Politecnico di Milano

SCHOOL OF INDUSTRIAL AND INFORMATION ENGINEERING

Master of Science - Management Engineering

Examination of prospects for Urban-Industrial Symbiosis development in Lombardy centered around the Construction & Demolition Supply Chain

Supervisor

Yulia Lapko

Candidates

Daniele Cardone – 915645

Marco Tognazzi – 928069

Academic Year 2020 – 2021

Contents

List of Figures

List of Tables

Acronyms List

Acronyms	Full term
ABS	Air cooled Blast Slag
AFC	Agri-food cluster
BATs	Best Available Practices
BF	Blast Furnace
BOS	Basic Oxigen Slag
C&D	Construction & Demolition
CE	Circular Economy
CISI	Consorzio Italiano Sub-fornitura Impresa
D&B	Drivers and barriers
EAF	Electric Arc Furnace
EEPA	Ecologically Equipped Productive Areas
EIP	Eco-Industrial Park
EMAS	Eco-Management and Audit Scheme
EPR	Extended Producers Responsibility
GBS	Granulated Blast Slag
IOA	Input-Output Analysis
IPCC	Intergovernmental Panel on Climate Change
IS	Industrial Symbiosis
LCA	Lifecycle assessment
LR	Literature Review
MFA	Material Flow Analysis
MSW	Municipal Solid Waste
NGO	Non-governmental organization
PRGR	Piano regionale gestione rifiuti
RM	Raw Material/s
ROs	Research Objectives
RQs	Research Questions
UIS	Urban-Industrial Symbiosis
UM	Urban Metabolism
UrS	Urban Symbiosis
VRM	Virgin Raw Materials
WEEE	Waste, electrical and electronic equipment

Preface

Abstract (English)

Environmental challenges have become one of the most important issue of the last decades. Both the huge amount of waste that is constantly produced and the increase in resource depletion rate will have devastating effects on the planet if not immediately addressed. Therefore, finding new innovative ways to deal with environmental problems is where most efforts from both companies and institutions are headed. A way in which both can achieve their environmental objectives is through the adoption of Circular Economy practises. In this context, Urban Industrial Symbiosis is a practical application of the CE model, that relies on the collaboration between different industrial and urban actors in order to maximize the value of material and waste flows. The objective of the thesis is to **assess current UIS development patterns in Lombardy**, particularly focusing on the C&D supply chain. To do so, two level of analysis have been adopted: A Macro level, where regional data is considered and both general economic and environmental benefits are calculated, and a Micro level where through a system of surveys and interviews, the perspective of selected actors is assessed and factors influencing their perspectives are discussed. The computations of the macro-analysis show that, by adopting UIS practices, waste producers could save up to 1042 M€/y (49%) and waste users up to 1094.M€/y (51%) for a total of **2150 M€/y** of economic savings/year, while the total amount of potential environmental savings generated is equal to **4693 ktCO2e/y**. On those figures the transportation impact is estimated to account for **4.12%** with respect to economic savings and **3.85%** with respect to environmental savings. The micro analysis highlights that economic, and normative drivers and barriers are still considered as the most relevant ones as they entail evident effects on companies' activities. Moreover, an analysis of from actors of the C&D supply chain is provided as well as the impact that a potential UIS system may on companies' exchanges. Results show that both the cement and steel sector are already virtuous example in terms of waste reuse while C&D actors may benefit more from materials' reuse.

Abstract (Italian)

Negli ultimi anni, le sfide ambientali a cui il mondo è sottoposto sono diventate sempre più rilevanti. Sia l'enorme quantità di rifiuti che viene giornalmente prodotta che l'aumento dell'utilizzo delle risorse avranno effetti devastanti sul pianeta se non affrontati immediatamente. L'economia circolare (CE) rappresenta un'opportunità per aziende private ed istituzioni per raggiungere obiettivi di carattere ambientale. La Simbiosi Urbana Industriale (UIS) è un'applicazione pratica dei principi della CE, che si basa sulla collaborazione tra diversi attori industriali e urbani al fine di massimizzare il valore dei flussi di materiali e rifiuti. L'obiettivo della tesi è valutare lo sviluppo della UIS nella filiera edilizia Lombarda. Per fare ciò, sono stati adottati due livelli di analisi: un livello Macro in cui, considerando i dati regionali, vengono calcolati i potenziali benefici economici e ambientali, e un livello Micro in cui attraverso un sistema di indagini e interviste, viene valutata la prospettiva degli attori selezionati e discussi i fattori che potrebbero avere un impatto sulle attività. I calcoli della **prima** mostrano che, i produttori di rifiuti potrebbero risparmiare fino a 1042 M €/anno (49%) e gli utilizzatori di rifiuti fino a 1094.M €/anno (51%), per un totale di 2150 M €/anno di risparmi economici. Si potrebbe inoltre arrivare ad abbattere fino a 4693 ktCO2e/anno. Su tali dati, si stima che il peso dei trasporti sia pari al 4,12% rispetto al risparmio economico e al 3,85% rispetto all'impatto ambientale. Successivamente, la **microanalisi** evidenzia che i driver e le barriere economiche e normative sono da considerarsi tra i più rilevanti in quanto comportano effetti evidenti sulle attività delle imprese. Inoltre, viene fornita un'analisi dei flussi degli attori appartenenti alla filiera edilizia, nonché l'impatto che un potenziale sistema di UIS potrebbe avere sugli scambi delle risorse tra imprese. I risultati mostrano che sia il settore del cemento che quello dell'acciaio sono già un esempio virtuoso in termini di riutilizzo dei rifiuti mentre quello edilizio potrebbe beneficiare di un maggiore riutilizzo dei materiali da costruzione.

Executive Summary

This section briefly recaps the contents of every chapter that has been included in this work. Further information concerning the **structure of the thesis** can be found in figure 0.1.

i. Introduction

Rapid Urbanization and Industrialization have forced the world to face many environmental challenges such as resource depletion, environmental emissions, severe smog events, and dramatic climate change. As a consequence, cities have come to play a critical role: a report from the UN-Habitat has estimated that cities alone constitute between 40 and 70% of GHG emissions and this number is doomed to grow. Nevertheless, within the boundaries of the urban ecosystem many potential flows could be turned into resources and limit this huge environmental impact. A particular branch of circular economy, named **Urban-Industrial Symbiosis**, has been receiving increasing attention because it can effectively minimize resource consumption and waste production by encouraging more efficient use of resources, and the use of waste as a resource. UIS could be a "win-win" strategy in reducing resources depletion, in better addressing the management of waste and in fighting climate change at global level by off-setting a critical share of carbon emissions, while generating economic returns. In harmony with that, the main purpose of this Thesis is to conduct a **exploratory study** on the field, centred around the **C&D supply chain**, to examine the prospects for development of **UIS** in the highly industrialized and urbanized **Lombardy** area, trying to investigate actors involved (governments, industrial and urban players etc.), flows (C&D, MSW, Metals, Cement etc.) and associated benefits (Environmental and Economic) as well as drivers and barriers fostering/hindering such development path (supply stability, geographical location, laws etc.). Behind the choice of centring the study around C&D sector in Lombardy there are mainly two reasons: the first is related to the **impact that the C&D supply chain** has on both the consumption of natural resources and the production of wastes, while the second is more of a **regulatory matter** as this sector has been highly targeted under both the European and the National/Regional level.

ii. Literature Review

The LR process started with the selection **of search engines and keywords**, which determined the creation of a final pool of 48 academic UIS papers. All of these were read and **classified** according to the type of analysis (Qualitative and Quantitative) and the type of research (Conceptual frameworks, Case studies and LRs). Afterwards, as the first step of the literature analysis, an **investigation of multiple stakeholders** from different fields and with different roles and interests was carried out. The main categories of actors identified are Central & Local Governments, Government agencies, public organizations, private associations, Universities, Business enterprises and Communities. Once having defined the potential actors, the focus shifted on the **exchangeable resource flows**. All the forty-seven synergies proposed by literature's authors have been initially mapped in a Supply and Demand Chart and later in a Flow Chart that also includes involved actors. After having analysed the studies from a whole UIS perspective, in accordance with the research objective of the Thesis, **the scope has been narrowed to the C&D sector**. The investigation process that was carried out at a broader level was repeated here. Actors revolving around the C&D supply chain were initially determined and possible synergies among them later assessed.

After having properly identified, classified, and mapped all the potential actors and flows involved, the attention of the LR was shifted towards the **analysis of factors**, i.e. all those aspects which could positively influence or hinder the development and the correct functioning of UIS practices. Factors have been pragmatically divided in six macro-categories: technological, informational, economic, organizational, regulatory, and environmental. Once having defined each single factor, seen that previous literature authors lacked in considering composite effects, a discussion has been held on the possible ways in which they may mutually influence (worsen, offset, or improve) each other. Subsequently, the investigation path moved toward possible **UIS development** phases. In accordance with what previously discussed by researchers, four development stages were identified: the first one where the system does not exploit UIS (called "no UIS"), the second one called "poverty stage" where UIS has just started its route, the third one called "economically viable stage" where the system starts benefitting from UIS, and the fourth where the city/area becomes economically, environmentally, and socially sustainable, i.e. "eco-area". Finally, when a clear and precise view on UIS key ingredients was available, the **geographical scope** of the analysis was narrowed down to Italy in order to evaluate potential of such systems. The first step was to check whether similar studies had been conducted in the country. However, as it has emerged from the small amount of literature available, Italian cases tended to omit the potential advantages arising from the urban context and directed their efforts on pure Industrial Symbiosis.

iii. Macro-Analysis

A macro-analysis is intended as **high-level regional** analysis focused on UIS in Lombardy as a whole and centred around the **C&D supply chain**, aiming at quantitatively estimating the economic and environmental savings potentially provided by the establishment of synergies. The will to carry out a quantitative analysis also derives from the fact that other case studies conducted in Italy limit themselves to qualitative considerations.

In the first place, the attention has been focused on gathering data on potential **volumes** exchanged and involved in possible symbiotic activities. As it has emerged, most part of waste volumes come from the C&D sector (76%) and the Iron & Steel (14%) and produced waste can be reused to substitute RM in industries such as Cement Production (19%), Iron & Steel Production (21%), C&D (33%) and Power Generation (27%). Potential **environmental and economic savings** have been later computed for each synergy and results show that, economically speaking, the actors that may benefit the most from correct waste re-routing are C&D companies, while the ones that may mostly benefit from replacing RM with waste are Iron & Steel companies. Environmentally speaking, the highest advantage arises from correctly addressing C&D, Urban (handled by waste collectors) and Iron & Steel Waste. On the top of that, the order of magnitude of the overall transportation impact (usually overlooked by authors in literature studies) has been estimated to be around 4%. Then, five criteria have been used to identify **best synergies**, i.e. the amount of volume exchanged, aggregate and specific savings (both economic and environmental). Results show that, due to their high economic value and emission factors, the synergies showing the greatest potential and priority are the ones related to metal scraps (e.g. iron, copper, brass, aluminium), followed by other C&D waste (e.g. wood, miscellaneous waste etc.), urban waste (plastics and organics) and part of Iron & Steel waste (GBS).

The biggest limitation of this macro-analysis derives from the lack of disaggregated data on public databases that has led to make assumptions that partially distort the goodness of numbers in mirroring reality.

iv. Micro-Analysis

Starting from the knowledge acquired on a higher level during the macro-analysis, the standpoint of research was shifted on a more specific **company-level** investigation centred around the C&D field, i.e. a "micro-analysis". The first step was the selection of companies. one-hundred and eighty-nine initial contact requests, including information about the project and a small survey, were sent out to companies operating along the supply chain with scarce results. Therefore, in order to find data, some personal contacts were used, and an initial pool of companies was developed. After this phase, the proper analysis started by reviewing companies' **sustainability reports**, as well as other publicly available data, in order to build an initial idea of each involved actor. At the same time, results of the survey were analysed to find drivers and barriers to companies' activities. After this phase, by merging data from the three mentioned sources, final results were developed. In particular, these include two flow charts of RM and waste both for the As Is situation and after the introduction of a potential UIS system, and a **deep analysis of D&B** currently impacting companies' activities. Nine potential symbiotic links between involved actors were found and their feasibility and nature discussed. The main limitations of this chapter are related both to the amount of data available and to methodological manners. As a matter of fact, the survey, that has been the main instrument to initially assess the view of companies on influencing factors was developed in a standardized way to allow an easier analysis of data from many companies. However, due to the fact that responses have been limited, this instrument could have been designed in a different way to allow companies to better characterize their answers. Lack of responses is also a factor that strongly mines the robustness of findings as the pool of companies cannot be properly considered big enough in statistical terms.

v. Conclusions

Both the macro and micro analysis, performed on very different levels have come together to the goal of **shedding light on UIS in Italy**. This is not as easy as one may think due to the colourful and **multi-sided nature of UIS**, that parallelly is its main strength and its main liability, as merging together different perspectives, different cultural and technological factors, different transportation and reutilization modalities, and different know-hows is extremely complex, requires commitment of many players and, above all, requires time and long-term vision. Therefore, the final **purpose of this Thesis** has been to lay the ground for future researchers and circular economy experts by providing the spark to enlighten the vast and unexplored UIS field, especially in Italy. However, it must not be forgotten that this work is only centred around the C&D supply chain and therefore only covers a small fraction of the whole UIS sphere; in this sense, many other sectors and actors need to be properly explored in order to fully establish where to start with changes. After having highlighted potential savings, influencing factors and impact on companies' activities, by relying on the little experience gained during this year of research, some **daring suggestions** for the future have been proposed to trigger the UIS diffusion in Lombardy and Italy:

- ✓ Renew an outdated regulatory framework that clearly does not reflect the needs of current industrial actors by better clarifying the priorities and the value of recovery activities.
- ✓ Develop a regional (and even national at some point in time) digital platform to exchange waste and tackle issues such as unbalance between waste demand and supply.
- ✓ Develop a solution to increase perceived quality of materials. An example may be a process of "waste branding" that aims at increasing the perception of companies concerning secondary raw materials.
- ✓ Adopt a proper system of taxes and incentives to even out the differences and turn the tables in favour of those UIS synergies that lead to good environmental returns but poor economic ones.

