UNIVERSITAT POLITÈCNICA
DE CATALUNYA
BARCELONATECH

Final Project

Industrial Management Engineering

Comparative study of Industrial Symbiosis in Italy and Spain

Author of the Final Project: Lluc Fullana Puig

Supervisor(s): Andrea Raggi, Jordi Fortuny

Submitted on: October 2019

Abstract

This project consists in the identification, explanation and comparison of Industrial Symbiosis (IS) cases both in Italy and in Spain. It was developed conducting a systematic literature review (SLR) of scientific papers related to IS cases. The results showed that Italy is a country with many industrial parks that could potentially develop as eco-industrial parks (EIPs) applying industrial symbiosis amongst the companies inside the parks. On the other hand, Spain is a lesser industrialised country with industries agglomerated in coastal communities such as Catalonia or Cantabria, and with less literature about Industrial Symbiosis examples.

All IS cases described in the project are compared through parameters such as networking, local stakeholders' investment, typology of area (planned, self-organised or facilitated), scope (local, regional or national/international), number of IS exchanges, sectors involved in the symbiotic exchanges, etc.

Moreover, a new nomenclature of symbiotic exchanges is proposed, linking individual industrial symbiotic relations to names from natural symbiotic relations which exist amongst living creatures. This classification can be upgraded in future studies.

Resum

Aquest projecte consisteix en la identificació, explicació i comparació de casos de simbiosi industrial (IS) tan d'Itàlia com d'Espanya. El projecte es va desenvolupar portant a terme una cerca sistemàtica de literatura (SLR) d'articles científics sobre casos d'IS. Els resultats diuen que Itàlia és un país amb molts parcs industrials que podrien desenvolupar-se com a parcs eco-industrials (EIPs) aplicant la simbiosi industrial entre les empreses dins dels parcs. Per altra banda, Espanya és un país menys industrialitzat, amb la indústria aglomerada en comunitats costals com ara Catalunya o Cantàbria, i amb menys literatura sobre exemples de Simbiosi Industrial.

Tots els casos d'IS descrits en el projecte es comparen a través de paràmetres com ara treball en xarxa, la presència d'inversors locals, la tipologia del parc (planificat, auto-organitzat o facilitat), abast (local, regional o nacional/internacional), nombre d'intercanvis simbiòtics, sectors involucrats en els intercanvis, etc.

Per últim, es proposa una nova nomenclatura d'intercanvis simbiòtics, relacionant intercanvis aïllats amb noms de relacions simbiòtiques presents entre éssers vius en la natura. Aquesta classificació es pot ampliar en estudis futurs.

Table of contents

List of Tables

List of figures

1. Introduction

1.1. Justification and concept definition

The concern regarding environmental issues such as air pollution, water pollution, global warming and so on, has become one of the most important and controversial topics worldwide. Moreover, the optimization of resources and energy consumption is also of paramount importance. These are the reasons why there have been more and more measures to try and reduce waste, pollution and consumption. One of the tools that effectively helps to achieve these objectives is Industrial Symbiosis.

It should be noted that Industrial Symbiosis is a branch of Industrial Ecology, and so, the definition of Industrial Ecology is important as well. Industrial Ecology aims to understand how industrial systems work, how they are regulated and how they interact with the biosphere; afterwards, based on this study, the idea is to determine how they could be restructured in order to make them compatible with natural ecosystems' functioning (Erkman, 2002).

Another approach to the definition of Industrial Ecology is "*the study of the flows of materials and energy in industrial and consumer activities, of the effect of these flows on the environment, and of the influence of economic, political, regulatory and social factors on the flow, use and transformation of resources*" (White, as cited in Schiller et al., 2014, page 1).

Before explaining Industrial Symbiosis, it is important to know what symbiosis means. Symbiosis, which derives from Greek "living together", consists in the natural relationship between individuals from different species, that can also be part of different reigns. This relationship is often needed for the survival of both species. An example can be the symbiotic relation between the clownfish and the sea anemone, in which the former protects the anemone from other fishes that would eat it and the anemone provides shelter for the clownfish against its predators (Wikipedia, 2019).

Based on the natural symbiosis, Industrial Symbiosis (IS) consists in the placement of a plurality of industries in a reduced space, working as a complex. This complex has the aim to optimize resources and energy in order to improve both economical and environmental performances (Jacobsen, 2006). The idea of Industrial Symbiosis is that a reduction of economic input usually links to a reduced environmental impact.

There exist various definitions of Industrial Symbiosis (IS), one of which was given by Chertow (2004): “Industrial Symbiosis engages traditionally separate industries in a collective approach to competitive advantage involving physical exchanges of materials, energy, water and/or by-products. The keys to industrial symbiosis are collaboration and synergistic possibilities offered by geographical proximity”.

The principles of Industrial Ecology and Industrial Symbiosis (IS) state that the transition of waste output from one facility into raw material into another one will generate environmental benefits due to a reduction of the input material and the cut of emissions (Jacobsen, 2006), which, at the same time, will normally develop into economic savings.

There is an evolution of the term Industrial Symbiosis, often referred to with other names. The first approaches to this concept were industrial eco-parks and islands of sustainability. They were born from the idea of creating “industrial biocenoses” around certain specific industries. These clusters would have minimal emissions, due to the exchanging of materials web amongst the industries included in them (Erkman, 2002).

This idea of geographical proximity can also go beyond just industrial eco-parks, and extend the web of exchanges to a higher scale. There exist three main types of IS, which will be shortly explained on the lines below (Domenech et al., 2019).

- Self-organised networks: they operate in a local level or at the industrial estate level. They are linked to clusters of manufacturing activities, often with the primary sector involved. They are business-as-usual transactions in countries with high-developed environmental awareness, with stricter regulations. They can also be operated by private actors with the local government support.
- Facilitated networks: these have a third party which coordinates the activity of the cluster. Thus, there is a firm or organisation which manages all the relationships inside the cluster for its better functioning.
- Planned networks: they result from a central vision. These are located in a specific industrial area and include shared infrastructures and services.

There is another classification, which divides the types of IS into local, regional and national/international IS webs (Domenech et al., 2019).

- Local cases of IS are an aggrupation of firms which are located within the proximity of a city, at most; resulting on their relations to be very direct and easy.
- Regional cases are IS cases that can have firms not necessarily located on the same city but on the same region. These are not as direct as the local ones but they are also very close and the transport of energy, waste or by-products is regulated by the same laws and rules.
- National and international cases are the ones which transport of goods is more complicated, because there is not much proximity among firms, meaning transport is long and more expensive. Despite this they are still viable, because otherwise, they would not be included as IS type.

1.2. The case of Kalundborg

One of the most well known cases of Industrial Symbiosis is in Kalundborg, Denmark, as it is often used as a role model of IS, as the main example to explain IS to an educational level. It is also curious to point out that the Kalundborg complex is a self-organised network, it was not created on purpose, like other IS cases. The case of Kalundborg (*Figure 1.1*) is based on a number of companies which are locked into a web of material and energy residues exchanged, all under a contract of dependency (Jacobsen, 2006). The focus of the Kalundborg complex is on the water- and steam-related IS exchanges (although not only on these), which also transcend to economic and environmental implications.

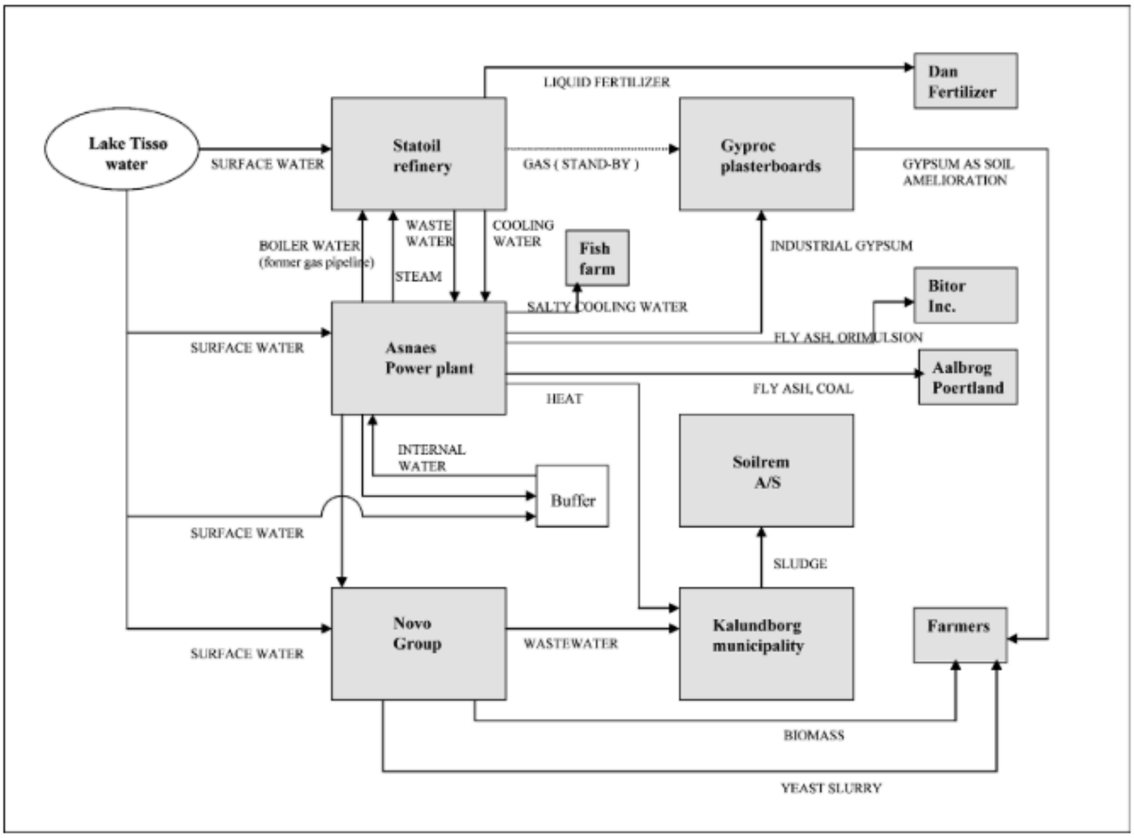

Figure 1.1. Kalundborg exchanges network. (Source: Jacobsen, 2006).

There are approximately 20 different by-product exchanges and a number of potential projects among the companies located in Kalundborg, which are based on water, solid waste or energy exchanges. As seen in *Figure 1.1*, there are several fluxes (Jacobsen, 2006):

- Wastewater and cooling water from the refinery are reused at the power plant. Wastewater is for secondary purposes and cooling water as feeder water for the boiler producing steam and electricity and as input water for the desulphurization process.
- The desulphurization process produces industrial gypsum which is used in producing plasterboard at the Gyproc factory, replacing the use of natural gypsum.
- The cogenerating plant produces heat for the town of Kalundborg and steam for the Novo facility and the Statoil refinery. The Novo facility is supplied with steam which only comes from the power plant; the refinery has steam produced thanks to pre-heated boiler water from the power plant in a total-supply-security system.
- Heated cooling water from the condensation process in the power plant is piped off to a fish farm nearby, increasing its efficiency, as the heated water ensures full production of the fish throughout all year.
- Solid by-products such as sludge from wastewater treatment, biomass from biogenetic fermentation or ash from coal combustion are recycled in many ways, both locally and elsewhere.

This was a simplified explanation of some of the different by-product, energy and waste exchanges that exist inside the Kalundborg IS cluster, from which we can easily extract the basics of Industrial Symbiosis. As it has such a clear web between the different plants, it is also notable why it is used as the main example to explain the IS concept at an academic level.

1.3. Objectives of the project

The issue of climate change is of high importance and the project developer is interested in industrial symbiosis. Also, he was living in Italy and he is originally from Spain, so these are the reasons why he decided to go on with this project.

The main objectives of this project are:

a. Learn about the existence and functioning of industrial symbiosis cases in Spain.
b. Learn about the existence and functioning of industrial symbiosis cases in Italy.
c. Compare the industrial symbiosis cases in Spain and Italy.
d. Develop a classification proposal of the different industrial symbiotic exchanges found, naming them after their natural cases equivalents.

To achieve these objectives the following tasks will be carried out:

a. Definition of the concepts of industrial symbiosis and industrial ecology as an introduction of the project.
b. Search and review of scientific papers related to industrial symbiosis examples in Spain and Italy.
c. Summarizing the objectives of these papers as well as the methodology used and the implementation level, identifying real examples of resource exchange between companies.
d. Comparison among these real case studies and what we can deduce from them.
e. Identifying different types of symbiotic relationships and propose a new classification. Naming the different IS types after similar behaviours found in natural ecosystems.

This project counts with some limitations as well:

a. The time to carry out the review project is limited.
b. The researcher will gather information from the online database service of three different universities, but has limited expertise in the field and has to rely fully on this information.

2. Methodology

A Systematic Literature Review (SLR) was carried out in order to retrieve scientific papers related to Industrial Symbiosis. DiscoveryUPC was the meta search engine used to explore the documents available to the library of the Universitat Politècnica de Catalunya (UPC) and several subscription databases. The searching criteria consisted in keywords which relate to the subject of this project.

After the search with keywords, a great number of scientific papers were found. These documents were then sorted as only on-line articles, as they are easier to access on PDF format. Moreover, all articles found were sorted to be only in English as well. In order to identify the ones useful for the project, the project developer read the title and abstract of the articles that were about the subject. After checking this, the project developer would download the documents and later on proceed to review them.

Table 2.1 shows the key words used in each search and the number of documents found that resulted useful for the project.

Table 2.1. Number of profitable documents found in the library database service.

Key words	Results	Observations
Industrial Ecology	53.215	2 papers used for the definition of the concept
Industrial Symbiosis	4.244	2 papers used for the definition and classification of the concept
Kalundborg Symbiosis	81	2 papers used to describe the Kalundborg case
Industrial Symbiosis Italy	97	20 useful articles
Industrial Symbiosis Spain	57	8 useful articles

- "Industrial Ecology" (53.215 articles): with the search of these keywords there were too many articles found, as this concept is not only antique but also very generic.

The project developer only needed to briefly define industrial ecology, so he used just two of the articles (See section 1.1), (Erkman, 2002; Schiller et al., 2014).

