Di Sostegno Alle Imprese Nca>
O	Public Administration And Defence; Compulsory Social Insurance	• 84.11.10 <Attività Degli Organi Legislativi Ed Esecutivi, Centrali E Locali; Amministrazione Finanziaria; Amministrazioni Regionali, Provinciali E Comunali>
P	Education	• 85.42.00 <Istruzione Universitaria E Post-universitaria>
S	Other Service Activities	• 94 <Attività Di Organizzazioni Associative> • 96.02.02 <Servizi Degli Istituti Di Bellezza>

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List of Abbreviations

APEA	Area Produttiva Ecologicamente Attrezzata
CE	Circular Economy
CFCs	Chlorofluorocarbons
EC	European Commission
EGD	European Green Deal
EIP	Eco Industrial Park
EOD	Earth Overshoot Day
ERP	Enterprise Resources Plan
EU	European Union
GDO	Grande Distribuzione Organizzata
HCFCs	Hydro Chlorofluorocarbons
IE	Industrial Ecology
IS	Industrial Symbiosis
LCA	Life Cycle Assessment
NISP	National Industrial Symbiosis Programme
PA	Public Administration
PLC	Programmable Logic Controller
PNRR	Piano Nazionale Di Ripresa E Resilienza
SD	Sustainable Development
SDGs	Sustainable Development Goals
SUN	Symbiosis Users Network
UN	United Nations

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