Research Philosophy

The philosophical paradigm used in this thesis, namely pragmatism, is hereby discussed.

Pragmatism accepts concepts to be relevant only if they support action. Pragmatics *"recognise that there are many different ways of interpreting the world and undertaking research, that no single point of view can ever give the entire picture and that there may be multiple realities"* (Saunders, Lewis, Thornhill 2012). Unlike positivism and interpretivism, pragmatism can integrate more than one research approach, strategy, and method (such as qualitative and quantitative) within the same study. The necessity of having methods that best fits the subject and its characteristics is the founding pillar of Pragmatism and following this concept, many different approaches have been used throughout this work to appraise different realities in multiple ways.

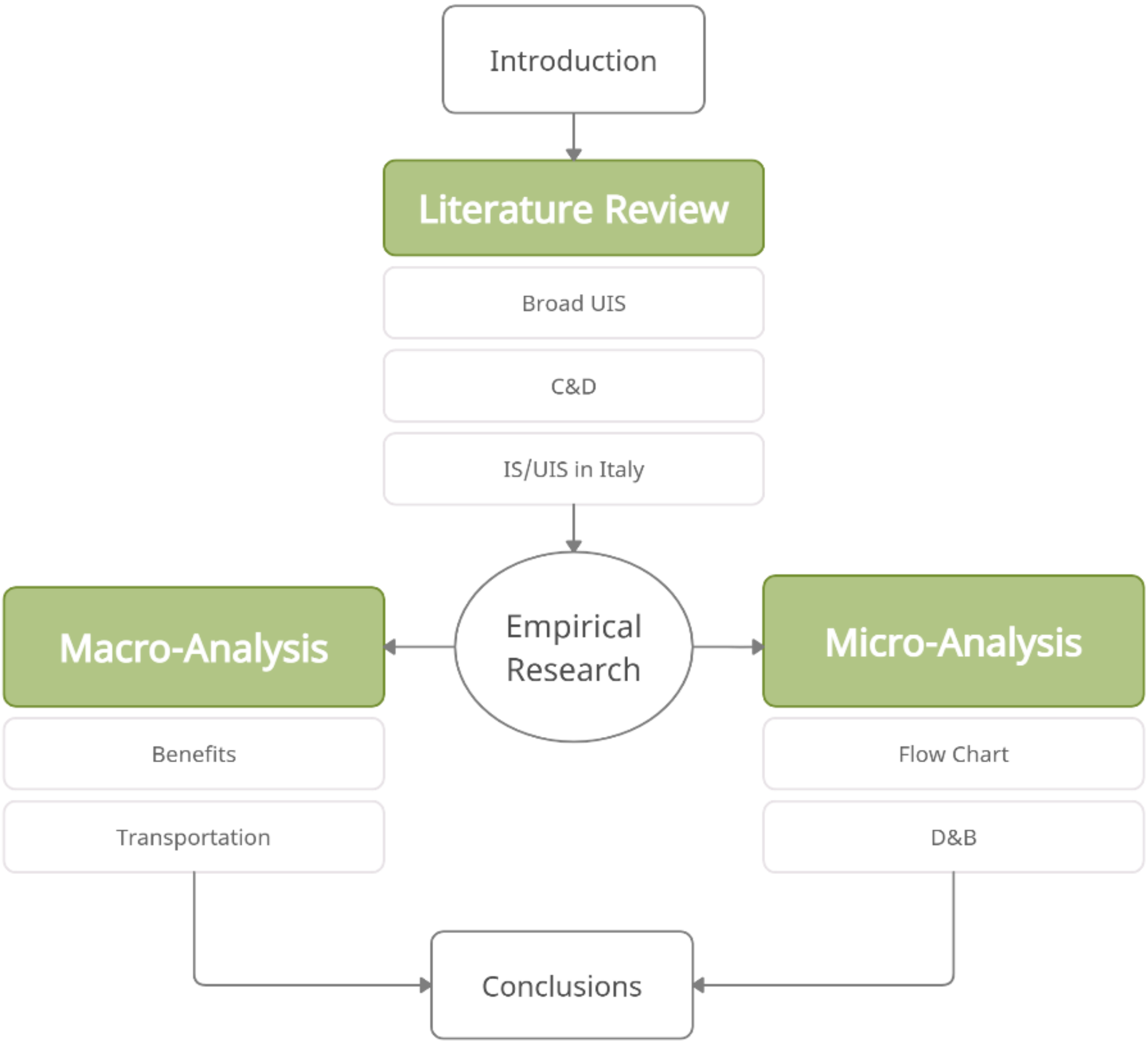


Figure 0. 1 General Map of the Thesis

1.General Introduction

1.1. Research Rationale

Rapid **Urbanization and Industrialization** have forced the world to face many environmental challenges such as resource depletion, increasing CO2 emissions, severe smog events, and dramatic climate change. **Industrialization**, defined as the large-scale introduction of manufacturing, advanced technical enterprises, and other productive economic activity into an area, society, or a country (Sminkey and Le Doux 2016), has to be blamed for such events as by-products arising from industries can adversely impact both human health and the environment. As an example, global estimates indicate that industry annually dumps between 300 and 400 million tons of heavy metals, solvents, toxic sludge, and other forms of waste in waterways (McCulligh and Fregoso 2019; A. Neves et al. 2020) and according to Eurostat in the 27 EU countries almost 900 Million tons of waste from production activities are landfilled every year and are responsible for methane gas emissions, leachate production, chemical and microbiological contaminants in air, water, and soil. Yet, the use of landfills to dispose urban waste is largely adopted both in low-income and in high-income countries. As an example, the two most populated countries in the world, China and India, make extensive use of landfills, where over the 80% of their municipal solid waste (MSW) is disposed (Albino, Fraccascia, and Savino 2015). Consequently, mitigating carbon dioxide emissions, which is the principal factor that influences global warming, has become a global priority. Many worldwide forums have been held to face this problem; in 2015 with the Paris Agreement, most countries in the world have committed to keep the temperature raise below 1.5° to try to tackle the adverse consequences that this effect has on both the environment and human health.

Surely, **cities** play a critical role in addressing this factor and its mitigation. According to a report from the United Nations, 54% of the world population lives in cities and this number is fated to grow as **urbanization** has become one of the main drivers for development, resource consumption and waste generation (Fang et al. 2017)**.** This might be considered as a positive socioeconomic factor as cities create wealth, generate employment, and drive human progress. However, failing to consider the impact of such improvements on the environment only shows the positive part of the picture without accounting for damages.

Also, industrialization and urbanization are striclty **related** and dependent on each other. As a matter of fact, historically the former has always led to the latter by creating new job opportunities that lured people to move into cities, while an increase in the city population oftentimes led to the creation of new businesses and indutries.. On the other hand, these urbanization rates are unsustainable under the Environmental perspective. A report from the UN-Habitat has estimated that cities alone constitute between 40 and 70% of GHG emissions and this number is doomed to grow as the increasing urbanization rates enlarge the burden of cities on the environment. Nevertheless, within the boundaries of the urban ecosystem many potential flows could be turned into resources and limit this huge environmental impact: MSW (Organic, Plastics, Paper etc.), C&D waste (metal scraps, wood, miscellaneous waste etc.), wastewater, post-incineration waste and others could all be redirected to a new purpose to lengthen their useful life and increase their lifecycle value. To help the creation of new cross-sectorial symbiotic links, many authors have dedicated their time studying the integration between urban and industrial environments, which is also the bridge that this Thesis tries to strengthen.

In particular, a specific branch of circular economy, named **Urban-Industrial Symbiosis**, has been receiving increasing attention because it can effectively minimize resource consumption and waste production by encouraging s the use of waste as a resource (Satoshi Ohnishi et al. 2018), the restoration and maintenance of urban environmental quality, and the promotion of highly efficient and effective urban and industrial planning, design, and management systems (S. Ohnishi et al. 2017).

In other words, UIS could contribute to the creation of a sustainable, safe, resilient, and inclusive ecosystem, in line with the 2030 Agenda for Sustainable development.

Yedla and Park (2017) describe the necessary conditions for the sustainability of a system, which is given by a double sided status of “external” and “internal” circumstances. The former refers to the capacity of the environment to supply the needed inputs to the ecosystem and also to accept the dissipated matter as a waste, elements that are limited by the finite nature of non-renewable resources and limited waste receiving capacity. The latter implies that sustainability of systems should be addressed more by attempting to improve the “internal conditions”, i.e. (industrial eco-) efficiency of the system. As a matter of fact, targeting the criteria of external sustainability alone (ability of the environment to supply/receive inputs and outputs) would not be enough. Hence, human systems need to adapt themselves to the endowments of the natural environment, and to do that it is necessary to meet the different internal conditions within a system. In harmony with that, UIS could be the leading path to sustainability by both promoting the introduction of material cycle approach to foster resource conservation and encouraging recycling by means of hybrid fuel-based production and manufacturing. In conclusion, UIS could be a **“win-win” strategy** by reducing resources depletion, better addressing the management of waste and fighting climate change at global level by off-setting a critical share of carbon emissions, while generating economic returns.

The countercheck of its potential is backed up by real applications which have been especially experimented in Asian countries. **China**, where urbanization and industrialization rates have been drastically increasing in the last decade, is making itself the ideal “laboratory” to practise Eco industrial development (Liang Dong et al. 2017) by applying many UIS practises. In the past decades, China has launched a series of projects for promoting sustainable urban development issues, i.e. eco-city project since 2003 (Caprotti, 2014; Lijuan et al., 2011; Nan Zhou et al., 2012b; Yang and Deng, 2013), circular economy city pilots since 2005 (Geng et al., 2009; Qiping, 2011; Su et al., 2013), low-carbon city project from 2010 (Dong et al., 2013a; Nan Zhou et al., 2012b; Wu, 2012). In parallel, in **Japan** the so called Eco-Town program, a state subsidized program (Rene Van Berkel et al. 2009), led to the establishment of 26 eco towns (including the renowned Kawasaki in 1997) and favoured the integration of IS and UIS seeking to maximise both economic and environmental benefits from close geographic proximity (R. Van Berkel et al. 2009)**.**

About EU continent, a comprehensive summary of existing European IS/UIS projects has been provided by Angela Neves (et al. 2019). All the studies conducted in **Italy** concern IS and do not account for the advantages unravelling from the urban context. The sole and one making exception (A. Simboli, Taddeo, and Raggi 2019) highlights the potential urban-industrial symbioses in the Pescara’s area, however it does not provide estimations regarding the economic and environmental savings generated. Moreover, to our knowledge, no previous study regarding UIS/IS has been performed in the Milan area and only one study concerning IS has been performed in Lombardy (Marchi, Zanoni, and Zavanella 2017).

1.2 Purpose of the Thesis

In harmony with what explained in 1.1, the main purpose of this Thesis is to conduct a **exploratory study** on the field, centred around the **C&D supply chain**, to examine the prospects for development of **UIS** in the highly industrialized and urbanized **Lombardy** area. By being an exploratory study, the level of analysis remains "high" and the aim of considerations/computations is centred around investigating the order of magnitude associated with UIS possibilities.

There are many reasons behind the choice of centring the study around C&D sector in Lombardy that can be grossly summarized into two groups: the first is related to the **impact that the C&D supply chain** has on both the consumption of natural resources and the production of wastes, while the second is more of a **regulatory matter** as this sector has been highly targeted under both the European and the National/Regional level:

- ✓ ***Environmental impact:*** this industry massively contributes to pollution and resource depletion as it is globally responsible for about **50% of the extraction of both minerals and energy , 35% of the waste produced (of which 50% concrete) and 40 % of global greenhouse gas emissions** (Xia, Ding, and Xiao 2020). Moreover, it also accounts for one-sixth of global freshwater consumption and one-quarter of wood consumption (Top 7 Most Polluting Industries | The Eco Experts). **Lombardy,** due to its high industrialization, is the Italian region with the highest production of both "non-hazardous special waste from C&D" (22% of the national level) and "hazardous waste" (33% of the national level) (ISPRA). And it handles the highest amount of "hazardous waste from C&D" and the second highest amount of "non-Hazardous waste from C&D". This impressive amount of waste that is generated yearly in Lombardy represents an enormous source of raw materials if properly valorised.

- ✓ ***Regulatory framework:*** At the European regulatory level, the building sector is one of the 5 reference sectors of the CE package (2015) and its importance has also been highlighted with the newly approved **Green New Deal**, that encourages member states to engage in a new renovation wave of both private and public buildings. Revamping operations or new constructions entail environmental benefits on one side and the production of new waste on the other side. The application of CE principles and UIS practises may be the solution to allow this improvement without generating a high burden on the environment. At the regional level, with the 2020 update of the PRGR (Piano regionale gestione rifiuti), CE practises (including UIS) have been highlighted as potential drivers for both environmental, economic, and technological innovations.

Based on these considerations, the development of an efficient UIS system in the C&D sector for Lombardy is crucial, especially considering that in the forthcoming future more and more resource will be harvested from cities rather than in the conventional way (Urban Mining).