- "Industrial Symbiosis" (4.244 articles): with the search of these keywords, there were many articles found. The project developer only needed the results of this search to define industrial symbiosis and classify its types. The articles found included information not directly related to the end-of-degree project: for example about methodology (combination of industrial symbiosis with other environmental tools), market design, case studies (in China, Colombia, Korea, etc.), education, governance, etc. The main journals were: Journal of Cleaner Production, Sustainability, Resource Conservation & Recycling and Education for Chemical Engineers, amongst others. From this search it can be seen that the subject is up to date, since many articles are from recent years.
- "Kalundborg AND Symbiosis" (81 articles): the case of Kalundborg is known as the most relevant IS case and it was worth explaining. The first articles go back to 1999 while there are two papers dated on 2019. Only one document was used in section 1.2 (Jacobsen, 2006).
- "Industrial symbiosis AND Italy" (97 articles): a lot of them are not directly linked to this project. They talk about: methodology (15), governance (4), design (3), LCA (9), natural symbiosis (7), waste valorisation (6), regulation and other factors (5), etc. There are 20 articles of interest whose abstracts were read and analysed. These articles of interest were classified in two types: the ones describing district cases and the ones describing individual symbiotic relations. These papers are summarised and discussed in the following sections.
- "Industrial symbiosis AND Spain" (57 articles): from all articles, only 8 were addressing subjects related to this project. Other articles are addressing similar topics to the Italian ones: methodology (9), design (3), waste treatment (5), natural symbiosis (5), LCA (3), challenges and governance (3), etc. The 8 papers of interest can be classified as regional examples and individual symbiotic relations.

It should be noted that the majority of documents found are published in the *Journal of Cleaner Production.* That said, there are documents belonging to other scientific journals such as *Resources, Conservation and Recycling* or *Sustainability*.

In addition to the scientific papers found by the SLR in the UPC database, a Google search was carried out in order to look for other Italian and Spanish industrial symbiosis cases, which did not result much profitable.

In order to compare the different industrial districts between Italy and Spain the following aspects have been taken into account:

- Implementation degree
- Scope of the area (local, regional or national/international)
- Type of area (self-organised, facilitated or planned networks)
- Number and type of sectors present in the area
- Number of symbiotic sharing described
- Etc.

In the case of the individual symbiotic relations, observations have been made to determine the kind of process needed to transform waste into resource. A new nomenclature defined by type of symbiotic exchange is proposed. This classification depends on the complexity of the process needed. Each type of IS exchange is named after its similarity with a natural symbiotic relation. No classifications by type of IS exchange in the literature have been found so far.

The structure of the project from here forth includes the study of Italian industrial symbiosis cases, followed by the study of Spanish industrial symbiosis cases and a comparison amongst all cases so far. After, there is a chapter dedicated to study individual industrial symbiotic relations and their classification by types, which then are identified with biological symbiosis cases found in natural situations. Last, there are the conclusions of the project and the references to articles used.

3. Industrial Symbiosis in Italy

According to Daddi et al. (2015) there were 84 approaches to EIP in Italy (data from 2010), which were located in only 5 of the 20 regions in the country (Emilia-Romagna, Friuli-Venezia Giulia, Liguria, Marche, Piedmont and Tuscany). Of all 84 cases, only 14 had the characteristics of a favourable EIP. From these cases only some have been explained in this project, due to the lack of information from the others. From 2010 to this day, there have also emerged new EIP studies in the literature, which are explained on this chapter.

Table 3.1 names each industrial district (studied in this project) from Italy, with its reference (where the information was found) and a few comments about them. With this table, the reader can have a general idea of how many cases are there and how they are.

Table 3.1. Italian industrial districts, with reference on sources of information and main explanations.

Industrial districts	Reference	Observations
Taranto (Puglia)	(Notarnicola et al., 2016)	Industrial park with few symbiotic relations but with a good potential of IS-based management.
Porto Marghera (Veneto)	(Mannino et al., 2015)	Industrial park that had a basic eco-industrial management with immature industrial symbiosis.
Pescara, Chieti, L'Aquila (Abruzzo)	(Taddeo et al., 2012) (Simboli et al., 2014) (Simboli et al., 2015) (Taddeo et al., 2017)	Three industrial clusters with potential symbiotic relations from the Abruzzo region located in three different areas: Pescara (chemical cluster), Chieti (automotive cluster) and L'Aquila (agri-food cluster).

Sicily (Sicilia)	(Cutaia, 2015) (Luciano et al., 2016)	The Sicilian IS activity includes a great number of sectors (manufacturing, scientific and technical, agriculture, etc.) especially located in the provinces of Syracuse and Catania.
Brescia (Lombardy)	(Marchi et al., 2017)	The main companies in the Brescia productive district include energy, environment and heat, steelmakers, cement production, solid waste and biomass treatment, wood production, etc.
Prato (Tuscany)	(Daddi et al., 2015)	There exist at least two EIPs in Tuscany: one dedicated to the textile sector (Macrolotto di Prato), and another is a tannery cluster. Both have centralised environmental services.
Ponterosso (Friuli-Venezia Giulia)	(Daddi et al., 2015)	The industrial park is composed by companies from a variety of industrial sectors, including chemistry, food production, glass machinery and producing components.
Padova (Veneto)	(Daddi et al., 2015)	One of the biggest industrial areas in Italy, managed by a consortium, served by a railway, post offices, restaurants, hotels, banks, business services, etc. It also has extensive green areas.
Ancona (Marche)	(Daddi et al., 2015)	Industrial area in the port of Ancona, operating in maritime activities such as mechanical repairs, shipbuilding, electrical systems, logistics, etc.

3.1. Taranto industrial district

The Taranto Industrial district is a park of heavy industries such as steelworks, oil refinery, cement industry and power stations, which have a consumption of 182.4 Petajoules per year (PJ/year) of energy. The complex is not symbiosis based but there is a study which was carried out in order to see which symbiotic relations these industries would most benefit from (Notarnicola et al., 2016). This study also quantified recycling of inefficient use and disposal of energy, material and by-products, among which are steelworks slag, mill scale, spent refractories and coal fly ash. Even with the existence of such opportunity, industrial symbiosis is still implemented at a really basic level due to some restrictions.

The productive district is formed by the Ilva integrated steelworks (the largest of its kind in Europe), a crude oil refinery, one of the largest naval ports in Italy, three power plants, a cement factory and a large beer factory, amongst others.

Since 1990, the district was declared an area of high risk of environmental crisis due to the alterations of the ground, water and air surrounding the district, resulting in environmental and health risks for locals.

3.1.1. Most relevant firms included in the district and its location

The relevant industries in the district were glimpsed in the last paragraphs, and are graphically presented in *Figure 3.1*.

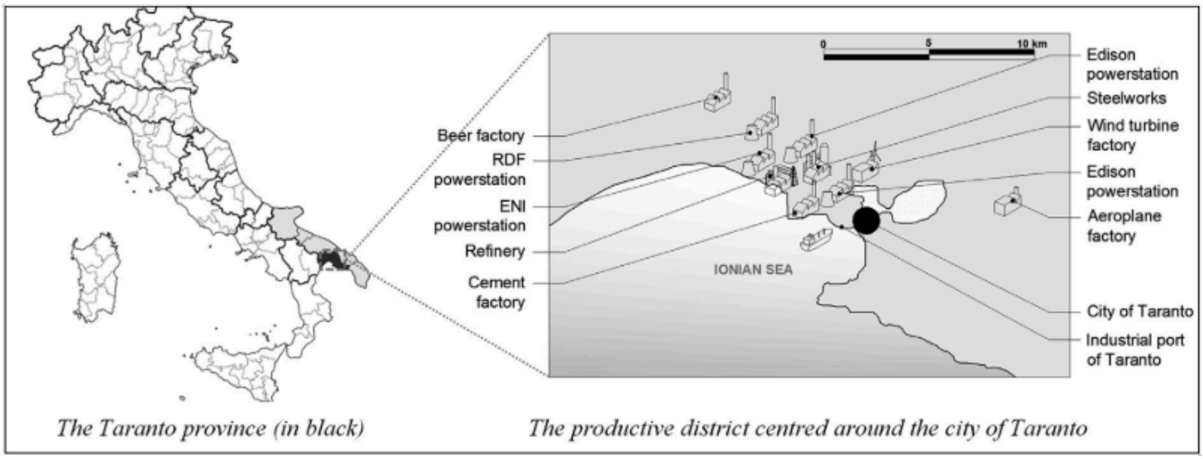

Figure 3.1. Location of the most important firms of the Taranto industrial district. (Source: Notarnicola et al., 2016).

In *Table 3.2* the main production characteristics of each industrial firm are listed.

Table 3.2. Main characteristics of the Taranto district industrial firms regarding production. (Source: Notarnicola et al., 2016).

Name of industrial firm	**Main production characteristics**
Steelworks (Ilva)	Production capacity of 11.5 Megatons per year (Mt/year)
Edison power stations (Combined heat and power plants CET2 and CET3)	Total electric power of 1065 Megawatts (MW)
Cement factory (Cementir)	Production capacity of 900 kilotons per year (kt/year)
Refinery (Eni)	Production capacity of 6.5 Mt/year of refined crude oil
Power station (Eni)	Total electric power of 87 MW
Industrial port of Taranto	Military, commercial and industrial ports
Beer factory (Heineken)	Production capacity of 200 million litres of beer/year
Wind turbine factory (Vestas)	Production of wind turbines, management of wind power farms in Puglia, the Balkan area and North Africa
Power station (RDF Appia Energy)	Management of waste to create refuse derived fuel for electricity generation, a 12.5 MW power station
Aeroplane factory (Alenia Composite)	Production of parts of the fuselage of the Boeing 787 Dreamliner

3.1.2. Material analysis

There is a yearly production of 3.17 Mt of material waste in the province of Taranto and a total recovery or disposal of 3.99 Mt, which means there is over 830 kt of waste originated outside the province that is managed inside of it.

In the management that nowadays is present in the district, there are activities used to dispose of the waste such as landfilling, composting, stocking for future recovery and spreading on the ground. These activities could be replaced by others that commit better into efficiently recycling waste.

Table 3.3 reports the main material waste produced and managed in the district; together with its origin, quantity and current management.

Table 3.3. Main material waste produced and managed in the industrial district of Taranto. (Source: Notarnicola et al., 2016).

Main material waste produced or managed in the district.

Waste type	Quantity (t/year)	Origin	Management
Untreated blast furnace slag	1.5 Mt	Steelworks Ilva	Only 15% of this is used by the local cement factories, the rest is shipped to South America
Untreated basic oxygen furnace slag	1.5 Mt	Steelworks Ilva	All used for land filling within the steelworks site
Refractory and other coating materials from metallurgy	87 kt	Mostly produced by the steelworks Ilva	Principally disposed off in landfill site
Mill scale	70 kt	Steelworks Ilva	5 kt used by local cement factory, the rest is shipped to China and Israel
Coal fly ash	38 kt	Imported from outside the province	Used within the province for cement production and in construction materials industry
Leachate	14 kt	From landfill site	Disposed in specific landfill site
Sludge from water filtration processes	57 kt	Produced by various firms	Disposed in landfill site

As can be seen in *Table 3.3*, there is a great amount of waste that is currently being shipped out to different countries or disposed of in landfills. Below, there is a study of the potential changes regarding this waste in an IS-based waste management (chapter 3.1.5. New possible symbiotic interactions).

3.1.3. Energy analysis

A study of the energy management was also carried out, along with the materials analysis, with the intention of finding possible IS interactions amongst the industries in the district (Notarnicola et al., 2016). All data needed was extracted from Regional Energy Plans, Regional Energy Balance reports drafted by ENEA (national state agency), data from TERNA (company responsible for the national electricity grid) and data obtained from the main firms of the district themselves.

Overall, 87% of the total energy consumption in the industrial park is by the industrial sector, whilst the remaining part is consumed by the tertiary, residential, transport and agriculture sectors. The consumption of the industrial sector equals 182.4 PJ/year, of which 68% is used by the steelworks, 11% by the oil refinery and 1.4% by the cement plant.

The cooling water or exhaust gases energy waste is 44.6 PJ/year, derived from the power stations located near the steelworks factory and the refinery; also derived from the cooling losses of the steelworks and the refining losses of the refinery. A huge 88% of the amount is from the power stations near the steelworks. This massive amount of energy waste could be usefully recovered and recycled.

3.1.4. Current level of IS

As the study was being carried out, there were already existing symbiotic relations that had been created spontaneously.

The main relations occur between the steelworks and the metal scraps collection around the province, which are then used in the steelworks factory.

There are also symbiotic relations on secondary industries (winemaking industries), which have environmental efficiency activities such as the production of spirits made from marc and dregs (wastes from winemaking). In addition, agricultural companies use olive oil mill wastewater as fertiliser.

The previous are only some of the current cases of relations amongst the industries. *Figure 3.2* fully illustrates all the existing relations:

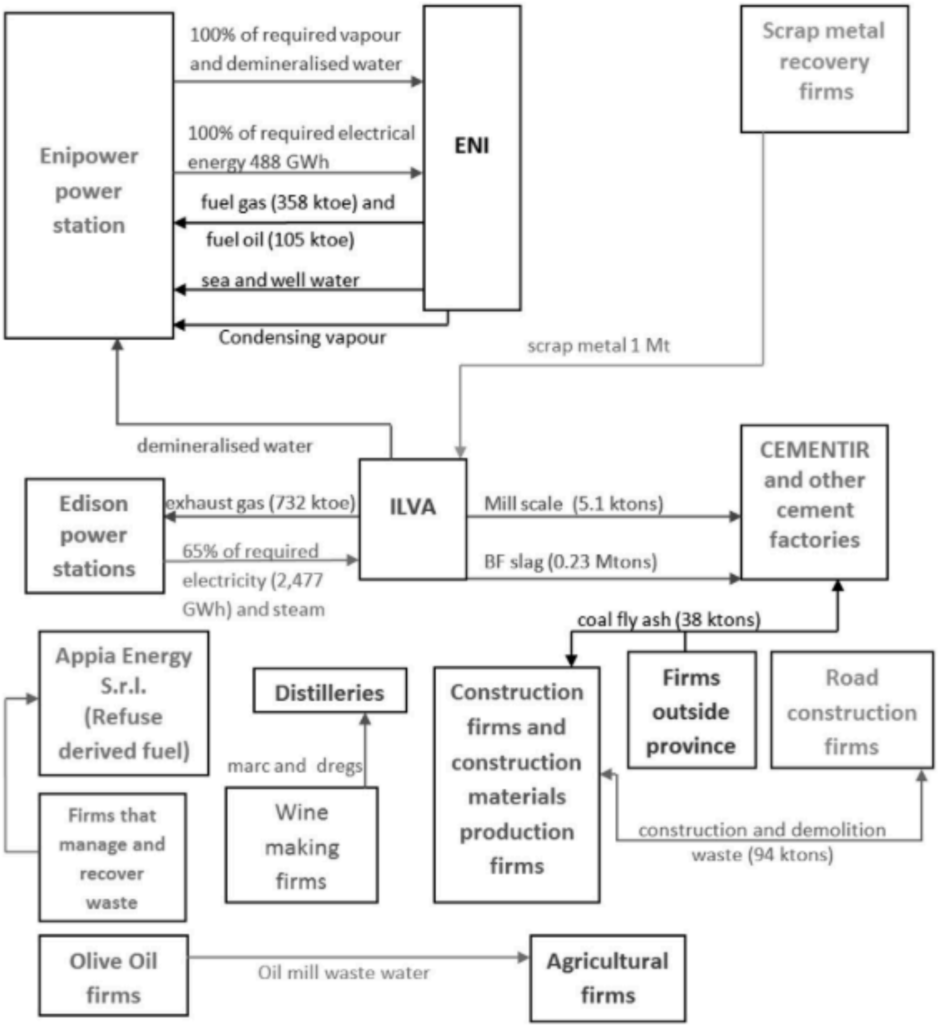

Figure 3.2. Existing relations between the district industries. (Source: Notarnicola et al., 2016).

3.1.5. New possible symbiotic interactions

As seen in the paragraphs above, there exist some symbiotic interactions amongst the industries in the district; however, at the bottom of *Figure 3.3*, one can see the total loss of transformation and cooling activities, which is huge.

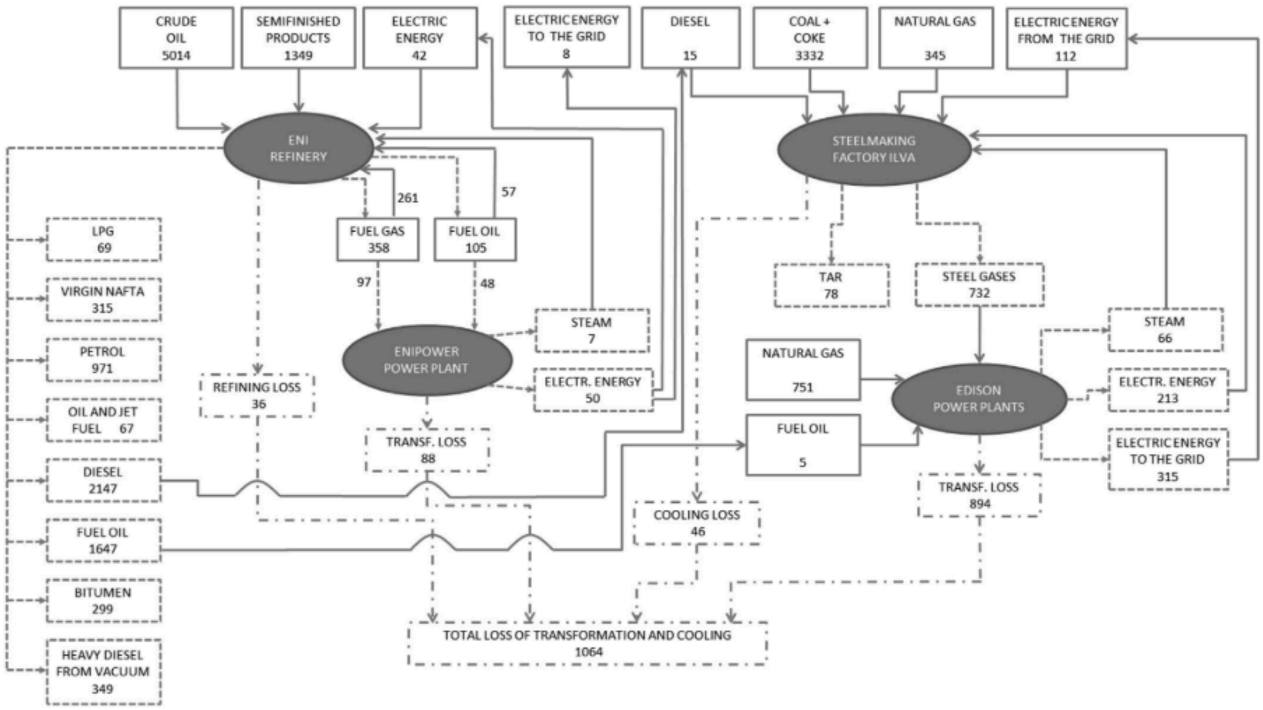

Figure 3.3. Heat loss (in ktoe) during transformation, refining and cooling activities. (Sources: ILVA steelworks, ENI refinery and Edison power plant Environmental Reports).

The following is a series of alternate uses for the waste energy (44.55 PJ/year) and the material waste and by-products (3,25 Mt).

- **Blast furnace and basic oxygen furnace slag**

The main slag types derived from the steelworks are blast furnace slag (BFS) and basic oxygen furnace slag (BOFS), they add up to 3 million tons of potentially recyclable by-product. Just about 15% of the BFS is reutilised in cement production, the rest is shipped to South America, while all the BOFS is being landfilled.

There are several new potential uses for both BFS and BOFS. Uses for BFS include: foundation material for road and railway construction, lightweight marine embankments, water treatment and glass manufacture. Uses for BOFS include: fertiliser, concrete aggregate and road paving.

- **Mill scale**

Also coming from the steelworks, it could potentially be used in the production of pellets and briquettes for other steelworks or electric arc furnaces. It can be used to produce magnetic ferrite spinel, which is used to produce magnets. It can potentially be used also in the improvement plans for the rail infrastructure of the region.

There are some other minor uses for mill scale such as the addition to casting sands in order to avoid porosity defect formation and the production of pigments for paints, plastics, cosmetics and cements, also glass making.

- **Refractories**

The yearly residue of refractory adds up to 78 kt. As it was implemented in a Japanese steelworks company, the ILVA steelworks could replace their refractory landfilling activity to a recycling one, turning refractories into roadbed material, slag conditioners or recycling the 20% of the waste into producing new refractory material. There could be a potential recycling of such waste in order to produce 380 kt of new refractory per year.

- **Fly ash**

The province is currently importing 38 kt of fly ash per year from a coal thermal power plant in the neighbouring region. It is mainly used for cement and concrete production. Assuming an additional import of 38 kt per year, all the fly ash could be used in the production of fly ash bricks.

There is also another use of fly ash in glass-ceramic products. If it were recycled for this purpose, it could be recycled in full on the six glass producing factories or in the ceramic district inside the region.

Fly ash can also be used in the structural quality of soil, on road engineering (up to 200 kg per square metre). Last, it can also be used as a soil fertiliser due to its high concentration of useful elements such as K, Na, Zn, Fe, Ca and Mg.

- **Waste energy**

As seen in previous paragraphs, there is an amount of over 1000 ktoe of thermal energy loss every year inside the district, which has a great potential of recovery and reutilisation.

One way to recover some of this energy could be in heating, recovering industrial heated wastewater and transfer it via a piping system to deliver hot water for domestic use or also in industrial buildings inside the district.

Another way of recovery of this thermal energy could be the production of electricity from low temperature heat, with an Organic Rankine Cycle (OCR). The energy recovered could be used in all the energy intensive industries in the province, such as glass, ceramic, oil refining factories and incinerators, hence reducing the use of fossil fuels and, in doing so, respectively reducing contribution to global warming.

3.1.6. Advantages accomplished by the implementation of the project

Table 3.4 illustrates and quantifies all the disposal costs avoided and the quantity of materials and energy recycled by the implementation of the measures mentioned in the paragraphs above.

Table 3.4. Data on the most significant quantifiable potential material waste recycling in the Taranto province. (Source: page 141 Table 5, Notarnicola et al., 2016).

Waste type	Potential type of recycling implementable in existing provincial context	Quantity of potential recycled waste (kt/year)	Total potential waste recycling/total available waste (kt/year)	% Potential recycling	Potential avoided disposal costs (M€/year)	Potential avoided energy use (toe/year)	Potential avoided GHG emissions (tons CO_2eq/year)
BFS	Foundation material for road and railway construction	890	1165/1275	91%	This is a by-product which is not disposed	7368	16,310
	Lightweight marine embankments	270					
	Water treatment	4					
	Glass manufacture	1					
BOFS	Fertiliser	930	1420/1500	95%	113.6	8981	19,880
	Concrete aggregate	400					
	Road paving	90					
Spent Refractories	Foundation material for road construction	78	156/78	>100%	9.4	493	1092
	Production of new refractories	78					
Fly Ash	Foundation material for road construction	38	152/38	>100%	7.6	240	532
	Fertiliser	38					
	Structural improvement of soil quality	38					
	Glass/glass-ceramics	38					

3.2. Eco-industrial development in Porto Marghera

The eco-industrial park in Porto Marghera, Venice, is a centre of chemical industry activity in Italy. It has been facing a decline in its development during the last 15 years due to both endogenous and exogenous factors (Mannino et al., 2015). The former are based on the siting and decisions made in the inside of the park, while the latter cannot be managed from the inside and are linked to regional and global issues affecting the park.

The eco-industrial park was created without an intent on industrial symbiosis, but its development changed so. This fact makes the industrial park in Porto Marghera a self-organised network, like the industrial park in Kalundborg.

Porto Marghera park was created in 1965 with a total of 229 companies. Last data from 2011 says there worked 690 companies. It was first mainly composed by industries such as: food; water, gas and energy; ceramic, glass and construction; chemical industry; mechanics; metallurgy, iron and steel industry and oil (Mannino et al., 2015). In 2011, the quantity of firms from these industries had dropped to half and other industries (especially on the logistics and commercial sectors) represented over 90% of the total companies in the industrial area.

3.2.1. Most relevant industries and lost symbiotic relations

Between 2004 and 2012 there have been many important companies that have been shut down due to the factors mentioned above, though mostly because of the implementation of a new environmental law (Article 17 of Legislative Decree n.22/1997, and also Article 9 of Ministerial Decree n.471/1999), which made companies responsible of pollution and contamination take full charge of the cost of removal (Mannino et al., 2015). Some of the most polluting industries had already been shut down, so the cost was even greater; that is why the park continued its decline.

Figure 3.4 represents the most relevant companies of the park and the main symbiotic relations existing in 2004 and *Figure 3.5* represents the ones in 2012. As can be seen in *Figure 3.5*, the main symbiotic relations had to be removed as a result of the Syndial chemical plant being shut down.

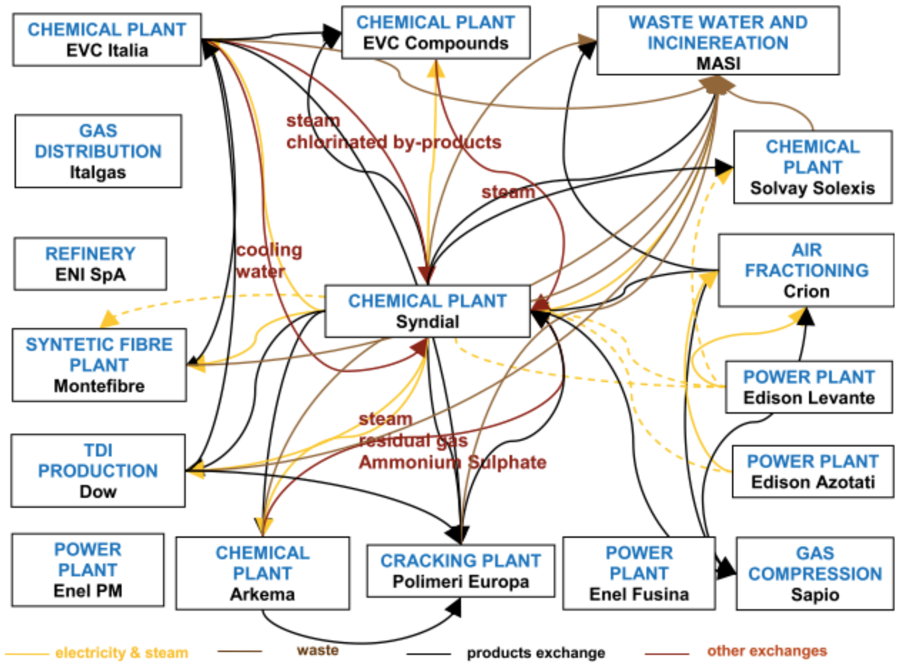

Figure 3.4. Main companies in Porto Marghera eco-industrial park in 2004 and its energy, waste and products exchange. (Source: Mannino et al., 2015).

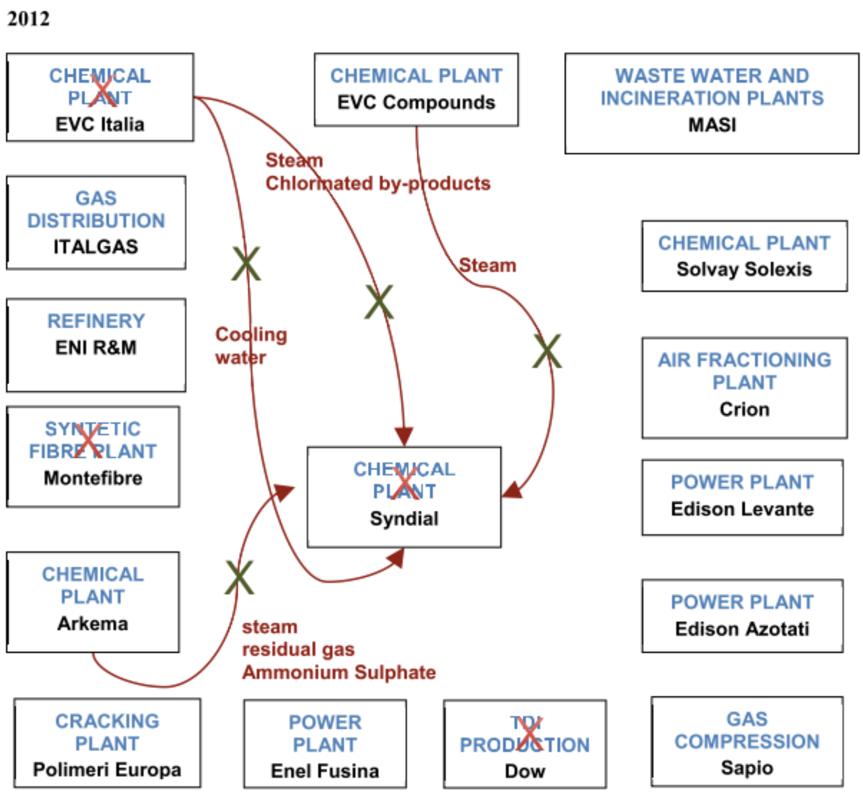

Figure 3.5. Main companies in Porto Marghera eco-industrial park in 2012 and the companies and exchanges shut down. (Source: Mannino et al., 2015).