1.3 ROs, RQs and Structure of the Thesis

Entering more in details, the **research objectives** are showed (table 1.1) and broken down into more specific **research questions** that have been answered all along the Thesis. The third column indicates whether the objective and the connected research questions are addressed into the LR part or into the field (or empirical) research, while the fourth column indicates the specific section in which the research questions are answered. Obviously, the LR and the empirical research are extremely connected and complementary to each other as the second part is largely based on the experience gained from the analysis of existing literature.

To accomplish those results, the project has thus been divided in two main parts: the first part of the project discusses the **LR** findings, i.e. what are the aspects that have already been studied by other authors, as well as the ones that need to be further explored. The second part of the project is a more focused and empirical analysis within the boundaries of **Lombardy** region, specifically designed around the **C&D supply chain**.

In fact, as a basis for the experimental part, it has been necessary to understand the composition of UIS first: its potentialities manly depend on the key ingredients involved (stakeholders, resource exchanges, etc.), the key factors affecting it (drivers/barriers), the key development stages to go through and its capability to generate value (economic, environmental, social). Subsequently, it has been necessary to adopt two different perspectives to better discuss UIS in Lombardy: in the first place, a **quantitative analysis** of the whole region, named Macro-Analysis, focusing on data from publicly available databases and existing literature findings has been carried out in order to appraise the environmental and economic potential of UIS on a regional basis.

Table 1. 1 Research Objectives, Questions and where they are answered.

Objectives	Research Questions associated	How	Section
1. Understand what are the **key ingredients** of UIS	•1.1. What are the key stakeholders for UIS? •1.2. What are the most common resource flows occurring in UIS?	LR	2,2
2. Explore the **factors** able to influence the UIS	•2.1. What are the factors able to hinder or drive UIS? •2.2. How can different factors interact and influence each other?	LR	2,3
3. Investigate **UIS development stages**	•3.1. What are the necessary and sufficient condition to develop UIS? •3.2. What are the key stakeholders involved in development and why?	LR	2,4
4. Understand and describe the current situation on the **UIS Italian Panorama**	•4.1. What is the current situation in Italy in terms of UIS? •4.2. What are the most important studies conducted in Italy so far?	LR	2,5
5. Identify **potential C&D actors** and their **input-output flows**	•5.1. What are the actors revolving around the C&D supply chain? •5.2. What are the most common exchangeable material flows among them?	LR	2,2
6. **Quantification of Economic and Environmental benefits** from the exchanges of the C&D related resources in Lombardy	•6.1. What are the actors generating the bulkiest volumes? Is the supply stable? •6.2. What are the best synergies in terms of environmental and economic benefits? •6.3. What is the order of magnitude of transportation impact?	Field Search	3,4
7. Select some actors revolving around the C&D sector and **analyse their main resource flows**	•7.1. What are the actors taken into account? What are the criteria? •7.2. What are their main flows? How could UIS impact them?	Field Search	4,4
8. **Analyse the feeling of actors about drivers and barriers** of UIS in Lombardy.	•8.1. According to the actors located in Lombardy, what are the most influencing factors?	Field Search	4,4
9. Provide **suggestions** about UIS development in Lombardy (and more in general Italy)	•9.1. What are the necessary conditions and steps for the UIS development in Lombardy/Italy?	Field Search	5

In the second place, a more **qualitative analysis** of specifically selected actors operating in the C&D supply chain has been performed in order to understand their "feeling" about UIS, the main flows exchanged and the factors affecting their position. The reason behind this choice lies in the trade-off between detail and depth of analysis: a quantitative approach at the Micro level would require a level of detail for each flow that is far higher than the purpose of this work, while a qualitative approach at macro level would have been too broad. As UIS is still a relatively unexplored field, and as this work aims to be set the basis for further research and to explore the whole supply chain rather than only some companies, it is firmly believed that this approach may result in the best possible outcome.

In accordance with the objectives and associated research questions, the Thesis has been structured as follows:

- ✓ the **LR part** (Chapter 2) starts with a clarification on some basic concepts and key definitions necessary for the general understanding of the thesis, followed by the explanation of methodological approach used and, consequently, a quick overview of contents is showed (Section 2.1). As next step, the key ingredients of UIS are discussed: the main stakeholders, materials flows, system boundaries and interactions between actors are investigated during the analysis (Section 2.2). Afterwards, the major factors characterizing the symbiosis are explored to find out which are the most crucial ones. It is important to know whether, within the literature, factors classifications have been rendered and whether these factors have been accredited as drivers or barriers. Subsequently, the relationships between those factors are analysed and most influential ones are pointed out (Section 2.3). Successively, UIS development paths are investigated trying to understand the role of each actor during each development stage (Section 2.4). Finally, an analysis is performed on the studies that have already been conducted within the Italian panorama (Section 2.5). As a final step of the LR a section is dedicated to recap all the gaps identified during the LR analysis (Section 2.6).
- ✓ the **Macro-Analysis** (Chapter 3) begins with explaining what the macro-analysis is about, which RQs are answered and how it is outlined. Consequently, it goes through the methodologies followed during the Data Collection process (Section 3.1), i.e. volumes of the flows and substitution factors of RM, and during the Data Analysis process (Section 3.2), in particular the ones used for the evaluation of environmental and economic savings, transportation impact and identification of the best synergies. Afterwards, the Findings are showed (Section 3.3) and then discussed (Section 3.4) by answering the addressed RQs. Conclusively, the main limitations of Macro-Analysis are pointed out (Section 3.5).

- ✓ the **Micro-Analysis** (Chapter 4) initially adopts a similar structure to the macro analysis by explaining RQs answered and the outline of the chapter. Then, before explaining the process of data collection (section 4.1) and data analysis (section 4.2), a section concerning the criteria for company's selection is proposed (section 4.0). To conclude the chapter, findings are presented (section 4.3) and later discussed (section 4.4). Limitations of the process are addressed at the end of the chapter (section 4.5), before proceeding with conclusions reported in chapter 5.

In conclusion, to wrap up the structure and give an overview of this Thesis, a Roadmap (figure 1.1) showing the key elements characterizing the research is hereby reported:

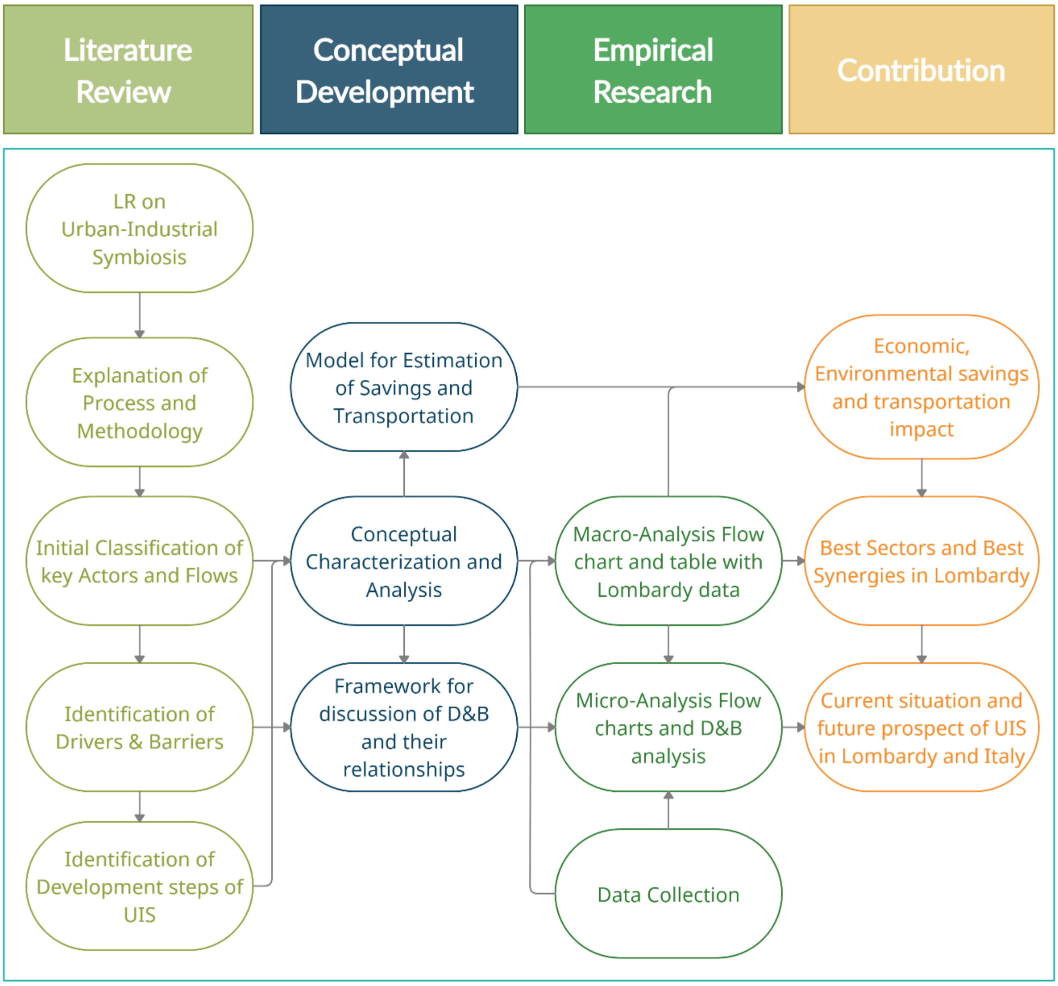


Figure 1. 1 Study Roadmap showing the most important steps.

2. Literature Review

2.1 Introduction to LR

2.1.1 Definitions of the most important concepts

Before starting with the LR, it is necessary to clearly point out what different terminologies mean, what it is intended in this study with urban-industrial symbiosis and why it can be the key for reaching sustainability (Table 2.1). Starting from the ethimology of the term, the concept of ‘‘symbiosis’’ originates from the notion of metabolism in biological communities where at least two otherwise independent/unrelated species exchange materials, energy, or information in a mutually beneficial manner. The word “metabolism” refers to the rates of consumption and exchange of materials among the entities. These entities can be either urban-based (e.g. a hospital or a household) or industrial-based (e.g. a production plant).

Industrial symbiosis (IS) is defined as “a subfield of industrial ecology that engages separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy and services” (Albino, Fraccascia, and Savino 2015). A definition provided by Lombardi and Laybourn (2012) includes another important factor that is the exchange of information flows: “industrial symbiosis engages diverse organizations in a network to foster eco-innovation and long term culture change… the exchange of knowledge, information and expertise also positively influences the physical flow of material and energy—thus we replace the physical exchange of resources as the core of industrial symbiosis with eco-innovation as the result”. Moreover, (M. R. Chertow 2000)**,** one of the most significant researcher of this field, described the key to successful IS as the “collaboration and the synergistic possibilities offered by geographic proximity”. This idea has been further extended to urban waste and energy exchange from industrial complexes, a concept known as **Urban symbiosis (UrS)** (Rene Van Berkel et al. 2009)**.** UrS is regarded as an extension of IS and is defined as “the use of by-products (wastes) from cities (or urban areas) as alternative raw materials or energy sources in industrial operations” (Rene Van Berkel et al. 2009; H. Dong et al. 2014). Both IS and UrS focus on waste recycling, heat exchange and a symbiotic network (including information exchanges) that can offer benefits to the entire society by saving virgin materials and reducing environmental emissions (H. Dong et al. 2014; S. Ohnishi et al. 2017).

Table 2. 1 Definition of UIS and associated concepts.

Concepts	Definition
Industrial Ecology (IE)	The concept of industrial ecology "requires that an industrial system be viewed not in isolation from its surrounding systems, but in concert with them. It is a systems view (interconnection between systems) in which one seeks to optimize the total materials cycle, from virgin materials, to finished material, to component, to product, to obsolete product, and to ultimate disposal. Factors to be optimized include resources, energy, and capital". (M. R. Chertow 2000)
Industrial Symbiosis (IS)	Industrial Symbiosis is a subfield of industrial ecology that engages separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy and services" (Albino, Fraccascia, and Savino 2015). "Our experience indicates that the exchange of knowledge, information, and expertise also positively influence the physical flows of materials and energy" (Lombardi and Laybourn 2012)
Eco-Industrial Park (EIP)	The exchange of material and other stream of by-products happen among industries clustered together and the type of symbiosis could vary depending on the character of different clusters. While cluster of similar industries coexisting in a geographical location can share certain common infrastructure such as power source, water sources, and waste discharge streams, different categories of industries clustered in a geographical location can get involved in the exchange of resources, by-products, and also waste products. Such industrial clusters where symbiosis is practiced could be called EIP. (Yedla and Park 2017)
IS Network/Virtual EIP	IS networks as "collection of long-term, symbiotic relationships between and among regional activities involving physical exchanges or materials and energy carriers as well as the exchange of knowledge, human or technical resources, concurrently providing environmental and competitive benefits" (Albino, Fraccascia, and Savino 2015).
Urban Metabolism (UM)	In practice, the study of an UM involves the quantification of the inputs, outputs and storage of energy, water, nutrients, materials and wastes for an urban region. (Simboli, Taddeo, and Raggi 2019)
Urban Symbiosis (UrS)	It is an extension of IS: it consists of the use of waste produced in cities by adjacent industries in their industrial operations, either as an alternative to raw materials or as a source of energy, facilitated by the geographical proximity between them (Van Berkel et al., 2009b).
Urban Industrial Symbiosis (UIS or IS/UrS)	In spatial perspective, urban industrial symbiosis optimizes the regional metabolic network through resources and infrastructures allocation, so as to reduce resource consumption and emissions, and coordinate the interaction between industries and urban development (Dong et al., 2013a,b; Gibbs and Deutz,2007).