3.2.2. Material and energy analysis

During Porto Marghera eco-park's best moment regarding industrial symbiosis, around 2004, the complex was a basic industrial ecosystem, but still immature. Amongst the main product exchanges, there were by-product exchanges of steam, cooling water, hydrogen and chlorinated substances (Mannino et al., 2015).

Some of the exchanges can be seen in *Figure 3.5*. Chlorinated substances were moved from the ECV Italia chemical plant to the Syndial chemical plant. Steam was a by-product in many chemical processes (in ECV, Arkema…) and also from electricity generation; it was used firstly to satisfy internal needs and the surplus was used by Syndial (Mannino et al., 2015). Arkema and Syndial exchanged residual gas (Ammonium Sulphate), while Syndial, Polimeri Europa and ECV Italia supplied hydrogen to Sapio and to ENEL Fusina.

Although these exchanges were real, they lacked the pursuit of environmental goals, as they were incidentally made just to reduce costs under a normal business scenario.

3.2.3. Future of Porto Marghera Eco-Industrial Park

As explained above, the industrial park of Porto Marghera suffered a decline over the past fifteen years. It has been due to the main chemical firms getting shut down: because of new managements, new laws or as a result of other firms stopping their activity (Mannino et al., 2015).

The situation of the park is now unstable and the possibility of new symbiotic relations seems far. The existing firms are not prepared for new IS relations and the fact that new multinationals and other big firms decide to build new industries in the park is rather unlikely (Mannino et al., 2015). Furthermore, the citizens' opinion on the chemical industry occupying Porto Marghera is a negative one, derived from past events.

Although there are no near future projects for reintroduction of IS based relations in Porto Marghera, the area is capable of being an IS park with proper reforms and investments.

3.3. Abruzzo industrial symbiosis project

There exist three different industrial clusters in the Italian region of Abruzzo which have been case studies in a project. The aim of that project is to analyse the factors that can favour or inhibit the realisation of an EIP (Taddeo et al., 2017).

The three industrial clusters operate in the chemical, automotive and agri-food industries and they are located (see *Figure* 3.6) in different provinces in the Abruzzo region: Pescara (chemical context), Chieti (automotive context) and L'Aquila (agri-food context).

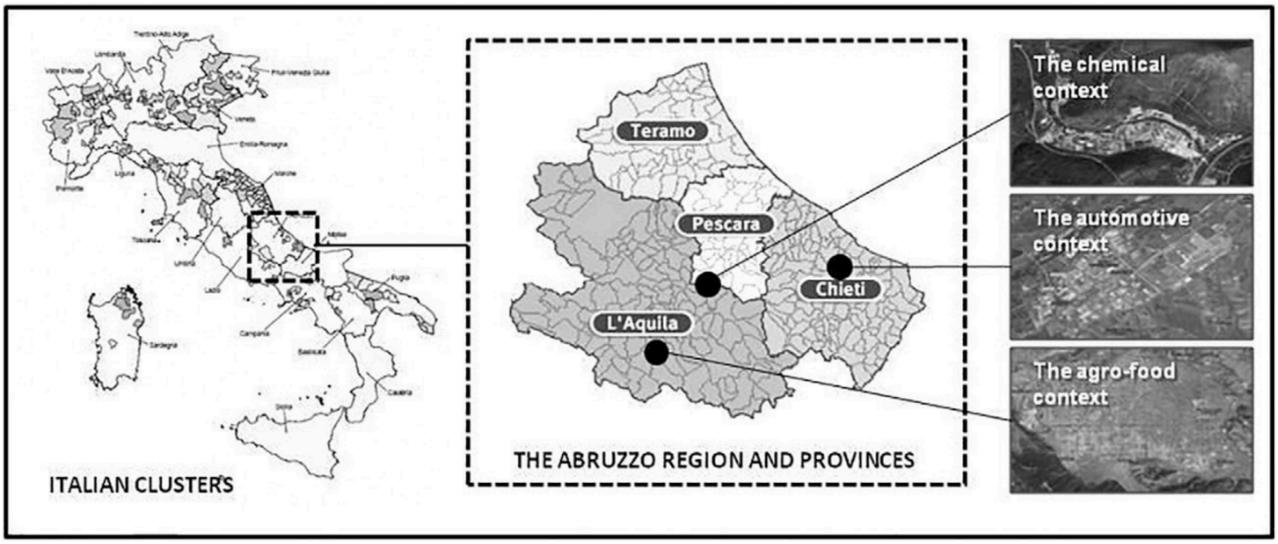

Figure 3.6. Location and identification of each industrial cluster in the Abruzzo region. (Source: page 57, Figure 1, Taddeo et al., 2017).

3.3.1. Introduction of the three clusters

Each of the clusters introduced above has different characteristics, the main of which are listed in *Table 3.5*.

Table 3.5. Most relevant features of the three industrial clusters in Abruzzo.(Source: Taddeo et al., 2017).

	Chemical Cluster	Automotive Cluster	Agri-food Cluster
Sector involved	Chemical	Automotive	Agri-food
Location	Pescara	Chieti	L'Aquila
Extension of the cluster	5 km	15 km	20 km
Number of companies	5	More than100	Around 330
Size of companies	Medium and large companies	Large and small companies	Small and medium companies
Processes detected	Basic chemicals, pesticides, silicates	Metalworking, moulding, machining, assembly, coating, plastic manufacturing, finishing, cabling, transportation and services	Farming, crop-processing, sugar factory
Existing relations	Supply and utilities sharing	Supply chain (in the form of network of small and medium enterprises)	Competition and supply
Current economic state	Crisis/dismantling	Maturity/decline	Maturity/decline
Presence of specific coordinating body	Local Observatory for the Chemical Industry	CISI consortium	Provincial Association of Agricultural Producers

3.3.2. Chemical cluster (Pescara)

The Bussi Chemical Site (BCS) is one of the first Italian industrial clusters, dating back to the beginning of the twentieth century (Taddeo et al., 2012). It is made from five industrial plants, which operate in: basic chemicals, pesticides, silicates, power generation and distribution.

In the recent years, the cluster has suffered a closure of some of its plants, as well as a reduction of personnel and a loss in competitiveness at a national level and beyond (Taddeo et al., 2012). As a result of the global economic crisis and the manufacturing crisis of the cluster, the site could not grow as a large business and so, a need of a reconfiguration of the industrial area and the creation of new synergies appeared.

A thorough study in the industrial cluster has empirically proven that industrial ecology, precisely industrial symbiosis could be implemented in the industrial site and building relations with other clusters present in the region (Taddeo et al., 2012).

3.3.3. Automotive cluster (Chieti)

The automotive cluster in Chieti is organised by a consortium (CISI). It was founded in 1992 by 13 companies. The managers created a network of small and medium-sized enterprises to implement just-in-time procedures (Simboli et al., 2014).

Nowadays the cluster has more than 100 companies. The cluster companies produce motorcycle parts, cars and motorised vehicles and its most important client is Honda.

The companies in the cluster are involved in 10 different processes: metalworking, moulding, machining, assembly, coating, plastic manufacturing, finishing, cabling, transportation and services. They manage five categories of materials: steel, cast iron, aluminium, rubber and plastics. Along with the automotive industries, there is an aluminium foundry acting as a supplier (Simboli et al., 2014).

3.3.4. Agri-food cluster (L'Aquila)

The one in L'Aquila is an agri-food cluster (AFC), it is called the Fucino upland. It consists in a drained wetland basin of around 16.000 ha. Vegetable crops are most common, the main of which are potato, carrot, fennel and lettuce.

In the 60's, some large companies established themselves in the region and so, industrialisation began. Big agricultural and food industries began to grow in the region, involved in the production and maintenance of agricultural machineries, transformation and conditioning of agri-food products and production and commercialisation of auxiliary materials (Simboli et al., 2015).

The AFC includes basic agricultural processes such as seeding, land preparation, transplanting, treatment and irrigation and harvesting. Some crops require other processes such as washing before packaging (Simboli et al., 2015).

There exist many potential symbiotic relations with other clusters, especially regarding the main auxiliary material wastes produced by the agri-food companies in the Fucino upland. These include films and packaging, boxes and pallets, septic sludge, used oils, iron and steel scraps, etc. (Simboli et al., 2015).

3.3.5. Current state of the clusters

The chemical cluster holds large size plants which have relevant impacts on the quantity and quality of the material flow that can be managed in the plants with a IS perspective (e.g. Hydrogen peroxide, Sodium Percarbonate, Sodium Hydroxide, Hydrochloric acid, Sodium Silicate). Also, toxic or hazardous substances are used as catalysts or auxiliary materials and a significant energy demand has emerged (Taddeo et al., 2017). There exists a gas power station that feeds the chemical plants (that could be of more utility, since the chemical cluster only uses less than a 20% of its potential) and also provides steam and demineralised water (Taddeo et al., 2017).

As regards the automotive cluster the processes that take place there are mainly secondary. There are many nontoxic and valuable scraps produced in these processes (e.g. steel, aluminium, rubber and plastics). There exists a seasonality on the demand, with a significant decrease of 40-60% from September to December and an obsolescence of machines and equipment in a relatively short time. This causes underutilisation of plants and workers. There is a need for a quality energy supply, required by the high-precision machinery (Taddeo et al., 2017).

The agri-food cluster produces great amounts of homogenous vegetable and non-vegetable waste. The former is used by the farmers as a fertiliser or animal feeding, whilst the latter is so variant as it emerges from many stages of the production chain. These materials include plastics, cardboard, paper, wood and metals. Last, the seasonality of this sector makes the input and output flows very variable (Taddeo et al., 2017).

3.3.6. New possible symbiotic interactions

According to the results of the study (Taddeo et al., 2017), many new symbiotic relations could be established in each of the three industrial clusters. Below, the potential symbiotic exchanges of each cluster are explained and illustrated.

- Chemical cluster in Pescara:

With the implementation of the IS based interactions in the chemical cluster, the power plant would provide electricity, steam and demineralised water to three other industries in the BCS cluster. The basic chemicals company could provide a company dealing with precious metal recovery (outside the BCS cluster), as well as other in-site industries. The micronized silica company could provide with silicates the companies inside and outside the cluster. Septic sludge and wastewater could be transported to a company performing gas/waste stabilisation and recovery. Basic chemicals could also be transported outside the cluster into the metal recovery company, which could also treat sludge from a galvanic treatment industry and spent catalysts from the motorcycle industry (Taddeo et al., 2017). *Figure 3.7* shows the new and old symbiotic exchanges for the BCS cluster in more detail.

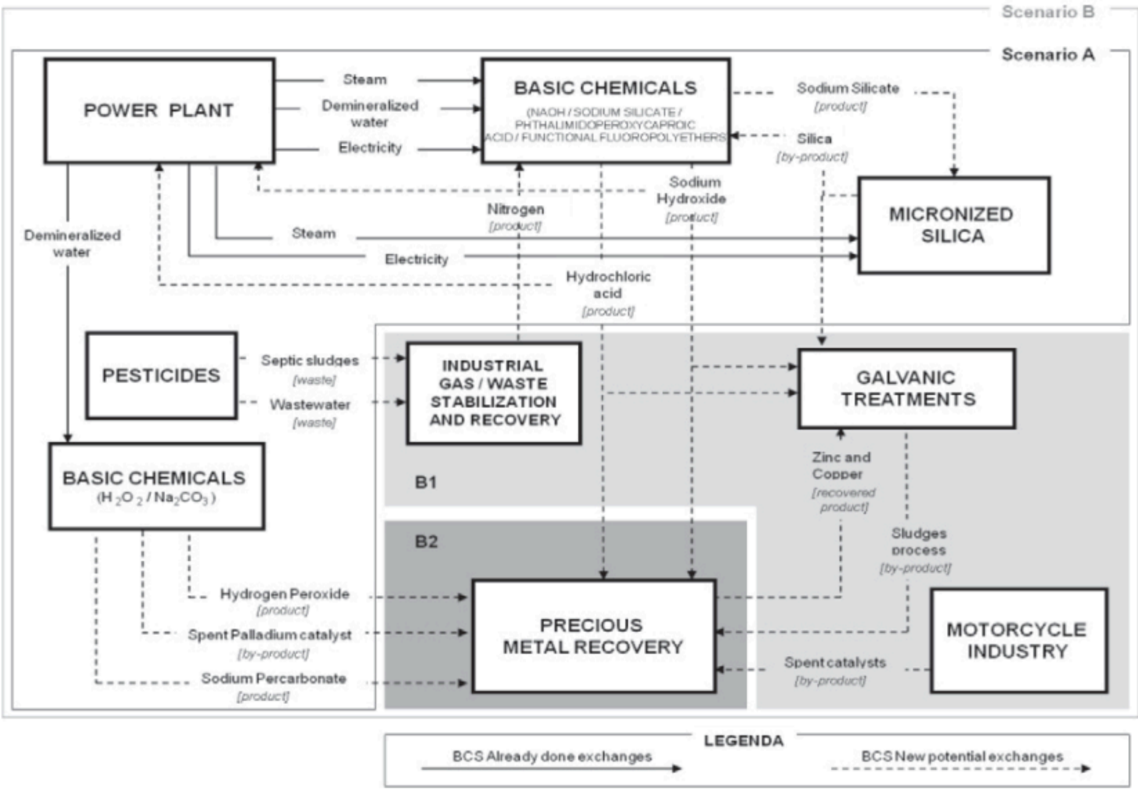

Figure 3.7. Potential symbiotic scenario in the BCS cluster after the study (new and old). (Source: Taddeo et al., 2017).

- Automotive cluster in Chieti:

The solutions for this cluster are based on industrial scraps. The scraps can be recycled inside the cluster, to obtain the same product again, they could be recycled into a different product or they could be sold as secondary raw-materials. The last option would include the services of a company from CISI entitled to handle waste, and the creation of a pre-treatment centre (PTC) that would exploit the surplus of working machines and equipment capacities from the companies. Another solution includes the management of products' end-of-life; this would provide collaboration with the final producer in the creation of a disassembling platform within the PTC. Last, the transportation service could be used for the collection and treatment of materials at their end-of-life as well. *Figure 3.8* shows the new and old symbiotic exchanges for the CISI cluster in detail.

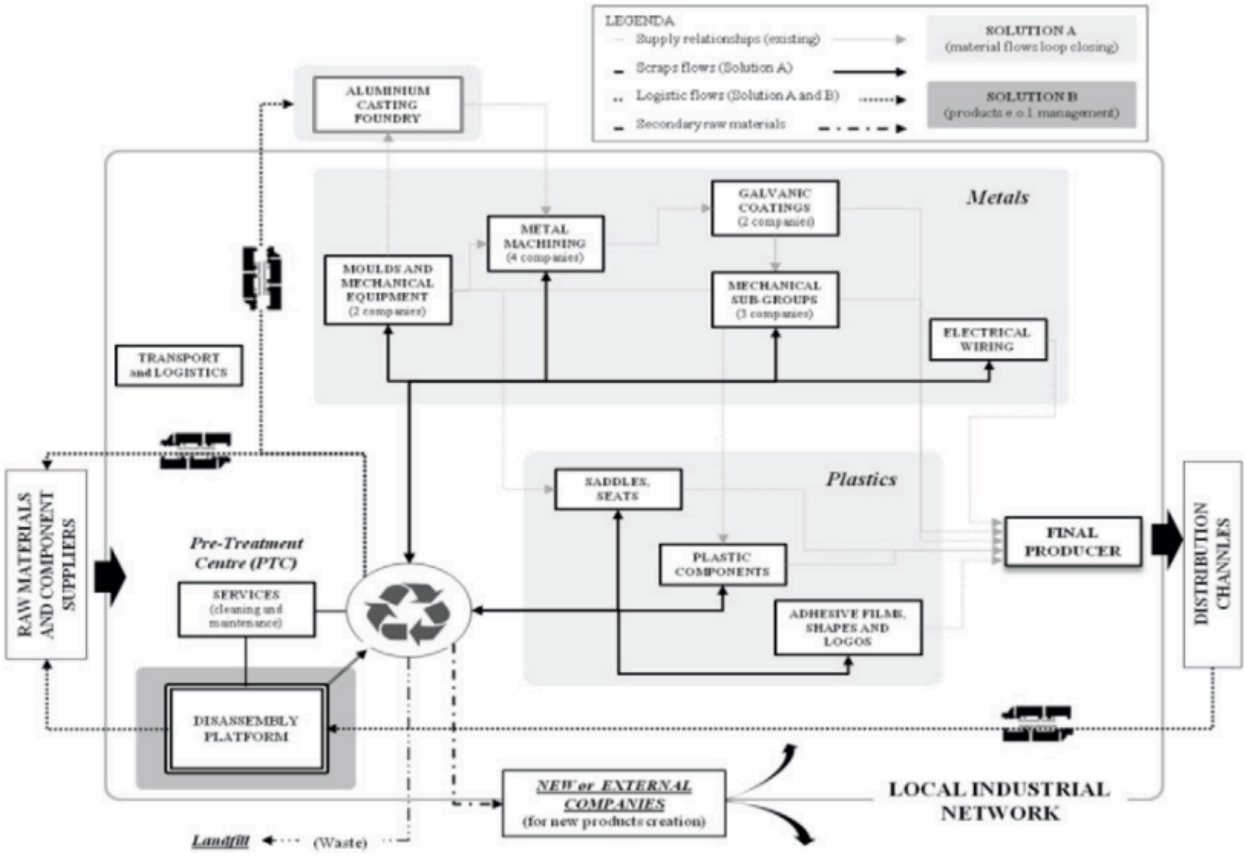

Figure 3.8. Potential symbiotic scenario in the CISI cluster after the study (new and old). (Source: Taddeo et al., 2017).

- Agri-food cluster in L'Aquila:

The measures taken in the agri-food cluster can be implemented both by individual companies and by collective measures. A common local recycling platform could be developed. It would catch flows of homogenous materials such as plastic wastes, treating and recycling them internally or selling them to other companies; it would also enable the establishment of new activities within the cluster. The involvement of other non-agricultural industries inside the cluster: a paper mill that could receive paper and cardboard waste, a company producer of PVC sewer pipes could use a percentage of plastic waste, a pellets and plywood panels producing company could use cardboard and wood waste. The use of the materials waste in the solutions described could include the creation of agriculture support devices, secondary logistics devices or heating on local settlements (Taddeo et al., 2017). *Figure 3.9* shows the new and old symbiotic exchanges for the agri-food cluster in detail.

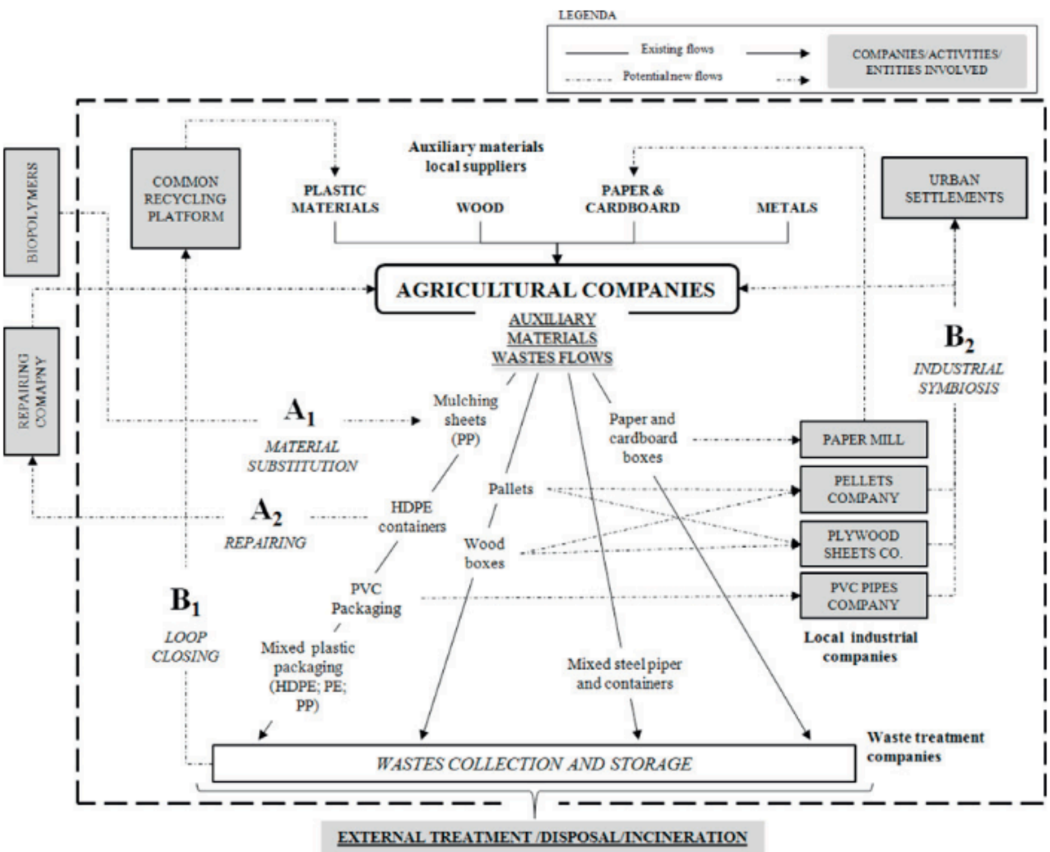

Figure 3.9. Potential symbiotic scenario in the agri-food cluster after the study (new and old). (Source: Taddeo et al., 2017).

3.4. Other Italian EIPs

After having described the first three cases in detail, as examples to understand how EIPs work and the exchanges the companies have amongst them, the remaining cases will be described in this chapter (3.4) in a shorter form. The necessary information for the comparison amongst cases will be found in section 6.

3.4.1. Sicilia platform

Both papers found about the Sicily case study (Cutaia, 2015; Luciano et al., 2016) explain the methodology used to implement an IS platform at a regional scale, in the districts of Syracuse and Catania. This methodology had been created by ENEA (Italian National Agency for New Technologies). The goal of the project was to provide a methodology and an instrument to help SMEs in the region to develop symbiotic opportunities. The approach included network activation, the analysis of the productive sectors in Sicily, data collection and companies involvement. Meetings were organised amongst companies to analyse potential synergies and resources sharing (Cutaia, 2015). More than 690 potential exchanges amongst companies were identified during the meetings.

The main sectors involved in the Sicilian platform (Luciano et al., 2016), with around 2000 companies, are manufacturing (34%), agriculture, forestry and fishing (15%), wholesale and retail trade (10%) and accommodation and food service activities (10%). There are other sectors with less presence such as construction, professional, scientific and technical activities, information and communication, etc.

Some of the recommendations after the project were to increase the diversity of the firms respects to the effective distribution within the productive sectors and an involvement of the missing companies (the ones not participating on the project). Also the increase of the presence of local stakeholders to ensure greater confidence in the symbiosis approach to companies.

3.4.2. Brescia district (Lombardy)

The case study is located in the district of Brescia, Lombardy. Inside the district there is a great number of companies which allows the secondary sector to be the most developed one (Marchi et al., 2017). There is currently a low number of transactions of resources flows amongst industries, but this study (Marchi et al., 2017) explains the potential raw materials, waste materials and energy flows among several companies, with the aim to reduce energy consumption, at the same time reducing costs and CO_2 emissions.

The companies considered in the study involve an Italian multi-utility company leader in energy, environment, heat and networks, five steelmakers, a cement producer, a company of treatment of solid waste and biomass, a wood chips producer, a fluff car treatment company, a road-making company and a caviar producer.

An analysis of energy flows within the district was also performed: a great amount of heat loss was identified within the steelmakers and the cement producer. This would represent a large potential for sustainable recycling (Marchi et al., 2017).

3.4.3. Prato (Toscana)

There is an EIP located in Macrolotto, in Prato. The industrial area is one of the most important European clusters for the textile sector (Daddi et al., 2015). There are around 380 companies.

The EIP has a centralised wastewater recycling plant for production and fire fighting. It is under the management of a non-profit organisation named CONSER and it manages the environmental infrastructures and services of the productive area. Macrolotto has an industrial aqueduct which fed by the recovering water from the wastewater recycling plant (Daddi et al., 2015).

There are also two photovoltaic plants that provide energy to make the kindergarten self-powered and to reduce the energy costs related to the recycling water system.

3.4.4. Ponterosso (Friuli-Venezia Giulia)

The industrial area is located in San Vito al Tagliamento. There are 142 companies in the EIP and they are very diversified both in size and products. They include chemical, food, glass, machinery and producing components (Daddi et al., 2015).

The EIP is managed by a consortium (Consortium for the Industrial Area of Ponterosso). In the park there are combined production plants and self-production of electricity and heat distribution plants. The consortium provided the area with a railway that connects it with the national network. In addition, the consortium also monitors various key local environmental performance indicators (Daddi et al., 2015).

The park includes a wastewater treatment plant which complies with the emission limits.

3.4.5. Padova (Veneto)

The industrial area in Padova is located in the region of Veneto and it contains about 1500 companies. The area is one of the biggest industrial parks in the north of Italy. It has been managed by a consortium of local public institutions since 1956 (Daddi et al., 2015).

The area is served with a railway, toll booths and service centres, with post offices, restaurants, banks and hotels amongst many other services. Around 50,000 people work in there and as a result, there are problems regarding transportation and traveling. The area appointed a mobility manager to identify opportunities of improvement and to promote new initiatives (Daddi et al., 2015).

The park has a well implemented industrial symbiotic network, with great services and technologies sharing, landscape ecology, and the involvement of local stakeholders.

3.4.6. Ancona (Marche)

The productive area of Ancona is the first of the Marche region. It began to develop in the 1980s and it is located in the port of Ancona. There is a consortium named ZIPA (Industrial Productive Zone of Ancona) established in the zone to manage the EIP (Daddi et al., 2015).

The are around 90 companies in the EIP and they are related to maritime activities such as ship-building, mechanical repairs, electrical systems, nautical décor, food supplies, logistics, shipping agencies and seafood processing. The consortium has another four productive areas in Marche and the shared services relate to training, consulting and support for companies of infrastructure for water discharge and waste (Daddi et al., 2015).

The manager of the EIP is focused with developing synergies and relationships with local communities. There is also a plan for environmental improvement, which is shared with local stakeholders.

4. Industrial Symbiosis in Spain

Not many evidences of industrial symbiosis in Spain were found; in fact, only six scientific papers were useful to the development of this project. After the review of such papers, a Google standard search was conducted in order to find more information about the cases identified in the articles found.

Also, just as in the last explained cases of Italian IS, the Spanish IS cases were explained briefly because detailed explanations from each EIP were not necessary for the sake of the comparison amongst Italian and Spanish cases, shown in chapter 5. The main aim of this project is the comparison amongst the cases and not the detailed explanation of them.

Table 4.1 names each industrial symbiosis case in Spain, with its reference (where the information was found) and a few comments about them. With this table, the reader can have a general idea of how many cases are there and how they are.

Table 4.1. Spanish industrial districts, with reference on sources of information and main explanations.

Industrial districts	Reference	Observations
XEI (Catalonia)	(Susur et al., 2019)	It was a project to build a thematic network in Catalonia aiming to involve academia, industry and policy-makers.
CICLE (Catalonia)	(Susur et al., 2019) (Puig et al., 2008a, 2008b, 2008c)	A project to implement industrial ecology within leather industries and within paper ones in Catalonia.
MESVAL (Catalonia)	(Susur et al., 2019)	A project with the aim to create a network amongst technological centres, chambers of commerce and universities of Catalonia, Tuscany (Italy) and Peloponnesus (Greece).