The main difference is that IS occurs at the inter-firm level because it includes exchange options among several organizations, while UrS occurs at city level since it extends the concept to urban-industrial synergies and provides the opportunity of building up fruitful exchanges of resources and waste between cities and local EIPs, consequently reducing carbon emissions both at industrial park and urban levels. Two of the most common examples regarding IS and UrS respectively are: BF Slag replacing a fraction of clinker in cement production (Rene Van Berkel et al. 2009) and Low pressure steam reuse as heat source for buildings (Liang Dong et al. 2014).

Urban-industrial symbiosis (UIS) is a further extention of both IS and UrS. In spatial perspective, urban industrial symbiosis optimizes the regional metabolic network through resources and infrastructures allocation, so as to reduce resource consumption and emissions, and coordinate the interaction between industries and urban development (L. Dong et al. 2013). Therefore, whether urban symbiosis only considers the utilization of waste produced by adjacent industries (R. Van Berkel et al. 2009)**,** UIS expands the relationships creation on a regional level by coordinating the interaction between industries and cities. An example of UIS could be the use of waste plastics from urban environment to replace coal for cement kiln supply (Hashimoto et al. 2010)**.**

With the introduction of IT technologies in the symbiosis world, it is also important to define **an IS network** as the "collection of long-term, symbiotic relationships between and among regional activities involving physical exchanges or materials and energy carriers as well as the exchange of knowledge, human or technical resources, concurrently providing environmental and competitive benefits": in other words, IS networks broke through the former geographical limitations of EIP and its developing direction is towards regional waste exchange network, so it's called "virtual" EIP (Albino, Fraccascia, and Savino 2015).

2.1.2 Process and methodologies

To answer the above-mentioned research questions, the following research process has been followed (figure 2.1). For the sake of transparency, the methodology followed during the LR partly originates from advices given in the book "Research methods for business students" (MacLean 2013).

The preamble to this section was the choice of which **research engine** to use. Scopus was chosen over other alternatives such as Google Scholar and Web of Science, as it allows a more structured research and gives all the information needed about the papers immediately. In this way it is quicker to find reliable and organized information for the analysis.

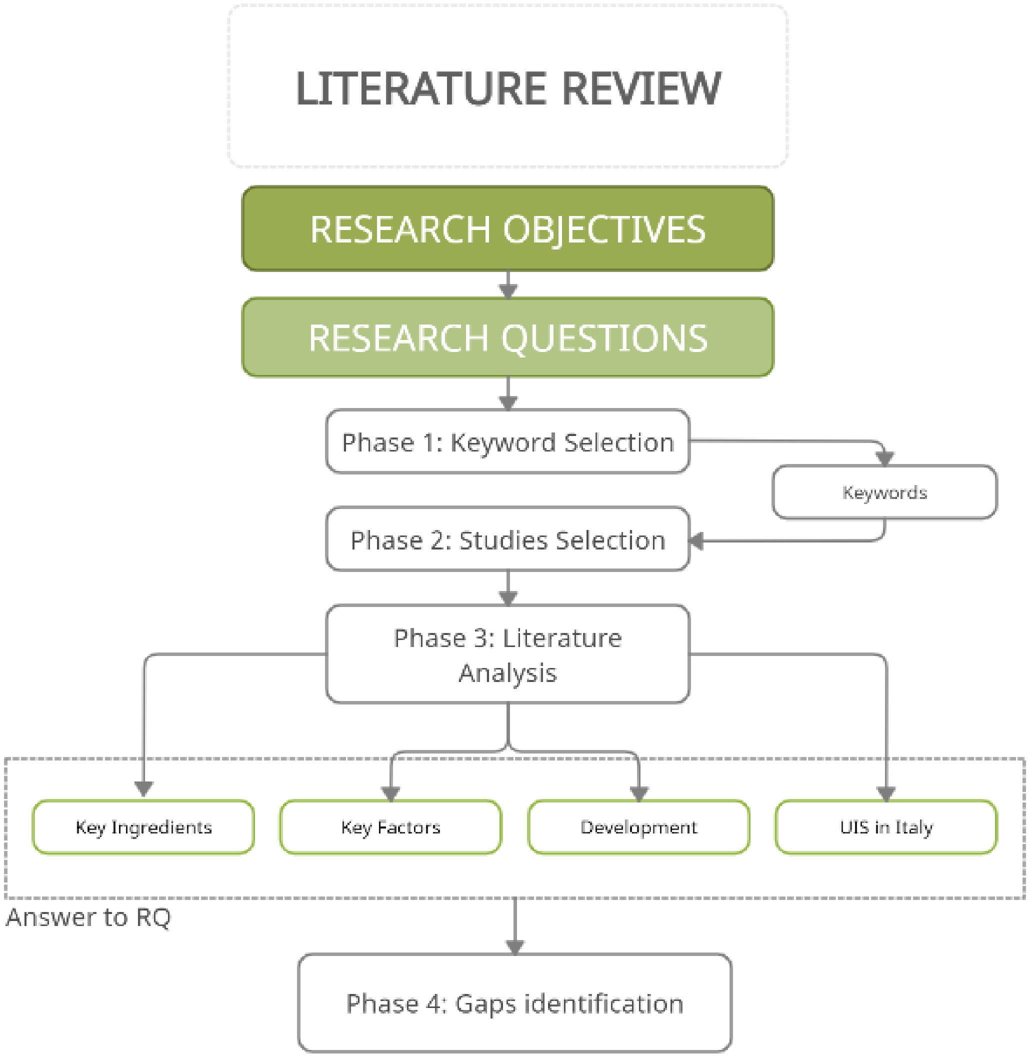


Figure 2. 1 Outline of Literature Review.

<u>Phase 1:</u> The pivotal decision regarded the selection of **keywords**. This step is the most important of the literature research as the outcome of the analysis entirely depends on it. As already mentioned, in order to guarantee an appropriate literature review on the whole UIS field, the first part of the research process has been dedicated to UIS at large and not specifically focused on C&D sector. Therefore, a semantic research for the terms that where most likely to be crucial for the purpose of this study, namely “Industrial Symbiosis”, “Eco-Industrial park” and “Urban Symbiosis” was needed. Then, starting from those three terms a list of keywords has been created. Particularly, the former has been developed based on

the study of Butturi (et al. 2019) who identified the concepts associated with the above-mentioned terms and has been reported in table 2.2.

Table 2. 2 Potential keywords considered.

Initial term	Relevant associated keywords and concepts
Industrial symbiosis	•"industrial symbiosis" •"industrial metabolism" •"industrial ecology" •"industrial eco-efficiency"
Eco-Industrial park	•"EIP" •"eco-industrial park*" •"mixed use eco-park*" •"Eco-industrial districts" •"Eco-industrial clusters" •"Eco-industrial estates" •"Eco-industrial regions"
Urban symbiosis	•"urban symbiosis" • "urban metabolism" •"Industrial symbiosis at urban level" •"urban-industrial synergies" •"eco-town" •"district heating"

"Industrial Symbiosis" is often referred to as "Industrial Metabolism", which more specifically concerns material and energy flows exchange, and it is part of "Industrial Ecology", whereas the concept of "Industrial Eco-efficiency" can be complementary to UIS seen as "internal condition for sustainability" discussed by Yedla and Park (2017) (Section 1.1). **"Urban Symbiosis"** is often referred to as "Urban Metabolism" or "Urban Industrial Symbiosis" or "IS at urban level" or "urban-industrial synergies". Other related concepts are the terms "eco-town" and "district heating", even if the latter only concerns heat exchanges between factories and urban areas (Butturi et al. 2019).

Moreover, the concept of **"Eco-industrial park"** is the transposition of IS principles in a real application. The denomination "Eco-industrial park" can have diverse synonymous often used in papers and articles, such as "Eco-industrial district"," Eco-industrial cluster" and "Eco-industrial estate", as well as "geographically concentrated industrial activities" (mainly process activities with close physical couplings of a relatively small number of materials and energy intensive production processes), "mixed industrial park" (where SMEs of different sectors with little coupling of production processes are concentrated in dedicated areas), and “eco-industrial regions” (referred to as administrative areas where diverse or related industrial enterprises are located) (Butturi et al. 2019).

Thereafter, the best keywords have been selected according to the highest number of results generated on Scopus. At first, **standalone research** has been conducted for each different keyword, then the ones that received most matches **were combined**. As a stopping signal, the fact that no additional papers were found when adding a keyword has been used. In the example of EIP the evidence shows that none of the synonyms is relevant in terms of boosting research results since most part of the former is found by digiting “eco-industrial park” and “EIP”. Same happens for IS by using “industrial symbiosis” and “industrial metabolism” and for UrS by using “urban symbiosis” and “urban metabolism “. Under the light of these consideration, the useful keywords left for the research are showed in table 2.3.

Table 2. 3 Keywords selected.

Initial Term	Best Keywords
Industrial symbiosis	•“industrial symbiosis” •“industrial metabolism”
Eco-Industrial Park	•“EIP” •“eco-industrial park*”
Urban symbiosis	•“urban symbiosis” •“urban metabolism”

<u>Phase 2:</u> Based on these keywords, **three separated study research were conducted**. The first one relates to the association IS-EIP and brings up to 2859 results. The second refers to Urban Symbiosis itself and outlines 754 results. The third and last research merges both perspectives into a unique research: (“industrial symbiosis” OR “industrial metabolism” OR “EIP” OR “eco-industrial park*”) AND (“urban metabolism” OR “urban symbiosis”) and resulted in 32 studies (figure 2.2). In keeping with this, figure 2.3 clearly points out that there has been a considerable amount of research for the IS-EIP and a fair amount of research for Urban symbiosis, but just few papers discuss the interconnections and interlinks between the two. This recognized the potentialities of the combination of these two concepts and started debating them together.

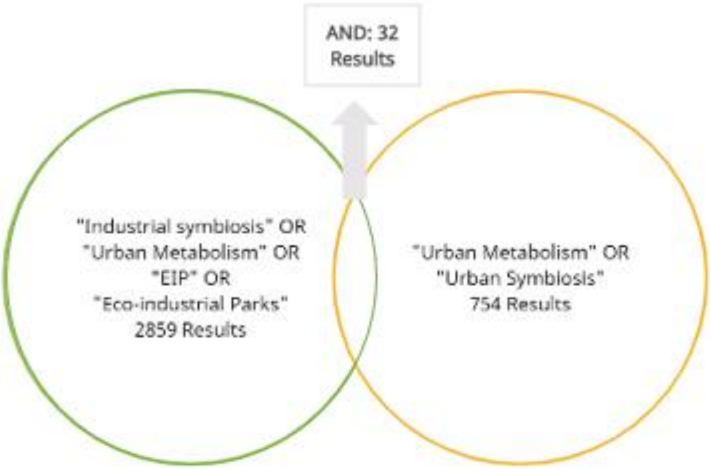


Figure 2. 2 Research results synthesis

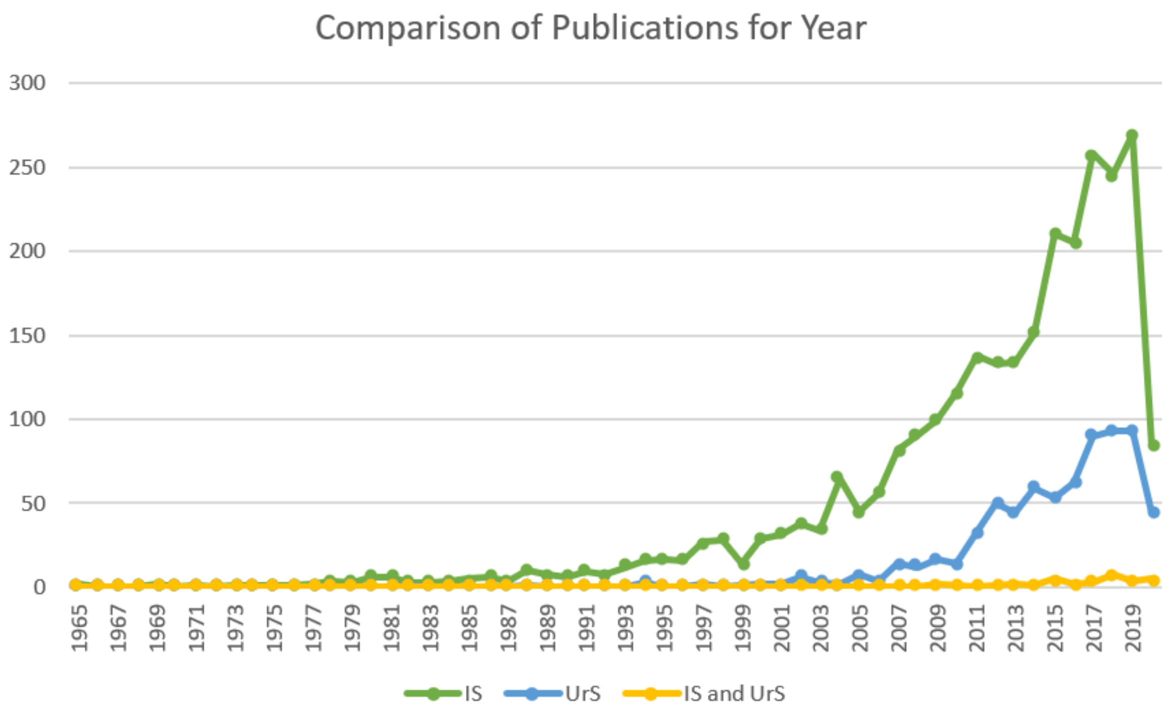


Figure 2. 3 Classification of studies per types of analysis conducted.