MITKE (Catalonia)	(Susur et al., 2019)	A project that created a network amongst regional companies from Basque Country, Catalonia and partners from seven other countries to transform industrial areas into sustainable spaces.
Manresa in Symbiosis (Catalonia)	(Susur et al., 2019)	An implemented industrial symbiosis project in a local and regional network. There is material exchange with a third party involved (Símbiosy) and financed by two agencies.
Vallès Circular (Catalonia)	(Susur et al., 2019) (Vallès Circular, 2016)	An initiative for an industrial area in two nearby municipalities, Sabadell and Barberà del Vallès (close to Barcelona), with around 2500 companies involved.
Metropolitan area in Granada (Andalusia)	(Zamorano et al., 2011)	A study for the implementation of environmentally friendly initiatives in a metropolitan area in Granada.
Printing plants' waste treatment (Galicia)	(Andrade et al., 2012)	A study for the improvement of industrial symbiosis of printing companies located in the Galician region.
SMEs symbiosis study (Cantabria)	(Puente et al., 2015)	A study for the implementation of industrial symbiosis in a local and regional scale in Cantabria with many sectors involved (like commerce, automotive, metallurgy, etc.).

4.1. XEI project (Catalonia)

This project was developed from 1999 to 2009 in Catalonia and it had the objective to create a thematic network of regional actors including researchers, universities, industry and governmental organisations (Susur et al., 2019).

As it was created in an early state of the industrial ecology concept, especially in a conservative country like Spain, to build a knowledge exchange network was not an easy task. Four Catalan universities initiated this project and it was financially supported by the Waste Agency of Catalonia, the Catalan Government at that time, the Department of Universities and the Research and Information Society (DURSI). This study was key to develop further studies on industrial ecology applications in the Catalan region.

The scope of the network was regional, with some international academic societies' connections as well (Susur et al., 2019). The project includes companies from many sectors.

4.2. CICLE project (Catalonia)

The project had two main objectives: to study the application of industrial ecology approach to the paper and leather sectors separately.

For the paper sector, the aim was to map the current situation of waste recycling and making improvement proposals following the principles of industrial symbiosis. A diagnosis was made identifying and quantifying the different waste flows produced by this industry in Catalonia and their destiny. At the time, the rough waste from the first filtration process was disposed of in landfill along with a high proportion of sewage sludge. The main improvements proposed were, therefore: the use of the Rofire technology to obtain energy from the rough waste, which would reduce CO_2 emissions by 85.8% and would be economically feasible (considering landfill costs of about 50.88 €/t) and the use of sewage sludge as fuel for cogeneration. This last option should be studied in depth for each particular company (Puig et al., 2008c).

For the leather sector, also a diagnosis of current situation of solid waste flows was quantified and proposals for waste minimization and waste-as-resource improved options were suggested. In addition, an eco-industrial park was designed to allocate the tanning industries together sharing common energy and waste management services (Puig et al., 2008a, 2008b).

4.3. MESVAL project (Catalonia)

This project was developed between 2004 and 2006 in Catalonia. It had the objective of building an industrial ecology network amongst technological centres, chambers of commerce and universities from Catalonia, Tuscany (Italy) and Peloponnesus (Greece) (Susur et al., 2019). It was funded by ECOSIND budget, which was another project and coordinated by the university UPC.

The vision of the network was to create a regional waste recovery strategy. There were also knowledge exchanges between the universities and other parties of the network.

The project involves companies in many different sectors which are not specified. They are included in the chambers of commerce.

The MESVAL project was the starting point of other future projects, like Manresa Circular, located in Catalonia (Susur et al., 2019).

4.4. MITKE project (Catalonia)

The MITKE project, developed in Catalonia from 2008 to 2011 had the objective to transform existing businesses and industrial areas in partner regions into sustainable spaces (Susur et al., 2019). It was funded by Interreg Program of European Commission and it was initiated by a consortium leaded by Sprilur (LIPS* Development Agency of Basque Country in Spain) and Incasòl (Catalan Land Institute). **LIPS: Local Industrial Production Systems.*

It had regional and international partners, forming a network of eleven partners including regional development agencies, business networks and land developers and research centres from Basque Country, Catalonia and regions of other seven countries (Susur et al., 2019).

At that moment there was a lack of consciousness regarding regional industrial symbiosis. As the project development coordinator Incasòl stated: "*We did not call it industrial symbiosis in the project, although we were with it all the time… For us it was* *about the fact of the collaboration between the LIPS and the companies. Industrial symbiosis was an ideal that we were trying to get to"*.

4.5. Manresa in Symbiosis (Catalonia)

The IS case in Manresa was the first implementation of an industrial symbiosis project in the region of Catalonia. It was implemented amongst local and regional actors through network building (Susur et al., 2019).

The Manresa project follows a cooperative approach to exchange resources, with given support from a third party, Símbiosy, who helps via an animation of a synergy web platform and designs industrial symbiosis strategies (ACR+, 2017).

The project counts with the support of the municipality and the project promoters: Manresa City Council and the Catalan Waste Agency.

4.6. Vallès Circular (Catalonia)

Vallès Circular is an initiative of circular economy and industrial symbiosis, promoted since 2014 by municipalities of Sabadell and Barberà del Vallès, consisting in a networking amongst companies located in a local and regional scope. The agreement is signed by 30 entities including municipalities, universities, research centres, business organisations and industries (Susur et al., 2019). Included in this area there are around 2500 companies.

The initiative is supported by the Government of Catalonia and the Barcelona City Counsel (Susur et al., 2019) and it is a live study with on-going conferences about changes in the industry and the relations between companies.

The companies from which the project is composed vary from technology, engineering, waste treatment and valorisation, artificial intelligence, 3D printing, eco-design and packaging, forestall biomass for thermal energetic use, etc. (Vallès Circular, 2019).

4.7. Sta. Perpètua de Mogoda (Catalonia)

The industrial area is located in Sta. Perpètua de Mogoda, a town 30 km northeast of Barcelona. It is in the basin of the Besós river and occupies an area of 15.7 km^2. There are around 500 businesses in the area, mainly SMEs (Small and Medium Enterprises), being it one of the most industrialised towns near Barcelona. Industrialisation was fast and unorganised and without cooperation amongst businesses (Sendra et al., 2007).

Forty businesses took part in the results of a research to an industrial symbiotic approach (Sendra et al., 2007). The predominating industries were chemical and metallurgical, although the EIP's vision is for a numerous variety of industries.

The results showed that the implementation of an EIP is viable and it would be mainly focused in material exchange, but further studies could find many other possible exchanges between more companies, as the study only took into account 40 of the 500 companies in the industrial area (Sendra et al., 2007).

4.8. Metropolitan area in Granada (Andalusia)

Although Granada is not a highly industrialised area in Spain, there is an industrial area, which has industries such as agricultural food manipulation, food industries, metal manufacturing industries and metalwork, construction related industries, general storage and distribution, among others (Zamorano et al., 2011).

A study was conducted (Zamorano et al., 2011) to treat the different types of waste in the industrial area. There are many types of waste among the companies; assimilated municipal waste, such as paper, plastic, glass…; inert wastes, such as construction waste, metals and mineral oil; hazardous wastes such as paint, adhesives or contaminated packages and other wastes like electronic ones. Currently there is a great percentage of waste which is directly disposed of in landfills (41.2%) and 47.1% is recycled or revalorised.

In general, the study found out via a SWOT analysis (Zamorano et al., 2011) that environmentally friendly strategies were lacking or were inexistent. There was a lack of awareness of the environmental issues in both workers and companies. Nevertheless, there is a huge place for improving and many opportunities were found (reduction of environmental impacts, potential partnership amongst companies, generation of wastes that are easily recyclable, etc.).

4.9. Printing plants' waste treatment (Galicia)

The case study is located in Galicia, north-west of Spain, where there is an association called AEAGG (Association of Graphic Arts Entrepreneurs of Galicia) which represents the Galician printing industry, joining 146 printing plants, all of them SMEs (Andrade et al., 2012). There is currently an intermediate waste manager which has a symbiotic relation with around half of the companies in the AEAGG, but this relation can be improved.

After implementing a study (Andrade et al., 2012) between the intermediate waste manager and one of the printing companies, results show a reduction of hazardous waste flows on the system and the recovery of an important part of them. Also, two waste streams disappear, meaning the amount of hazardous waste managed by the intermediate is reduced.

4.10. SMEs symbiosis study (Cantabria)

The case study is located in the Besaya region, in Cantabria, and it involves 161 companies located in nine different industrial areas. By sectors, 40% work in commerce, repairing motor vehicles, motorbikes and motorcycles and personal domestic articles, 16% in metallurgy and metallic products manufacturing, 13% in construction and 31% in diverse sectors such as real estate services, paper industry, food and chemical industry, among others (Puente et al., 2015).

The results show opportunities on substituting resources with waste products and sharing waste management services and infrastructures. The implementation of the study contemplates relations at a local and regional scope. There are many shared services referred to in the study (Puente et al., 2015) such as the use of waste treatment and recovery installations, transport of waste to municipal management points, use of waste storage spaces, etc.

5. Comparison amongst Italian and Spanish IS cases

The comparison amongst the cases will be conducted regarding certain items, which are listed and explained below: implementation degree, scope, type and main sectors involved. In addition, two parameters are selected to measure the area dimensions: number of sectors present and number of symbiotic exchanges.

- Implementation degree: this item classified the IS cases into implemented or non-implemented cases. There are many cases that are only projects while some of the cases really exist.
- Scope of the area: the extension of the area or IS case, it can be either local (L), regional (R) or national/international (N/I).
- Number of sectors present in the area: the number of industrial sectors present in the area (for example oil refinery, cement factory of steelworks, etc.).
- Sectors: this item aims to list the main sectors involved on the IS exchanges.
- Number of symbiotic exchanges described: only the existing number of symbiotic exchanges will be counted in the tables. There may be cases in which exchanges are not explained or specified, in that case, a (-) will be written. It is important to point out that information was taken from scientific papers' descriptions and not collected personally, so it may not be of high accuracy. Also, in the cases which are just studies for now, there are two values: the first one is the number of symbiotic exchanges which exist already and the second are the potential new exchanges, which are marked with asterisk (*).
- Type of area: as mentioned in the introductory chapter, there are three types of areas, regarding their management (in the case of not yet implemented IS cases, this will be hypothetical):
  a. Self-organised networks (S): emerging as a result of direct interaction among industrial actors. They operate in a local level or at the industrial estate level. They are linked to clusters of manufacturing activities, often with the primary sector involved. They are business-as-usual transactions in countries with high-

developed environmental awareness, with stricter regulations. They can also be operated by private actors with the local government support.

b. Facilitated networks (F): these have a third party which coordinates the activity of the cluster. This third party monitors the benefits (both environmental and economical) achieved by the IS.

c. Planned networks (P): they result from a central plan or vision. They are top-down initiatives (there is an organisation with power over an industrial area, which decides over the companies and synergies). These are located in a specific industrial area and include shared infrastructures and services.

Table 5.1 illustrates the above explained parameters selected to define IS cases for Italian EIPs.

Table 5.1. Italian IS cases' parameters information.

Industrial districts	Reference	Implemented	Area scope	Area type	No. of exchanges*	No. of sectors	Sectors
Taranto (Puglia)	(Notarnicola et al., 2016)	No	L	P	≈15 ≈37*	8	Steel, cement, power stations and refinery
Porto Marghera (Veneto)	(Mannino et al., 2015)	Yes, declining	L	S	Before 42 Now ≈7	≈12	Chemical, waste and water, oil and energy
Pescara (Abruzzo)	(Taddeo et al., 2012) (Taddeo et al., 2017)	No	L, R	S, P	3 15*	1	Chemical
Chieti (Abruzzo)	(Simboli et al., 2014)	No	L, R	F, P	-	1	Automotive

	(Taddeo et al., 2017)				7*		
L'Aquila (Abruzzo)	(Simboli et al., 2015) (Taddeo et al., 2017)	No	L, R	S, P	3 10*	1	Agri-food
Sicily (Sicilia)	(Cutaia, 2015) (Luciano et al., 2016)	Yes	R	F	690*	≈17	Manufacturing, agriculture, forestry and fishing, food services…
Brescia (Lombardy)	(Marchi et al., 2017)	No	L	S, P	17*	8	Steel, energy, cement, solid waste treatment…
Prato (Tuscany)	(Daddi et al., 2015)	Yes	R	F	?	1	Textile
Ponterosso (Friuli-Venezia Giulia)	(Daddi et al., 2015)	Yes	L	F	?	≈5?	Chemical, food, glass, machinery…
Padova (Veneto)	(Daddi et al., 2015)	Yes	L	F	?	?	?
Ancona (Marche)	(Daddi et al., 2015)	Yes	L	F	?	1	Maritime

* For planned networks there are two different numbers. The first one is related to the already existing symbiotic exchanges and the second is for the potential ones. Also, in the case of Porto Marghera, there is data from the past number of exchanges (before) and the current number (now).

Certainly there has been information which was not found in some cases, being it imprecise (which is marked by the sign "≈") or unknown (which is marked by a "?" sign).

In the case of the industrial clusters of Pescara and L'Aquila, in Abruzzo, there is a certain level of IS implemented, although with the studies made it is supposed to grow (that is why they are classified as self-organised networks). In the case of Chieti, also in Abruzzo, there exists a consortium which coordinates the activities, making it a facilitated network. All of them are also classified as planned networks (hypothetically) because there is a study (Taddeo et al., 2017) which aims to create symbiotic interactions amongst the three clusters, making them potential IS based clusters.

Table 5.2 presents the same parameters as *Table 5.1* with Spanish IS cases.

Table 5.2. Spanish IS cases' parameters information.

Industrial districts	Reference	Implemented	Area scope	Area type	Num. exchanges	Num. sectors	Sectors
XEI (Catalonia)	(Susur et al., 2019)	No	R	P	?	?	Many sectors
CICLE (Catalonia)	(Susur et al., 2019)	No	R	P	?	2	Leather and paper
MESVAL (Catalonia)	(Susur et al., 2019)	No	R, N/I	P	?	?	Many sectors
MITKE (Catalonia)	(Susur et al., 2019)	No	N/I	P	?	?	?
Manresa in Symbiosis (Catalonia)	(Susur et al., 2019) (ACR+, 2017)	Yes	L/R	P	?	?	?
Vallès Circular	(Susur et al., 2019)	Yes	L/R	P	?	?	Many sectors

(Catalonia)	(Vallès Circular, 2016)						
Sta. Perpètua de Mogoda (Catalonia)	(Sendra et al., 2007)	No	L	P	?	>2	Chemical, metallurgy
Metropolitan area in Granada (Andalusia)	(Zamorano et al., 2011)	No	L	P	?	?	Many sectors
Printing plants' waste treatment (Galicia)	(Andrade et al., 2012)	Yes	R	S, P	?	1	Printing
SMEs symbiosis study (Cantabria)	(Puente et al., 2015)	No	L, R	P	≈17	Many	Commerce, automotive, metallurgy, construction

Among the Spanish IS cases, there is a great lack of knowledge, as information found in the papers was often not highly descriptive; in such cases the information box is filled with a question mark (?), meaning not enough information was found to fill the box.