Consequently, this LR has been focused on the 32 UIS results; however, 3 of them were not publicly available, therefore the initial pool of papers has been restricted to 29. Then, after the examination of these studies, other studies were added to the pool through the snowballing method. Particularly, Fraccascia (et al, 2018) provides useful insights that partially overlap with the interest of our LR review. Consequently, 19 documents that have been cited by the author were added to the pool of analysis bringing the total number to **48**

papers. At the end, after having analysed and explored these papers, some searches have been conducted for the C&D sector too. Many academic articles have been read to obtain a general understanding of C&D sector dynamics; however, they do not strictly relate with UIS and so they have not been added to the pool of papers.

Anyhow, among the read papers the ones of particular interest for the connection between UIS and C&D sector have been used to build the C&D flow chart in paragraph 2.2.3 (figure 2.10).

2.1.3 Overview of the results

Phase 3: Before moving to the actual analysis of results, a proper classification of the studies was needed.

All the documents were classified according to the **type of analysis** (figure 2.4) into Qualitative (that describe some aspects of symbiosis without using numerical computations) and Quantitative (using numerical computations methodologies to assess different parameters of different symbiosis) and according to **the type of research** (figure 2.5) into Conceptual frameworks, Case studies and LRs.

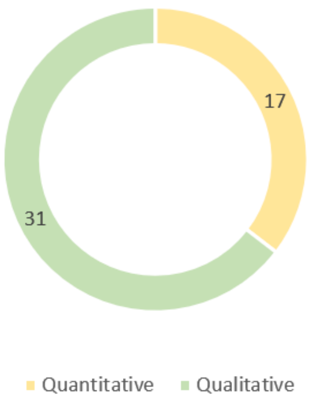


Figure 2. 4 Classification of studies per types of analysis conducted.

Qualitative: The relevance of these papers (as for this study) is mainly related to the understanding of what are UIS key ingredients and what are the developmental steps to follow. For instance, R.Van Berkel (et al. 2009) adopts an holistic approach in describing the Eco-Town program run in Japan and, in some parts, explicitly talk about material flows and related applications. Others (Chen et al. 2012; Lenhart, Van Vliet, and Mol 2015) discuss and examine the potential barriers/enablers of IS-UrS. Similarly, Yedla and Park (2017) discuss the drivers/barriers of eco-industrial networking and identify what are the conditions and strategies required at different levels for development. In connection with IS networking, G.-F. Liu and Chen (2013) investigate the win-win effects of IS on the field of socio-economic consequent to the NISP (national industrial symbiosis programme) launch, i.e. a nationwide symbiosis programme started in the UK. Even though it is not the main focus of this study, there are also some information about EIP development: for instance, the economic, social and environmental benefits (Park et al. 2008; Sacirovic, Ketin, and Vignjevic 2019). Moreover, Fraccascia (2018) looks for synergies and barriers/enablers to materials exchanges from the producer to the new potential user. Enablers/barriers discussed are quantity, stability of the flows, awareness, treatment technology, price of waste disposal vs input purchasing and government subsidies.

Quantitative: The importance of this category of studies is given by the fact that they allow to evaluate what the real impacts of UIS/IS practises have had on real life scenarios and to initially determine whether a certain material symbiosis is able to guarantee savings or not. Obviously, the advantages connected with UIS linkages cannot be determined a priori as they are influenced by various factors (section 2.3) but through the analysis of previous data a "pre-evaluation" can be provided. Here the objective is to clear **how authors usually quantify UIS** value and which methodologies they use: MFA, LCA, IOA and Emergy analysis have generally been the most adopted ones. However, due to the fact that MFA ignores the quality characteristics of the material flow and the contribution of natural and socio-economic system to environmental emissions (Fernandez-Mena, Nesme, and Pellerin 2016), lacks the life cycle view (Sun et al. 2017) and needs precise data that is not always available (Liang Dong et al. 2014; Li, Dong, and Ren 2015), the number of studies that used a pure MFA analysis to quantitatively assess environmental benefits of industrial system is limited. Within our pool of research, examples of the application of this approach include a chemical industrial park in north western China (Guo et al. 2016), a cement plant centred urban ecosystem (Cao et al. 2018), the resource intensive steel based cities of Jinan and Liuzhou (Liang Dong et al. 2014) and the Kawasaki Eco Town (Rene Van Berkel et al. 2009). In order to fill the gaps of MFA, the LCA (Life Cycle Analysis) method, which is suitable for environmental assessment of all products and services, can be used However, LCA artificially cuts the objectively continuous production process which causes errors, and it also requires more detailed data (Fernandez-Mena, Nesme, and Pellerin 2016; Geng, Tsuyoshi, and Chen 2010; Sun et al. 2017). An input output analysis (IOA) may be adopted to fill these gaps by adopting a broader perspective and avoiding unnecessary artificial cuts. There are also cases (Liang Dong et al. 2013, 2016, 2017) where these two methodologies have been combined in the so-called Hybrid LCA model that can be used to analyse micro entities too with an Input output approach (Fang et al. 2017) but still faces problems connected with the fact that estimations may not be adequately informative since many other materials are produced out of the cities but consumed within them (Ramaswami et al., 2008). To better fills the gaps, a comparison of MFA, LCA and Emergy has been proposed by (S. Ohnishi et al. 2017) and the result of the study highlighted that the Emergy approach entailed higher savings than the ones calculated through the LCA due to the broader perspective adopted; consequently if policymakers were to consider only an LCA approach, results would be underestimated leading to less attractiveness of UIS. The Emergy analysis can also be effectively combined with the MFA as demonstrated in both Yongcheng (Lu et al. 2020) and Liuzhou (Sun et al. 2017). In the first study, a combination of 39 symbiotic activities was evaluated in a city where mining and related activities are the dominant industries for the economy. In the second case, the hybrid model was applied to the city of Liuzhou, the industrial centre of the Guangxi province whose economy is strictly dependent on iron and steel production (L. Dong et al. 2013). Although the studies were conducted in a precise manner under the environmental perspective, they completely lack a study regarding the economic feasibility of UIS projects. The main gap associated to these used methodologies relates to the fact that they are not able to quantify social value, which is neglected. Social value is very difficult to be numerically expressed, anyhow thanks to sustainable urban and industrial development the positive externalities generated on the community are many (e.g. increased property value, occupation, lower pollution..) and may account for a considerable share on total benefits. Furthermore, the impact of transportation is overlooked in most of the studies: authors focus is on the environmental and economical savings that are entailed by each material flow in the symbiosis but, they fail to report the impact of transportation cost and factors external to the symbiosis on results. Neglecting transportation not only means to neglect a considerable part of the emissions, but it entails not considering the real economic viability of resource exchanges.

Other than the classification according to the type of analysis conducted (quantitative vs qualitative), the literature studies have been classified also according to the **type of research** (figure 2.5) performed:

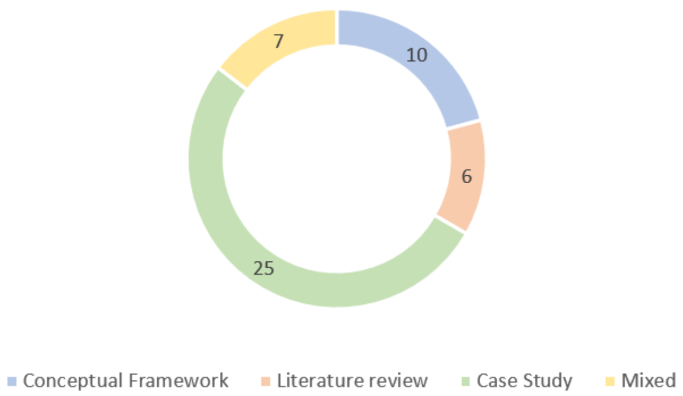


Figure 2. 5 Classification of studies per type of research conducted.

Conceptual frameworks: intended as those papers that analyse the topic from a theoretical perspective, for instance by generalizing some aspects within a new theoretical framework which could be then applied to different situations, i.e. without empirical data collection.

Case studies are the application of UIS/IS concepts to different regions of the world; a case study can both be a qualitative assessment or a quantitative one according to the perspective adopted by authors. There can be also an "hybrid" paper (12,5% of papers in our pool) that is something in between these two types where authors both discuss a new theoretical framework and apply it to a specific case.

LRs: Previous Literature Reviews on different topics related to symbiosis, which have been done in the past by other authors.

A detailed table containing a complete classification of all the read studies can be found in appendix ("Literature Table").

The following sections present the results obtained from Literature Analysis. Key ingredients (stakeholders and materials flow) have been discussed in section 2.2, followed by D&B (section 2.3) and development stages (section 2.4). At the end of the LR, an analysis of current LR regarding UIS/IS in Italy has been provided (section 2.5) and lastly, a definition of the key gaps of current studies concludes the chapter (section 2.6).

2.2 Key Ingredients of UIS

In this section the main objective is to answer the research questions related to finding the “key ingredients” in order to support the realization of the final goal of this work, i.e. to spot and map the potential actors and resources exchanges in Lombardy. The term key ingredient refers to both **stakeholders** participating in the symbiosis and **resources exchanged** in the network. Once the general background provided by literature had been analysed, the most common kinds of actors and resource flows to look for became clear. To be thorough in this part is important as UIS projects happen to be very complex since they involve multiple stakeholders operating in different fields (e.g., citizenships, companies producing and using wastes, government, companies collecting wastes etc.) and every actor of this intricate system usually has different interests from the others and can play a totally different role. The investigation is completely focused on the literature contents: the first paragraph (2.2.1) discusses and frames literature concerning key stakeholders, while in the second one (2.2.2) the same has been done with literature containing the resource flows and the interconnections between actors. The third paragraph (2.2.3) proceeds with a characterization of the C&D field and an analysis of its supply chain.

2.2.1 Classification of Stakeholders

One of the key purposes of this LR is understanding how UIS could affect the interests of each actor belonging to the system and which advantages or disadvantages could it bring to them. Thus, as a first step when studying a UIS system, it is fundamental to identify the stakeholders revolving around it. In the existing literature analysed for this study, no previous study has strongly focused on the stakeholders involved in UIS, thus a very precise classification does not exist. However, it is possible to uncover them by using a **reverse approach**, as many academic papers (table 2.4) tend to state what the actors exchanging the flows within a system are when displaying the results of their computations or when defining the system boundaries. Accordingly, the table below illustrates some studies in which different categories of actors have been identified as well as a frequency analysis that shows how often these actors have been considered in literature.

Table 2. 4 References of actors involved per paper.

		(S. Ohnishi et al. 2017)	(L. Dong et al. 2013)	(L. Dong et al. 2013)	(Lu et al. 2020)	(Kerdlap et al. 2019)	(Geng, Tsuyoshi, and Chen 2010)	(Fang et al. 2017)	(Sun et al. 2017)	(L. Dong et al. 2017)	(Li, Dong, and Ren 2015)	(Ong, Ie, and Ang 2016)	(L. Dong et al. 2013)	(Hashimoto et al. 2010)	(L. Dong et al. 2016)	(Cao et al. 2018)	(Liang Dong et al. 2014)	Freq.
I	Industrial waste Collectors	x	x		x			x	x		x			x	x		x	9
	Rubber Producers			x				x	x			x						4
	Chemical Producers	x		x			x		x					x			x	6
	Cement producers	x	x	x	x		x	x	x	x	x	x		x	x	x	x	14
	Iron & Steel Mill	x	x	x	x		x	x	x	x	x			x	x	x	x	13
	Ceramic Producers															x		1
	Biofuel Producer						x											1
	Paper Mill	x		x										x				3
B	Farmers				x	x						x	x					4
	Mines			x				x		x	x				x	x		6
	Power Plants			x	x	x		x	x		x	x	x		x	x	x	11
U	MSW collectors	x		x	x			x	x			x		x				7
	Hotels/Restaurants					x												1
	Wastewater Treatment Plants	x		x													x	3
	C&D companies	x												x				2
	Residentials / Offices				x												x	2

Governments are not mentioned in table 2.4 as the table only refers to studies in which actors exchange physical flows. Anyhow it does not mean that governments are not involved in UIS, therefore, after having identified the possible actors exchanging flows it is necessary to classify them and have a more accurate understanding of their nature. Among the analysed studies, one in particular might be helpful to accomplish this: Liu and Chen (2013) explain what is the **role that each actor** has within UIS development process and, to do so, actors are positioned according to different categories: Central & Local Governments, Government agencies (e.g. EPB, NDRC), public organizations (e.g. industry associations), private associations (e.g. NGO), Universities, Business enterprises and Communities. This classification evidently highlights what the main categories of actors that can take part to UIS according to their social-legal role are and it has been used in paragraph 2.4.2 to define the Role of the different UIS actors in development**.**