Also, the case of the Galician printing plants' waste treatment is considered as a self-organised network and also planned, as at the moment of the study (Andrade et al., 2012) there was existing symbiosis but an improvement was being planned by the organisation.

There are other key elements useful for a comparison amongst the EIPs (Daddi et al., 2015): the presence of material and/or energy exchanges, the shared services (like wastewater treatment or common buying), the facility sharing (when more than one firm works with the same machinery or in the same building), networking (sharing information, participating in the same projects, etc.) and the local stakeholders involvement (i.e. municipality). All these key elements are presented in *Table 5.3* for Italian IS cases. Cases that derive from projects have two lines, the first is the current state and the second refers to the same case after the implementation of the studies in the project.

Table 5.3. Key elements' information for Italian IS cases.

Industrial districts	Material Exchange	Energy Exchange	Shared services	Facility sharing	Networking	Local stakeholders
Taranto (Puglia)	✔ ✔✔	✔ ✔✔	- -	- -	- -	- -
Porto Marghera (Veneto)	✔	✔	-	-	-	-
Pescara (Abruzzo)	✔ ✔✔	✔ ✔✔	✔ ✔	✔ ✔	- -	- -
Chieti (Abruzzo)	- ✔	- -	- ✔	✔ ✔	✔ ✔	- -
L'Aquila (Abruzzo)	✔ ✔✔	- -	- ✔	- -	- -	- -
Sicily (Sicilia)	✔	-	✔	✔	✔	✔
Brescia (Lombardy)	- ✔	- ✔	- -	- -	- ✔	- -
Prato (Tuscany)	-	✔	✔	?	✔	✔
Ponterosso (Friuli-Venezia Giulia)	-	✔	✔	?	✔	✔
Padova (Veneto)	-	-	✔	-	✔	✔
Ancona (Marche)	-	-	✔	-	✔	✔

Following, *Table 5.4* shows the Spanish IS cases' presence or absence of the key elements mentioned above in the *Table 5.3* of Italian cases.

Table 5.4. Key elements' information for Spanish IS cases.

Industrial districts	**Material Exchange**	**Energy Exchange**	**Shared services**	**Facility sharing**	**Networking**	**Local stakeholders**
XEI (Catalonia)	-	-	✔	-	✔	✔
CICLE (Catalonia)	✔	✔	✔	-	✔	-
MESVAL (Catalonia)	-	-	✔	-	✔	✔
MITKE (Catalonia)	-	-	?	?	✔	✔
Manresa in Symbiosis (Catalonia)	✔	-	?	?	✔	✔
Vallès Circular (Catalonia)	✔	✔	?	?	✔	✔
Sta. Perpètua de Mogoda (Catalonia)	✔	✔	-	-	-	-
Metropolitan area in Granada (Andalusia)	✔ ✔	- ?	- ✔	- ?	- ✔	- ?
Printing plants' waste treatment (Galicia)	✔ ✔✔	- -	✔ ✔✔	- -	- -	? ?
SMEs symbiosis study (Cantabria)	✔	-	✔	✔	✔	?

In the Spanish cases, there is a predominance of projects (especially in Catalonia) and there are few known implemented IS cases (such as Manresa and Vallès). There is an important lack of information about industrial symbiosis examples and the ones identified are not explained fully; as can be seen, with many of the fields in the tables (like sectors involved or known exchanges, both material and energy ones, etc.) are filled with question marks, as information could not be found. This is one of the main characteristics of Spanish cases.

6. New classification by type of IS exchange

6.1. Individual symbiotic relations

Carbon capture and reuse in a sugar factory

There is a study (Duraccio et al., 2015) on two companies located nearby inside of an industrial district which location was not provided. The first company is a natural gas combined cycle (NGCC) power plant, which produces an annual amount of electricity of 4 billion kWh. The annual CO_2 emissions sum up to 1.7 million tonnes.

The second company is a sugar factory, in which processes there is a phase where a carbonation process is carried out. This process requires lime milk and CO_2 as input raw materials and it consists in the removal of impurities from raw sugar juice and transforming it into thin juice. The CO_2 reacts with the lime and produces calcium carbonate. Thus, this phase could potentially use the power plant's CO_2 emissions avoiding to buy CO_2 from other companies.

After the study was conducted, the results showed that the operational costs of the sugar factory would be reduced by a huge 58%. In addition, the power plant also has a positive impact, with a decrease of 7% of CO_2 emissions (Duraccio et al., 2015).

Recycling of WEEE

A group of three companies located in the Marche region, central Italy. They are related to waste electrical and electronic equipment (WEEE), which currently represents an important issue for the modern society. A circular economy and an industrial symbiotic approach is needed to mitigate the environmental problem and recover value from end of life (EoL) products/materials (Marconi et al., 2018).

The first company (A) is a small enterprise authorised as a WEEE treatment centre. It receives EoL household appliances and disassembles them in different materials (plastics, metals, etc.). Mixed plastics are commonly disposed of in landfills.

The second company (B) is a material recycler which inputs plastics, rubbers, etc. and granulates or powders them for second life applications.

The third company (C) is a compound producer that mainly uses PP and PE as input.

The output materials in company A are similar to the input materials in company B. In addition, there can be a correlation between companies B and C, creating an industrial symbiosis amongst the three companies (Marconi et al., 2018).

Heat and CO2 recovery in a greenhouse

The case study is located in Brescia, Lombardy and it consists in a potential symbiotic relation between a hypothetic factory and crop fields in a nearby greenhouse installation. The idea is to use heat and CO_2 from the factory and transport it to the greenhouse installation. The implementation of this will capture up to 21% of the emitted CO_2 and will save up an amount of 8.1€ per square meter in each production cycle in average (Marchi et al., 2018).

The study conducted took into account three different crops: tomatoes, cucumbers and strawberries. The increased production as a result of CO_2 enrichment was between 30% and 38,5% in all three.

The benefits of the implementation of this project are the reduction of CO_2 emission, the economic savings from avoiding other heating methods and also the extra earnings provided by an improved yield production of crops (Marchi et al., 2018).

Reused materials for concrete production

The case of Formigrup, in the Vallès Circular initiative (in Catalonia), is a concrete producing company which uses recycled materials as additives, for example recycled plastic in light concrete or glass fibres in other types of concrete. It also uses: incinerator slag, sludge from ceramic companies and cast iron sands (Vallès Circular, 2016).

Reuse of wastewater

In the Vallès Circular initiative (in Catalonia), there is the case of a cosmetic company (HIPERTIN), which produces wastewater from the cleaning of reactors and machinery. This wastewater is later utilised for other types of companies such as AÏGUES SABADELL, a company that treats wastewater amongst many other water uses (Vallès Circular, 2016).

Slaughterhouse waste recycling

Also in the Vallès Circular initiative, there is a Slaughterhouse (Escorxador de Sabadell), from the meat industry. It has several wastes recycling: the blood from animals goes to a plasma producing plant, sludge from a treatment plant goes to a biogas plant and manure from animals goes to a composting site to produce compost for gardening (Vallès Circular, 2016).

Cosmetic company's waste recycling

In Vallès Circular, there is a company called PROVITAL which produces, distributes and investigates fine chemicals from the cosmetic industry. The company manages waste at a 70% on industrial symbiotic activities. It includes composting of vegetable remains for agriculture, leaking dirt, biologic sludge and vegetal oils (Vallès Circular, 2016).

Industrial wipers reuse

In Vallès Circular there is a company which enables industrial wipers to be reused. Some companies use industrial wipers and, after these are used, they become residue. Instead of disposing of them in landfills or incinerating them, another company collects and washes the industrial wipers for future uses (Vallès Circular, 2016).

Dining canteens waste recycling

In Vallès Circular, companies from the industrial district have dining canteens and they have food which is not eaten, so it ends up being organic matter. It is then gathered separately to make composting instead of disposing of it in the waste bin, where it was mixed with many other residues and was more difficult to recover (Vallès Circular, 2016).

Waste heat from a power plant to a steelworks

In the Taranto industrial park (Notarnicola et al., 2016) there are many companies and many symbiotic exchanges among them, as described in section 3.1. One of them is the heating from the Edison power plant which is used by the ILVA steelworks company .

Mill scale to produce magnets and railway infrastructures

In the Taranto industrial park (Notarnicola et al., 2016), another material exchange involves the ILVA steelworks company and the mill scale waste, which is later used by other companies to produce magnets and railway infrastructures, among other uses.

Use of marc and dreg (winemaking) for spirits

In the Taranto industrial park (Notarnicola et al., 2016) there are symbiotic relations between winemaking industries and distilleries, which have environmental efficient activities such as the production of spirits made from marc and dregs (wastes from winemaking).

Facility sharing in automotive cluster

One of the three clusters in Abruzzo, the one in Chieti, is based on companies in the automotive industry. As there is a seasonality on demand, the plants and workers are underutilised. The project (Taddeo et al., 2017) resolves that facility sharing among companies would be a great improvement.

Table 6.1 summarizes the different individual symbiotic relations found in scientific sources. There are the sources and some observations too.

Table 6.1. Individual symbiotic relations in Italy and Spain with a short description.

Individual symbiotic relations	Reference	Observations
Carbon capture and reuse in a sugar factory	(Duraccio et al., 2015)	A study based on two companies: an NGCC power plant and a sugar factory, which will use the CO_2 emissions from the first one.
Recycling of WEEE	(Marconi et al., 2018)	A study of a potential symbiotic relation amongst three companies regarding waste of electric and electronic equipment.
Heat and CO_2 reuse in a greenhouse	(Marchi et al., 2018)	A symbiotic relation between a hypothetic factory which provides a greenhouse installation with heat and CO_2.

Reused materials for concrete production	(Vallès Circular, 2016)	Glass fibers, plastic or rubber are reused in the production of concrete.
Reuse of wastewater	(Vallès Circular, 2016)	Wastewater is reused in different industries after cleaning machinery of a cosmetic company.
Slaughterhouse waste recycling	(Vallès Circular, 2016)	Blood, sludge and manure are used in different processes for composting purposes.
Cosmetic company's waste recycling	(Vallès Circular, 2016)	A company has a 70% of industrial symbiosis implementation for the recovery of vegetal oils and waste for composting purposes.
Industrial wipers reuse	(Vallès Circular, 2016)	A company gathers dirty industrial wipers from other companies, washes and returns them for additional uses.
Dining canteen waste recycling	(Vallès Circular, 2016)	Food waste from dining canteens in the industrial district is used for the production of composting.
Waste heat from a power plant to a steelworks	(Notarnicola et al., 2016).	A power plant provides a steelworks with electricity and heating.
Mill scale to produce magnets and railway infrastructures	(Notarnicola et al., 2016).	A steelworks company with mill scale as a residue, which is later utilised by other companies in the production of magnets and railway infrastructures.
Marc and dreg (winemaking) for spirits	(Notarnicola et al., 2016)	Marc and dreg are wastes from winemaking, which are later used in the production of spirits by a distillery.
Facility sharing in automotive cluster	(Taddeo et al., 2017)	Underuse of facilities in the automotive cluster due to seasonality can result in facility sharing as a solution among companies.

6.2. Encountered differences among exchanges

There are different types of relations between the company producing the waste and the company recycling or reusing it depending on the type of waste being treated. On the other hand, the process to recycle the waste may differ from one case to another: for example, sometimes it is possible to recycle the whole waste mixture while others only a small part of it needs to be separated from the whole and is able to be recycled (process named classification of waste).

The classification of the different types of exchanges made here is done regarding the type/part of waste valorised (direct residue or small part of a mix) and the type/part of product obtained (product or filler). These characteristics are shown with more detail in *Table 6.2*, where twelve types of exchanges are listed. Each type of exchange should have an identification with situations on the animal world (analysed in section 6.3).

Table 6.2. Classification of industrial symbiotic exchanges types.

<table>
<tr><th>Residue</th><th>Product obtained</th><th>Type of exchange</th><th>Residue</th><th>Product obtained</th><th>Type of exchange</th></tr>
<tr><td rowspan="2">Heat (energy)</td><td>Bio-product</td><td>Type a</td><td rowspan="4">Small part of a mixture of waste</td><td>Bio-product</td><td>Type g</td></tr>
<tr><td>Non bio-product</td><td>Type b</td><td>Non bio-product</td><td>Type h</td></tr>
<tr><td rowspan="2">Water</td><td>Bio-product</td><td>Type c</td><td>Filler for bio-product</td><td>Type i</td></tr>
<tr><td>Non bio-product</td><td>Type d</td><td>Filler for non bio-product</td><td>Type j</td></tr>
<tr><td rowspan="2">CO_2</td><td>Bio-product</td><td>Type e</td><td rowspan="4">Direct residue</td><td>Bio-product</td><td>Type k</td></tr>
<tr><td>Non bio-product</td><td>Type f</td><td>Non bio-product</td><td>Type l</td></tr>
<tr><td colspan="2" rowspan="2">Facility sharing</td><td rowspan="2">Type o</td><td>Filler for bio-product</td><td>Type m</td></tr>
<tr><td>Filler for non bio-product</td><td>Type n</td></tr>
</table>

6.3. New bio-resembling nomenclature proposal

It is difficult to find detailed and explained industrial symbiotic exchanges in the bibliography and when they are explained, they are not classified in types of exchanges; this is why in section 6.2 exchanges were classified in types and in this section a new classification nomenclature is proposed.

From the individual IS exchanges encountered so far (explained in chapter 6.1), there have been several types of exchange identified (see *Table 6.2*). *Table 6.3* shows the industrial symbiosis examples identified and classified in the types described in *Table 6.2*.

Table 6.3. Identification of the examples with the symbiotic exchange types.

Residue	Product	Type of exchange	Example
Heat (energy)	Bio	Type a	**Heat** and CO_2 reuse in a greenhouse
	Non bio	Type b	Waste heat from a power plant to a steelworks
Water	Bio	Type c	Reuse of wastewater for irrigation
	Non bio	Type d	Reuse of wastewater for cleaning purposes
CO_2	Bio	Type e	Heat and **CO_2** reuse in a greenhouse
	Non bio	Type f	Carbon capture and reuse in a sugar factory

Small part of a mixture of waste	Bio	Type g	
	Non bio	Type h	
	Filler for bio	Type i	Dining canteens waste recycling
	Filler for non bio	Type j	Recycling of WEEE (only the plastic part is recycled)
Direct residue	Bio	Type k	
	Non bio	Type l	Industrial wipers reuse Mill scale to produce magnets and railway infrastructures
	Bio filler	Type m	Slaughterhouse waste recycling Cosmetic company's waste recycling Marc and dreg (winemaking) for spirits
	Non bio filler	Type n	Reused materials for concrete production
Facility sharing		Type o	Facility sharing in automotive cluster

Before identifying industrial symbiosis cases with cases in nature, it should be noted that natural relations and ecosystems are much more perfect and in reality. Industrial relations are not so similar with biological ones as the latter are formed by an evolution of thousands of years (the fact that a company can use residual CO_2 does not mean that it is the same process that plants do, which is using CO_2 from the atmosphere in order to grow; the similarity is simply that both use CO_2, nothing more).

Even so, we have to keep observing nature as an inspiration source for inventions or initiatives that can be born from it. Although the complexity of industrial ecosystems and the connections that derive from them may seem like a utopia for us humans, many times a simple approach can bring great results.

Table 6.4 relates the industrial symbiosis types of exchanges with a new nomenclature proposal, based on resembling cases among living species, which are obviously obtained from the natural world (these cases are not natural symbiosis, they contain many different relations among species and the environment which are or are not symbiotic).

Table 6.4. New bio-resembling nomenclature proposed for industrial symbiotic exchanges.

Exchange types	Natural name	Comments
Type a	Dung beetle	Heat: A beetle that collects manure and digs it with its eggs. Fermentation of the manure produces heating, which helps breeding the offspring.
Type b	Dung beetle non bio	
Type c	Filtrating plants	Water: plants take advantage of urine coming from animals to extract the nitrogen and benefit from it while cleaning the water.
Type d	Filtrating plants to non bio	
Type e	Photosynthetic plants	CO_2: A vegetable captures CO_2 to grow (absorbing carbon to create organic matter).
Type f	Photosynthetic plants to non bio	
Type g	Bearded vulture	Small part of a mix to product: the bearded vulture collects bones from dead animals and ascends to great heights to drop them, once in pieces, he swallows them and nourishes from the bone marrow.
Type h	Bearded vulture to non bio	
Type i	Intestinal bacteria	Small part of a mix to filler: Bacteria help metabolise inside organisms and also separate other indigestible matter. They benefit the other species.
Type j	Intestinal bacteria to non bio	
Type k	Protozoa	Direct residue to product: protozoa decompose the waste from the soil (cellulose, organic litter, bacteria, fungi…) to feed themselves.
Type l	Protozoa to non bio	
Type m	Plant roots	Direct residue to filler: the roots from plants absorb essential minerals from the soil, which are usually needed in small amounts.
Type n	Plant roots to non bio	
Type o	Goby fish and snapping shrimp	Facility sharing: A blind shrimp shares its burrow with a goby fish in exchange of protection.

7. Conclusions

This work has put industrial symbiosis in context, has explained and compared industrial symbiosis cases in two different countries (Italy and Spain) and last, has proposed a new nomenclature for different types of industrial symbiosis exchanges. Below are written the conclusions derived from it.

Italy can be considered an industrialised country: as this project has shown, it has a great number of industrial parks throughout many of the Italian regions. The country could invest in the creation of EIPs, by implementing industrial symbiosis on the already existing parks. Of course this is not of instant application but it is a potential process. As seen in this project, there exist many studies on Italian industrial districts, which means there has been growing awareness on those issues by Italian technicians, business-people and researchers.

In Italy, regarding the scope and type of industrial areas, most of them are on a local scope (maximum at a regional scale in some cases), which means industrial symbiosis, if present, is usually located in small areas.

Most of the areas are facilitated, which means a third party is managing the symbiotic relations. There are also some self-organised cases but not many planned ones. The fact that there exist not many planned networks says that when constructing industrial areas, the organism responsible did not think of industrial symbiosis. The exist, though, many cases with studies to improve already existing industrial areas.

Italian IS cases lack energy exchanges (exchanges are normally material based). There is also little facility sharing, although this aspect is harder to find anywhere. Finally, there is not much local stakeholders' investment, which affects the implementation of IS for sure.

In the case of Spain, the country is not as industrialised as Italy. Industries are agglomerated in coastal regions, especially in the community of Catalonia (where seven out of the ten Spanish IS cases were found), but also in Galicia, Cantabria, etc.

Information on Spanish industrial symbiosis cases is very limited, so the conclusions may not be highly accurate.

There are some Spanish industrial parks and possible IS approaches described; few of them already implemented. It is safe to say the majority of Industrial Symbiosis cases and Industrial parks that could potentially become EIP are located in coastal areas. As regards of the scope of Spanish IS cases, they are both local and regional in most cases and there is also one international case (networking).

Most of the cases in Spain are projects or studies on how to implement industrial symbiosis and they are not active just yet (or they were not at the moment the article was published). There is a lack of information about the number of exchanges and sectors involved in these cases.

The main characteristics of Spanish IS cases are, aside from the missing information: a good involvement of local stakeholders, which is certainly a great point in favour and differs from the Italian cases; the presence of networking in many cases, meaning companies have a great communication among them, and finally, a lot of cases where companies shared services, which is also a great positive point. The main things Spanish IS cases lack are energy exchanges and facility sharing, like in Italy.

Finally, IS exchanges were classified in different types and a new nomenclature was proposed to identify each type. This new nomenclature is related to biological symbiosis and other natural relations cases found in natural ecosystems but it is just a starting point for discussion, as it is difficult to identify biological situations in nature for the project developer as he is not educated in this field.

For sure there are limitations to the nomenclature proposed to classify the IS exchanges, among them the high number of different types found (which could be simplified, in families for instance, for a better understanding) and, on the other hand, it does not take into account the significance in the market of the final product obtained (commonly used or artisanal products/materials).

Special Thanks

I would like to thank UPC university for being able to utilise their library database service. Without access to this service, the project would have been more difficult and would also have taken much more time to develop.

I would also like to thank Università degli Studi Gabriele d'Annunzio for welcoming me on my Erasmus exchange and providing the assistance I needed (including their database service, which was not used in the end but is a valuable source of information).

Another indispensable piece for conducting this project have been the authors of the scientific papers, without them this project would not exist. Moreover, I would like to thank professor Tiberio Daddi, who sent some scientific papers via email.

I would like to thank Pilar Del Río and Martí Badal, two biologists that helped me finding cases of natural relations which were identified by the industrial symbiosis ones (section 6.3 tables).

I would like to thank both Dr. Rita Puig and Dr. Pere Fullana for helping me conducting the project properly and especially helping creatively in the development of chapter 6, related to the new nomenclature for industrial symbiosis individual exchanges; such idea came from them.

I would like to thank Professor and project coordinator Jordi Fortuny for the help he provided in guiding me on all necessary aspects to the correct development of this project.

Finally, I would like to especially thank the project supervisor in Italy, Dr. Andrea Raggi, who helped him throughout all the course of the project being there, guiding and helping, correcting and proposing changes.

References

ACR+, 2017. FISSAC - Site visit to the industrial symbiosis project "Manresa en Simbiosis" [WWW Document]. URL http://www.acrplus.org/en/events/event/323-fissac-site-visit-to-the-industrial-symbiosis-project-manresa-en-simbiosis (accessed 9.20.19).

Andrade, L.C., Míguez, C.G., Gómez, M.C.T., Bugallo, P.M.B., 2012. Management strategy for hazardous waste from atomised SME: Application to the printing industry. J. Clean. Prod. 35, 214–229. https://doi.org/10.1016/j.jclepro.2012.05.014

Cutaia, L., 2015. The experience of the first industrial symbiosis platform in Italy. Environ. Eng. Manag. J. 14, 1521.

Daddi, T., Tessitore, S., Testa, F., 2015. Industrial ecology and eco-industrial development: Case studies from Italy. Prog. Ind. Ecol. 9, 217–233. https://doi.org/10.1504/PIE.2015.073414

Domenech, T., Bleischwitz, R., Doranova, A., Panayotopoulos, D., Roman, L., 2019. Mapping Industrial Symbiosis Development in Europe_ typologies of networks, characteristics, performance and contribution to the Circular Economy. Resour. Conserv. Recycl. 141, 76–98. https://doi.org/10.1016/j.resconrec.2018.09.016

Duraccio, V., Gnoni, M.G., Elia, V., 2015. Carbon capture and reuse in an industrial district: A technical and economic feasibility study. J. CO2 Util. 10, 23–29. https://doi.org/10.1016/j.jcou.2015.02.004

Erkman, S., 2002. Industrial ecology: An historical view. J. Clean. Prod. 5, 1–10. https://doi.org/10.1016/s0959-6526(97)00003-6

Jacobsen, N.B., 2006. Industrial symbiosis in Kalundborg, Denmark. J. Ind. Ecol. [online] 10, 239–255.

Luciano, A., Barberio, G., Mancuso, E., Sbaffoni, S., La Monica, M., Scagliarino, C., Cutaia, L., 2016. Potential Improvement of the Methodology for Industrial Symbiosis Implementation at Regional Scale. Waste and Biomass Valorization 7, 1007–1015. https://doi.org/10.1007/s12649-016-9625-y

Mannino, I., Ninka, E., Turvani, M., Chertow, M., 2015. The decline of eco-industrial development in Porto Marghera, Italy. J. Clean. Prod. 100, 286–296. https://doi.org/10.1016/j.jclepro.2015.03.054

Marchi, B., Zanoni, S., Pasetti, M., 2018. Industrial Symbiosis for Greener Horticulture Practices: The CO2 Enrichment from Energy Intensive Industrial Processes. Procedia CIRP 69, 562–567. https://doi.org/10.1016/j.procir.2017.11.117

Marchi, B., Zanoni, S., Zavanella, L.E., 2017. Symbiosis between industrial systems, utilities and public service facilities for boosting energy and resource efficiency. Energy Procedia 128, 544–550. https://doi.org/10.1016/j.egypro.2017.09.006

Marconi, M., Gregori, F., Germani, M., Papetti, A., Favi, C., 2018. An approach to favor industrial symbiosis: The case of waste electrical and electronic equipment. Procedia Manuf. 21, 502–509. https://doi.org/10.1016/j.promfg.2018.02.150

Notarnicola, B., Tassielli, G., Renzulli, P.A., 2016. Industrial symbiosis in the Taranto industrial district: Current level, constraints and potential new synergies. J. Clean. Prod. 122, 133–143. https://doi.org/10.1016/j.jclepro.2016.02.056

Puente, M.C.R., Arozamena, E.R., Evans, S., 2015. Industrial symbiosis opportunities for small and medium sized enterprises: Preliminary study in the Besaya Region (Cantabria, Northern Spain). J. Clean. Prod. 87, 357–374. https://doi.org/10.1016/j.jclepro.2014.10.046

Puig, R., Argelich, M., Solé, M., Bautista, S., Riba, J., Fullana, P., Gazulla, C., Calvet, D., Raggi, A., Notarnicola, B., 2008a. Industrial Ecology as a planning approach for a sustainable tanning industrial estate. J.Soc.Leather.Tech.Chem. 92, 238–244.

Puig, R., Cervantes, G., Rius, A., Martí, E., Solé, M., Riba, J., 2008b. Ecologia Industrial aplicada al sector adober de Catalunya. Afinidad 65, 423–429.

Puig, R., Rius, A., Martí, E., Solé, M., Riba, J., Fullana, P., 2008c. Ecologia Industrial aplicada al sector paperer de Catalunya. Afinidad 65, 262–268.

Schiller, F., Penn, A.S., Basson, L., 2014. Analyzing networks in industrial ecology e a review of Social-Material Network Analyses. J. Clean. Prod. 76, 1–11. https://doi.org/10.1016/j.jclepro.2014.03.029

Sendra, C., Gabarrell, X., Vicent, T., 2007. Material flow analysis adapted to an industrial area. J. Clean. Prod. 15, 1706–1715. https://doi.org/10.1016/j.jclepro.2006.08.019

Simboli, A., Taddeo, R., Morgante, A., 2015. The potential of Industrial Ecology in agri-food clusters (AFCs): A case study based on valorisation of auxiliary materials. Ecol. Econ. 111, 65–75. https://doi.org/10.1016/j.ecolecon.2015.01.005

Simboli, A., Taddeo, R., Morgante, A., 2014. Analysing the development of Industrial Symbiosis in a motorcycle local industrial network: The role of contextual factors. J. Clean. Prod. 66, 372–383. https://doi.org/10.1016/j.jclepro.2013.11.045

Susur, E., Hidalgo, A., Chiaroni, D., 2019. The emergence of regional industrial ecosystem niches: A conceptual framework and a case study. J. Clean. Prod. 208, 1642–1657. https://doi.org/10.1016/j.jclepro.2018.10.163

Taddeo, R., Simboli, A., Morgante, A., 2012. Implementing eco-industrial parks in existing clusters. Findings from a historical Italian chemical site. J. Clean. Prod. 33, 22–29. https://doi.org/10.1016/j.jclepro.2012.05.011

Taddeo, R., Simboli, A., Morgante, A., Erkman, S., 2017. The Development of Industrial Symbiosis in Existing Contexts. Experiences From Three Italian Clusters. Ecol. Econ. 139, 55–67. https://doi.org/10.1016/j.ecolecon.2017.04.006

Vallès Circular, 2019. Vallès Circular, MARKET PLACE 2019 [WWW Document].

Vallès Circular, 2016. Simbiosi Industrial a Barberà del Vallès, Sant Quirze i Sabadell. [WWW Document]. URL https://www.youtube.com/watch?v=O3jrcVJ6wSs

Wikipedia, 2019. Symbiosis [WWW Document]. https://en.wikipedia.org/wiki/Symbiosis.

Zamorano, M., Grindlay, A., Molero, E., Rodríguez, M.I., 2011. Diagnosis and proposals for waste management in industrial areas in the service sector: Case study in the metropolitan area of Granada (Spain). J. Clean. Prod. 19, 1946–1955. https://doi.org/10.1016/j.jclepro.2011.07.004