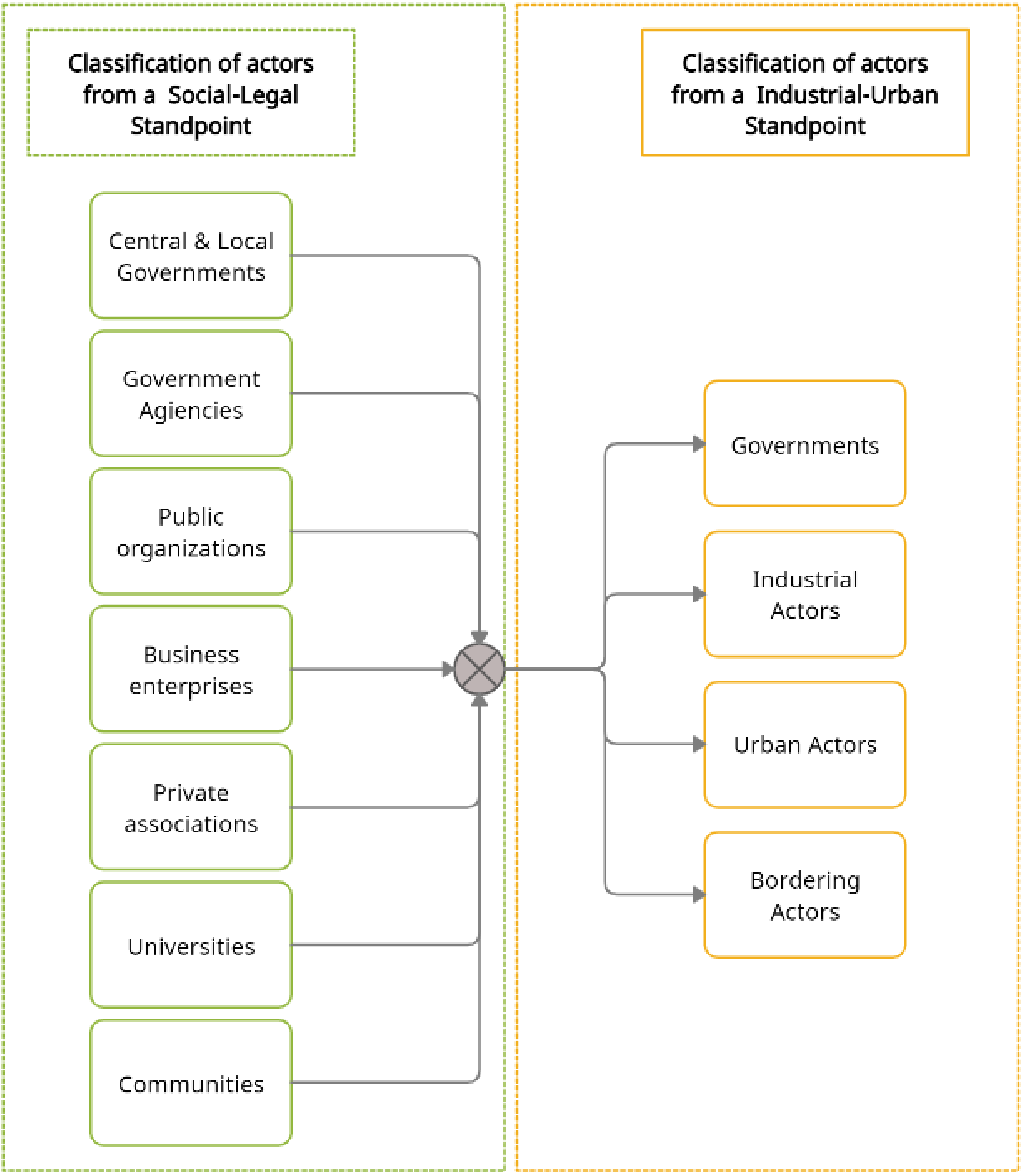


Figure 2. 6 Categorizations of actors involved in UIS.

However, as the papers cited in the table above implicitly confirm too, this kind of classification (the one in green from figure 2.6) is **not suitable** when analysing and displaying the resource flows that characterize the symbiosis. In fact, due to the fact that actors are seen as entities exchanging the resources, there is no need to know whether organizations are public rather than private or whether the government acts through a public organization rather than an agency for flows mapping sake. What is important to know is whether the actor considered belongs to the industrial world and/or to the urban context, or neither to the first nor to the second one. In this way, it is possible to understand the type of symbiosis occurring by knowing whether the flow only relates to the urban environment (UrS), the industrial environment (IS) or both (UIS). Therefore, a **simpler classification** (showed in yellow in figure 2.6) considering four categories of actors has been deployed in paragraph 2.2.2: Government, Industrial Actors, Urban Actors and Bordering Actors. The first stands for both local and central governments, the second one embeds all the actors belonging to the industrial world (e.g. material producers, scrap generators, industrial waste collectors etc), the third one is referred to all the actors located in a urban environment (universities, households, MSW generators and collectors, restaurants etc.), and the fourth one envelops all the actors neither belonging to the industrial nor to the urban actors, but revolving around them (mines, power plants and farmers). In accordance with this simpler classification the identified actors have been coloured in green (urban), orange (bordering) and grey (industrial) (Table 2.4). Again, governments do not physically exchange resources thus they have not been included in the flow map, but their role will be better discussed in paragraph 2.4.2. As a first proxy of the impact that different categories of actors belonging to the system have on waste generation, it is possible to compute the proportion of **aggregate waste volume produced** per actor by using the quantitative data about waste generated. The average quantities of waste produced per type of flows are displayed in table 2.6 (specific references per paper can be found in the appendix "LR Synergies") while aggregates per type of actor are reported in table 2.5. As table 2.5 shows, the greatest % by far comes from industrial actors (71.97%), followed by urban and bordering ones (around 14%).

Table 2. 5 Proportion of aggregate waste produced per actors' categories.

Actors	Aggregate volume of waste (Kt/y)	% of waste generated on total
Bordering	4996,335	13,60%
Industrial	26431,7567	71,97%
Urban	5298,62	14,43%
Total	**36726,7117**	/

2.2.2 Key material flows

In this paragraph the methodology used for the identification of the UIS key sectors and of the UIS typical materials exchanges are explained. The aim is to take all the information available from literature concerning different cities/areas and use them to create a **generalized framework** explaining the UIS flows characteristics. According to the Guiyang's local document of "12th five-year plan of industrial integration" the key industrial sectors involved in IS are: "Aluminium industry", "Phosphorus chemical industry", "Iron/steel industry", "Cement sector", "Coal chemical industry" as well as "Power generation industry" (Dong et al., 2016; Fang et al. 2017). As for the purpose of this study, where the focus is not just on IS but on UIS, there is the need to further investigate the literature case studies to find out which are the most involved sectors when extending the scope towards the urban environment. It must be specified that most of the papers analysed in the literature refer to China and Japan (there is a gap in the Italian context), therefore when analysing the Italian context possible differences must be investigated. The approach used to point the other sectors out has been **totally based on the analysis of the literature**; in fact, starting from the actors identified in the paragraph before it is also possible to understand the sectors involved. In addition, from quantitative papers (full references are visible in the section "LR Synergies" of the appendix) it has been possible to find out what are the most common resource flows exchanges between the actors. The information regarding sectors and typical resource exchanges are meant to be conveyed into a general **UIS supply and demand chart**, where the sources and sinks are connected to the waste involved. The idea of using a supply and demand chart, has been taken from several studies [Liuzhou city (Sun et al. 2017) and Guyiang city (Li, Dong, and Ren 2015)]. Differently from them, who use this representation to describe the symbiosis of a specific area/city, here it is used to portray generally what could be the most typical resource wastes related to UIS and what could be the most common sectors involved. The creation of something similar has been attempted by Liang Dong (et al. 2016), where the authors have showed how, in theory, the representation evolves when passing from IS to UIS: in addition to the previous IS scenario, additional waste steel and waste plastics can come from the commercial and residential area while waste (low pressure) industries can be used into the urban area industries can be used into the urban area (Fig 2.7 taken from Liang Dong (et al. 2016)).

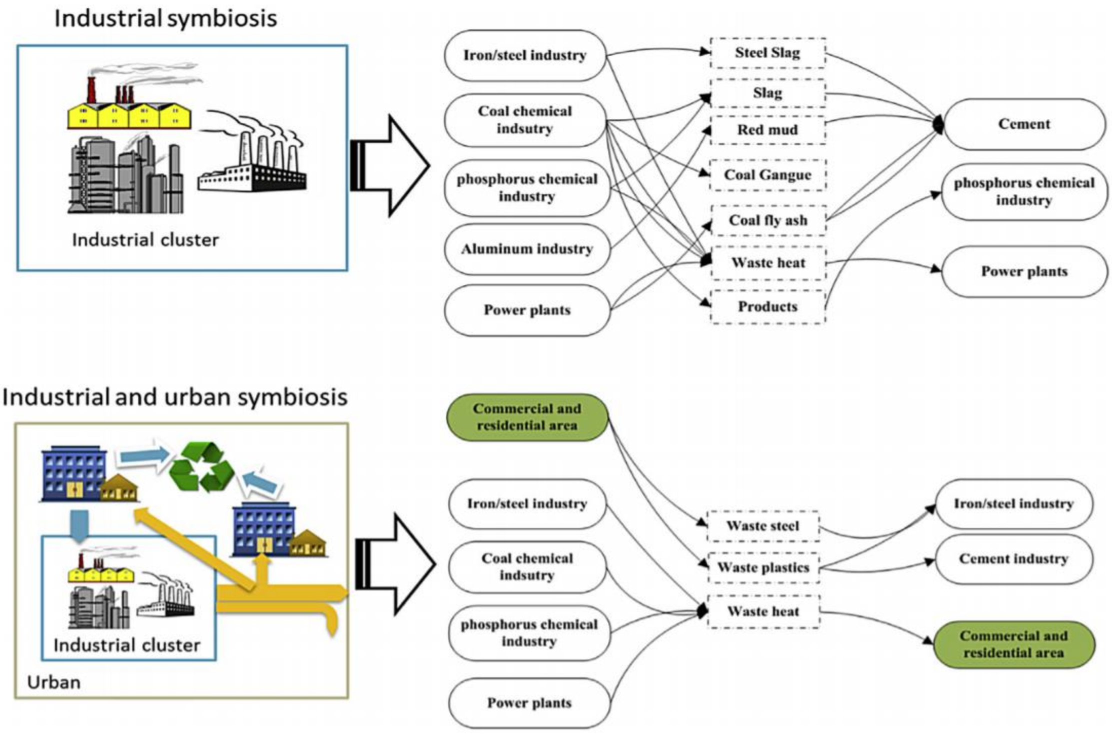


Figure 2. 7 Design of symbiosis scenarios. Taken from Liang Dong (et al. 2016).

However, in figure 2.7 many of the possible **flows are missing,** therefore, to map what are all the possible actors involved and all the possible connections within the UIS system identified in the literature a new theoretical supply and demand chart has been drafted in figure 2.8. Similarly to the stakeholder's classification proposed above, the actors of the system have been **coloured differently**: Green circles refer to the urban actors, Grey circles refer to industrial actors and Orange denote the bordering actors. In this way, it is possible to look at the different waste exchanged (in the middle) connected to the single/multiple actors who produced them (on the left), and on the right the single/multiple actors who use them as raw materials. An example is Plastics that can come both from the industrial context (industrial waste collectors) and the urban context (MSW collectors) and can be used in many sectors, such as chemicals, cement, iron & steel and power production. The number of total waste exchanges identified from the literature papers is 47 and, to map them altogether an alternative way to the Supply & Demand chart has been used.

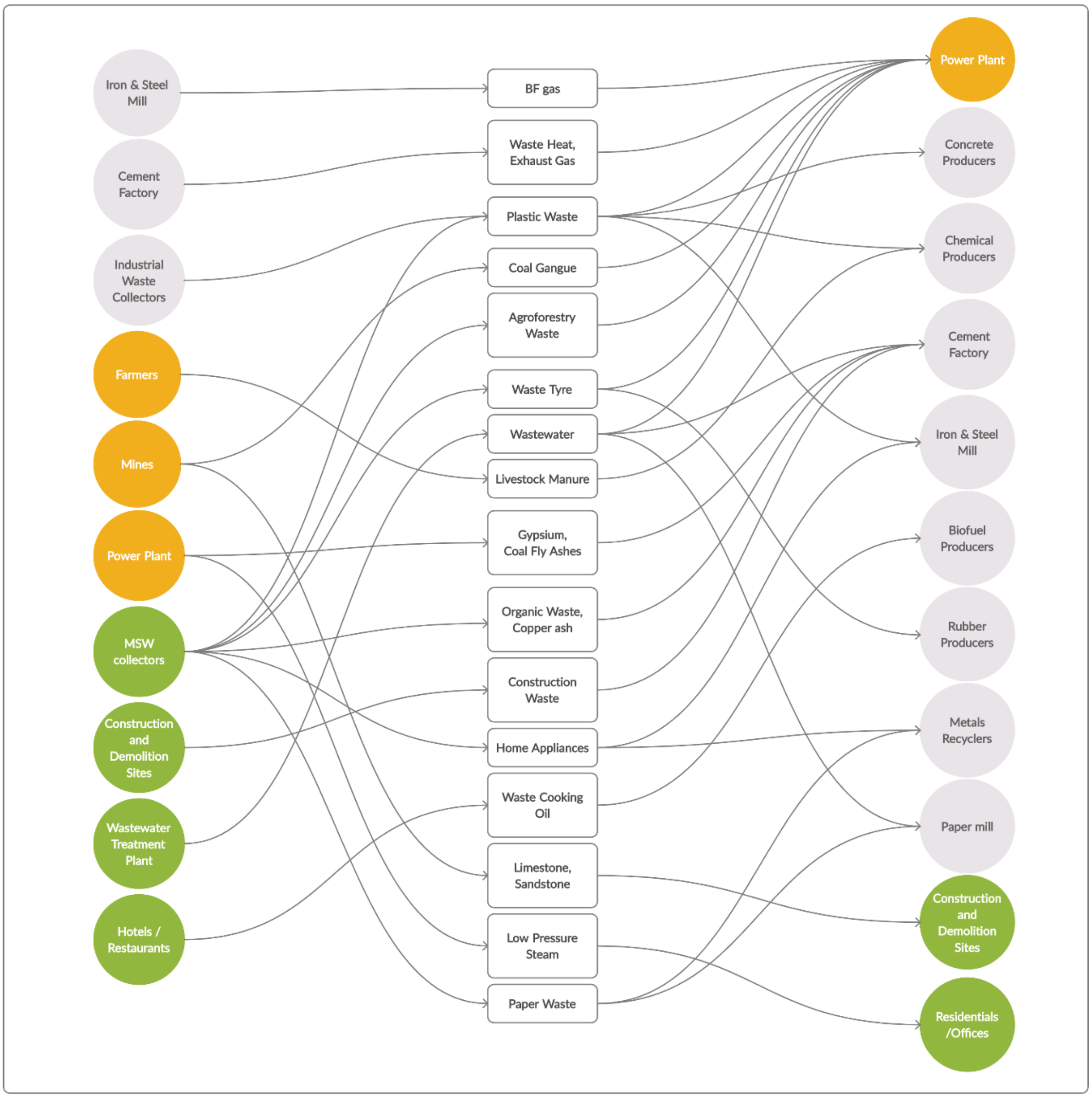


Figure 2. 8 Potential Supply and Demand chart referring to all the LR findings

To represent the flows, literature oftentimes use a **flow chart** where all the actors belonging to the system are represented together with resource exchanges between all of them. Sometimes authors draft a "real" flow chart by mapping all the resource flows of a specific case study referred to a specific system, while other times the authors draft a "conceptual" flow chart where all the potential resource flows are represented (potential means that they do not refer to any city or real system but are discussed from a theoretical point of view). Therefore, it is possible to divide the studies in two categories, the ones drafting the flow chart conceptually and the ones utilizing the flow chart as tool for representing real case studies:

Conceptual Flow Charts: The first conceptual frameworks focuses on waste production and collection in relation to the energy production, remarking that the efficiency of the application of Urban Symbiosis approach may be different depending on specific city considered (according to factors such as household dimension and composition, average age, frequency of food purchasing, average income, collection management offered by municipality, waste disposal costs, economic incentives to recycling, food prices) (Albino, Fraccascia, and Savino 2015). Despite its precision in describing the waste production and collection process, it does not include industrial or other urban flows. Whereas, in another study (S. Ohnishi et al. 2017) both urban and industrial activities are reported within the conceptual boundaries, also giving the order of magnitude in terms of volume transferred; anyway, food and other possible flows are neglected. It is the opposite for another case study (Kerdlap et al. 2019), where the focus of the paper is just on flows of food waste coming from farms and hotels/restaurants. Finally, in the last study worth to be mentioned here (Angela Neves et al. 2020)**,** the author sets out to present a conceptual framework which encompasses the various flows that exist across the industrial part and the urban part focusing on the capture and potential use of carbon dioxide; it is the first time that the incorporation into UIS of carbon dioxide capture and its transformation into fuel has been addressed.
Flow Charts for specific case study: on the other hand, other case studies do not provide a conceptual map of the flows, but use it as a tool to describe the flows exchanges present characterizing the city of reference (Hashimoto et al. 2010; Martin, Poulikidou, and Molin 2019): **Kawasaki,** (Liang Dong et al. 2016; Fang et al. 2017; Li, Dong, and Ren 2015): **Guyiang**, (Liang Dong et al. 2013, 2017; Sun et al. 2017): **Liuzhou**, (Liang Dong et al. 2014): **Jinan**.

By putting together all the information contained within the mentioned papers (both conceptual and case studies), a **completer "conceptual" flow chart** can be drafted. In figure 2.9 all the resource flows identified are represented, which obviously are coherent with the connections drew into the supply and demand chart. To improve the readability of the map, different colours have been used for the materials having multiple purposes, such as plastics, wastewater paper waste and home appliances. Remember that when the exchange is typical of IS, i.e. the exchange happens exclusively among industrial actors, the line tracing the flow is dashed. Whereas, when the exchange is typical of UIS, i.e. the exchange happened between urban, industrial, and boarding actors, the lines are continuous. For example, red mud or desulfurization by-products (dashed) are not related to the urban context or its boundaries, thus their lines are dashed.

All the identified 47 flows (mapped below) are described into detail in table 2.6, by stating the waste and type of resource involved, the actors between which the exchange happens, the type of symbiosis (UIS or just IS), the type of resource exchanged (material (M), energy(E) or water (W)), the city in which that exchange happens (the full table with references per single paper can be read in the sheet "LR Synergies" of the appendix) and the quantities exchanges provided by the papers (considering a certain substitution factor). Having this table of flows will help in the investigation/identification of the possible Lombardy resource flows. Conclusively, to provide a clearer understanding of how each symbiosis happens, in the appendix ("Flows Description") a short description of each has been given jointly with the description of the substitution factor, i.e. the rate at which the waste can substitute the exchanged resource.

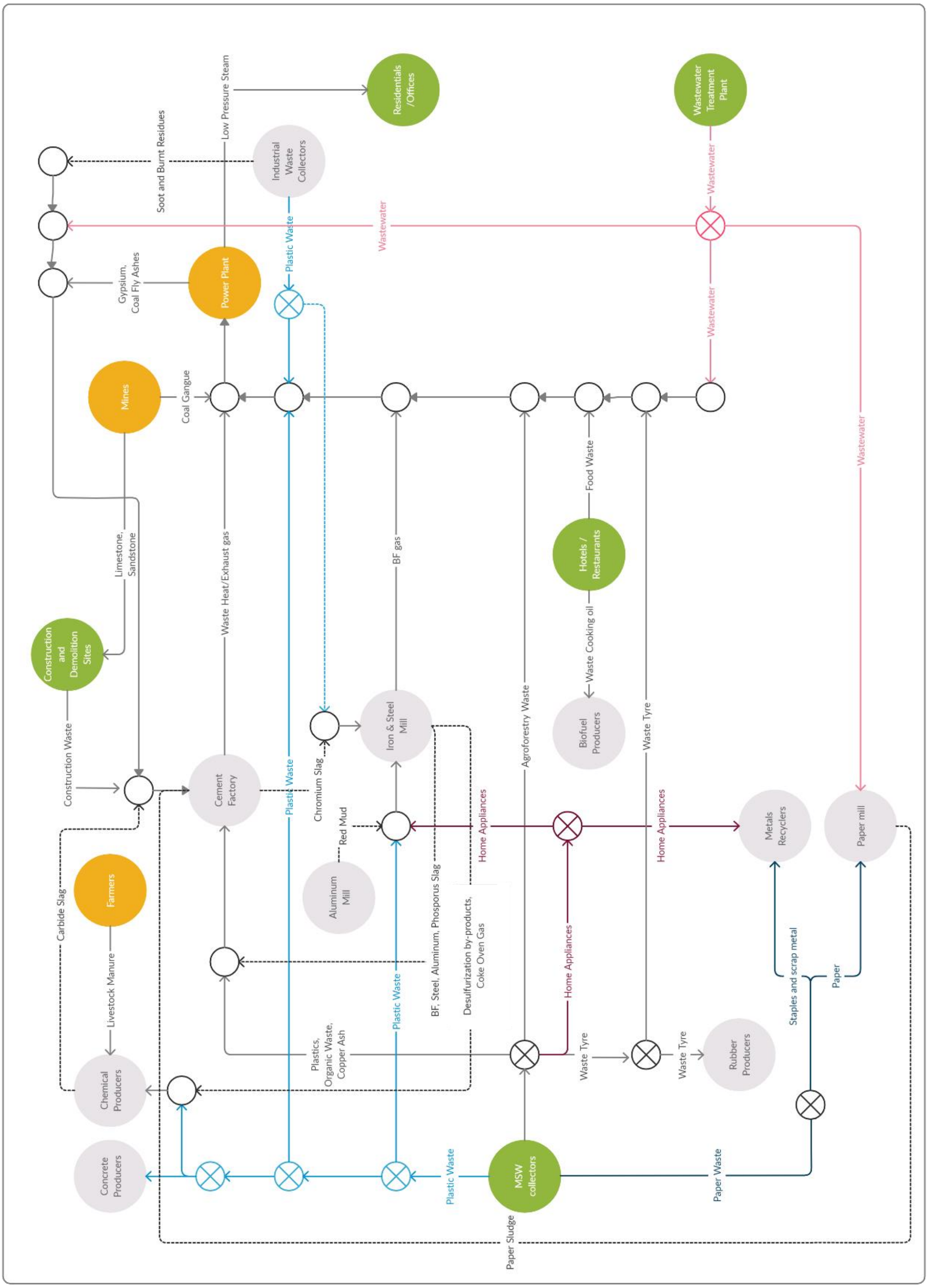


Figure 2. 9 Potential Flow chart stemming from LR findings.

Table 2. 6- part 1: All the Synergies proposed by Literature Authors in different studies and cities.

	Symbiosis	Resource Tranferred	Resoruce Substituted	From	To	UIS/IS	Type of flows	City	Volume of waste [kt/y]	SF	Volume of resoruce substituted [kt/y]
1	Plastic reuse in form-boards	Mixed plastic waste (containers and wrapping)	Plywood forms	Municipal Waste Collectors	Chemical companies	UIS	M	Kawasaki	18	2.64	47.52
2	Synthesis gas for ammonia production (equivalent of coal substituted)	Mixed plastic waste (containers and wrapping)	Coal	Municipal waste collectors	Chemical companies	UIS	M	Kawasaki	37	0.351	13
3	Replace coke for BF supply	Plastic waste	Coke	Industrial /commercial waste collectors	Iron and Steel mills	UIS	M	Kawasaki, Jinan, Liuzhou	97	0.98	95.06
4	Replace coal for cement kiln supply	Waste plastic	Coal	Industrial/commercial waste collectors	Cement Producers	UIS	M	Kawasaki	6.75	1.53	10.33
5	Replace coal for cement kiln supply	Organic Waste	Coal	Industrial/commercial waste collectors	Cement Producers	UIS	M	Kawasaki	14.86	0.65	9.659
6	Replace coal for cement kiln supply	Soot and Burnt Residue	Coal	Industrial/commercial waste collectors	Cement Producers	UIS	M	Kawasaki	0.7	1	0.7
7	Alternative RM for Concrete	C & D Scraps	Concrete	Construction and demolition (C&D) sites	Cement Producers	UIS	M	Kawasaki	70.7	1	70.7
8	Slag replacing a fraction of clinker in cement production	BF slag	Clinker	Iron and steel mill	Cement producers	IS	M	Kawasaki, Liuzhou, Jinzhou, Guiyang, Xinfeng, Jinan, Yongcheng	1143.0	1	1143.0
9	Slag replacing a fraction of clinker in cement production	Steelmaking slag	Clinker	Iron and steel mill	Cement Producers	IS	M	Liuzhou, Jinzhou, Jinan, Yongcheng	1197.6	1	1197.62
10	Use fly ashes to replace clinker	Coal Fly Ashes	Clinker	Power Plants	Cement Producers	IS	M	Midong, Yongcheng, Guiyang, Liuzhou, Xinfeng	313.4	1	313.4
11	Substitute cement RM	Phosporus Slag	Clinker	Iron and steel mill	Cement producers	IS	M	Guyiang	500.0	1	500
12	Substitute cement RM	Aluminum Slag	Clinker	Iron and steel mill	Cement producers	IS	M	Guyiang	400.0	1	400
13	Substitute cement RM	Paper sludge	Clay	Paper producers	Cement Producers	IS	M	Kawasaki	16.8	15.65	263
14	Replace limestone	Carbide Slag	Limestone	Chemical companies	Cement Producers	IS	M	MIdong	1030.60	1	1030.6
15	For Copper cement production	Copper ash	Clinker	Urban context	Cement Producers	UIS	M	Midong	15.00	1	15
16	Gypsum from desulfurizationd as hardener in concrete production	Gypsum	Clinker	Power Plant	Cement Producers	IS	M	Jinzhou, Midong, Xinfeng, Jinan	32.83	1	32.825
17	Alternative cement RM from Mines	Iron mines tailings	Clay	Mines	Cement Producers	UIS	M	Xinfeng	460.00	1	460
18	Alternative cement RM from Mines	Iron mines tailings	Bricks	Mines	Bricks producers	UIS	M	Xinfeng	900.00	2.11	1900
19	Production of Fertilizers from desulfurization	Desulfurization by-products	Fertilizers	Iron and Steel mill	Chemical companies	IS	M	Liuzhou	8.1	NA	NA
20	Recycling of Chromiun Slag as sinter ore	Chromium Slag	Sinter ore	Chemical companies	Iron and Steel mills	IS	M	Jinzhou, Jinan	120	NA	NA
21	Glass Ceramics production from steel slag	Molten Steel Slag	Ceramics RM	Steel mill	Ceramic producers	IS	M	Xinfeng	15.00	1.333	20.00
22	Wear-resistant Ceramics production from steel slag	Cooled Steel Slag	Ceramics RM	Steel mill	Ceramic producers	IS	M	Xinfeng	40.00	1.5	60
23	Waste Steel recycling	Urban steel waste	Iron ore	Industrial/commercial waste collectors	Iron and Steel mill	UIS	M	Jinzhou, Kawasaki, Midong ,Yongcheng, Guiyang, Liuzhou, Jinan	778.71	1.6	1245.93

Table 2. 6-part 2: All the Synergies proposed by Literature Authors in different studies and cities.

	Symbiosis	Resource Tranferred	Resoruce Substituted	From	To	UIS/IS	Type of flows	City	Volume of waste [kt/y]	SF	Volume of resoruce substituted [kt/y]
24	Red mud reuse to refine ferrous elements	Red mud	Iron ore	Aluminum mill	Iron and steel mill	IS	M	Jinan, Jinzhou	1600.00	0.281	450
25	Waste tyre replacing rubber	Waste tires	Rubber	Urban context	Rubber Producers	UIS	M	Midong, Guyiang, Liuzhou	13.83	0.65	8.992
26	Incineration of waste tyres	Waste tires	Coal for electricity	Municipal waste collectors	Power Plants	UIS	M/E	Yongcheng	0.02	0.5	0.01
27	Agroforestry Waste replacing coal for power generation	Agroforestry waste	Coal for electricity	Municipal Waste Collectors	Power plants	UIS	M/E	Yongcheng	281.10	0.461	129.7
28	Incineration of Straw	Straw	Coal for electricity	Farmers	Power Plants	UIS	M/E	Liuzhou	503.00	0.32	162.50
29	Electricity production from MSW incineration	MSW	Coal for electricity	Municipal waste collectors	Power plant	UIS	M/E	Yongcheng	428.00	0.211	90.4
30	Plastics wastes for power supply	Plastic Waste	Coke for electricity	Industrial/commercial waste collectors	Power Plants	UIS	M/E	Guiyang	10.00	1.267	12.667
31	Coal Gangue used to produce energy	Coal Gangue	Coal for electricity	Coal mines	Power Plants	IS	M/E	Midong, Guyiang, Xinfeng	465.00	0.3	139.5
32	Cogeneration by using waste heat from Kiln exhaust gas	Waste heat/ Kiln exhaust gas	Coal for electricity	Cement Producers	Power plants	IS	E	Xinfeng	115.522 GWh	7.22	16.00
33	BFG for power supply (replace coal)	BFG gas	Coal for electricity	Steel & Iron mill	Industries/power production	IS	E	Jinan, Kawasaki, Yongcheng	1195.56	0.106	126.20
34	Alternative Coal for Hydrogen Production	Coke Oven Gas	Coal for hydrogen production	Iron and steel mill	Chemical companies	IS	M	Jinzhou, Liuzhou, Jinan	25.44	1.909	48.565
35	Steam reuse as heat source	Low Pressure Steam	Coal for electricity	Power plant/industrial actors	Urban context	UIS	E	Yongcheng, Jinan	1319.481 GWh	7.22	188.20
36	Steam reuse as heat source	High Pressure Steam	Coal for electricity	Power Plant/Industrial Actors	Industrial districts	IS	E	Yongcheng	12476.408 GWh	7.22	1728.00
37	Livestock manure reutilization for Fertilizer Production	Livestock Manure	Fertilizers	Farmers	Chemical companies	UIS	M	Yongcheng	12.00	1	12
38	Straw reutilization for Fertilizer Production	Straw	Fertilizers	Farmers	Chemical companies	UIS	M	Yongcheng	20.00	1	20
39	Plant ash reutilization for Fertilizer Production	Plant ash	Fertilizers	Farmers	Chemical companies	UIS	M	Yongcheng	8.00	1	8
40	Distiller's grains reutilization for Fertilizer Production	Distiller's grains	Fertilizers	Breweries	Chemical companies	UIS	M	Yongcheng	20.00	1	20
41	Paper recycling	Paper waste	Virgin Fiber Pulp	Industrial/commercial waste collectors	Paper Producers	UIS	M	Kawasaki	69.00	0.788	54.34
42	Strawboard Production	Paper waste (waste yellow straw boards)	Strawboards	Municipal Waste Collectors	Paper Producers	UIS	M	MIdong	21.30	1.667	35.50
43	Fluorescent lights recycling	Flurescent lights	Glass, Aluminum, Mercury	Industrial/Commercial Waste collectors	Recycling plants	UIS	M	Kawasaki	NA	NA	NA
44	Home appliances dismantling	Home appliances	Non-ferrous metals recovery from separated parts and shredder residue	Municipal waste collectors	Iron and steel producers & non ferrous materials users	UIS	M	Kawasaki	NA	NA	NA
45	Treated municipal water reuse	Wastewater	Water	Waste Water Treatment Plant	Iron and steel	UIS	W	Jinzhou, Jinan	2000.00	1	2000
46	Treated municipal water reuse	Wastewater	Water	Waste Water Treatment Plant	Thermal Power Plant	UIS	W	Midong	366.00	1	366
47	Treated municipal water reuse	Wastewater	Limestone	Waste Water Treatment Plant [WWTP]	Cement Producers	UIS	W	Kawasaki	20.00	2.75	55

2.2.3. Focus on C&D

After having defined the broad scope of UIS, in accordance with the fifth research objective of the Thesis there is the need to **deep dive into the C&D sector**, which is the subject of the subsequent field search. This paragraph mainly addresses two points: the first one is about defining the scope of analysis, i.e. what are the actors revolving around the C&D that could potentially establish fruitful symbiosis while the second one is about defining possible resource exchanges and synergies created among considered actors.

It is important to observe that usually traditional IS/UIS analyses include cross-industrial and **cross-urban links** and they do not generally focus only around one industry. Based on that, as this Thesis mainly considers C&D, it is fundamental not to observe just a single actor belonging to the C&D supply chain as in this way all the possible synergies related to the other actors/sectors would be neglected and the picture would not be complete. Therefore, when defining C&D actors, the cross-links between **C&D supply chain and related industries** need to be outlined. For this reason, the accomplished framework does not only include all the active actors belonging to the C&D world, but rather envelopes potential substitution opportunities with resources and wastes produced by actors in other sectors.

To build the framework, the **starting point** has been the analysis performed by Luciano (et al. 2020) on the C&D supply chain: the study outlines an MFA to provide a functional-cognitive framework to direct the use of all the available resources including raw materials, products and by-products but also residues and wastes. Furthermore, the overall waste production of the C&D chain is investigated as well as potential opportunities for RM substitution in the C&D supply chain by using waste coming from other industries.

Nonetheless, the analysis performed by Luciano is carried out at national level and it is limited to the identification of volumes, thus data needs to readapted on a regional level in this Thesis in order to quantify possible environmental and economic benefits generated. Also, metals used for construction are not mentioned and detailed flows regarding quarrying waste and C&D are missing, thus additional effort is required to spot the possibilities of reutilization for the different types of waste. As for this purpose, Dahlbo (et al. 2015) provides details regarding the most common C&D categories while Gruppo Maffei (2008) explains what are the residues of quarrying activities and their reutilization options. Last but not least, Falp (FALP) explains what are the main metals used in construction and what are their main applications. Also, by leaning on what has been found in previous UIS LR it is possible to pinpoint different options of waste requalification. At the end, based on the flows contained in table 2.6 and in the mentioned studies, it is possible to draw a complete picture (figure 2.10, where references are clearly visible) of the most important **categories of actors** involved, the flows that they exchange and the available options to reutilize the waste (both coming from C&D industry and correlated). The categories of associated actors were also taken into account in compliance with the ones considered by ISTAT (ENIT 2020), where

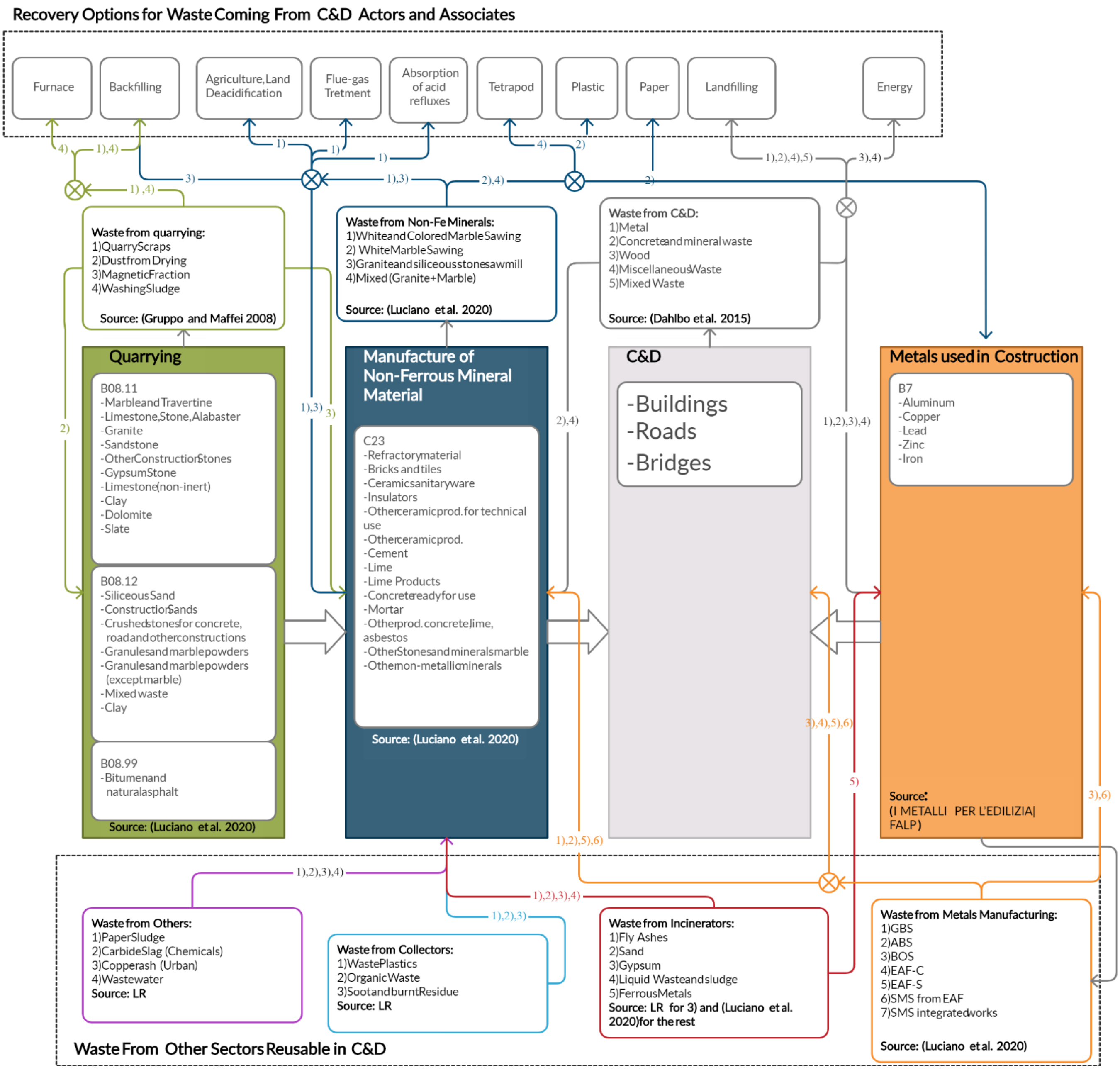


Figure 2. 10 - Overview of potential synergies built around the C&D supply chain.

the supply chain relationships and interlinks between different Italian industries are also mentioned.

As a result**, figure 2.10** shows the categories of actors involved and the potential flows exchanged within the boundaries of the analysis (C&D sector and related ones). According to the previous considerations, there are four main categories of interest contained in four coloured "blocks": quarrying companies, non-ferrous mineral materials manufacturers, C&D companies, and metal producers. The main types of waste generated by each "block" have been listed and marked with a number within a "box". For instance, according to Dahlbo (et al. 2015) the most common types of waste produced by the C&D actors can be divided in metal, concrete and mineral waste, wood, miscellaneous waste and mixed waste. The arcs that originate from the "boxes" (containing the wastes list) represent the potential possibilities to reuse the waste in another block or in same block. The numbers on the arcs refer to the associated type of waste contained in the box where the arc itself sets off.

The loop can be both closed and open: as long as the waste remains within the C&D supply chain, the loop is considered closed. On the other hand, according to table 2.6, there can be other paths to reuse the waste coming from the C&D supply chain (defined as "recovery options" in figure 2.10), as well as other actors (such as incinerators, waste collectors, paper producers and chemical companies) may be able to reuse waste inside the C&D supply chain. In these cases, the loop is considered open.

2.3 Identification of Drivers and Barriers

The main purpose of this section is to uncover what are the **main factors** affecting UIS to support the later on described micro-analysis (Chapter 4) and to respond the RQs 2.1 and 2.2. By factors, all those aspects which could positively influence or hinder the development and the correct functioning of UIS practices are considered. The process of identification has been utterly based on reading and analysing the academical papers previously selected. Table 2.7 reports the studies where the examined factor has been found. About UIS literature, it must be underlined that (at the best of our knowledge) there **are no comprehensive frameworks** able to fully categorize the factors and explain why they act as a driver rather than a barrier or vice versa. The only study (Angela Neves et al. 2019) showing a comprehensive framework discussing the key drivers and barriers is exclusively related to IS, and has therefore been taken into account as comparative framework but not directly used to realise the potential of UIS factors. In addition, the mentioned framework does not explain the relationships between factors. As for UIS literature, Chen (et al. 2012) considers and discusses three factors (project scale, recycling boundary, and types of waste) and their relationships in accord their environmental benefits and operational performance. Despite being a very analytical discussion able to provide insights about the three discussed factors, it does not consider all the possible others that have been spotted in other works. A completer one in terms of number of driver and barriers involved, is based on the Korean eco-industrial park (EIP) experience and reviews the key drivers to such networks, identifies what are the conditions and strategies required at different levels, and barriers for their implementation (Yedla and Park 2017). The methodology used by the authors is quite simple as factors (D or B) that mostly concern the development, or their case study are listed, and then their effect on UIS is explained.

The outcome is the creation of a unique, holistic, and structured framework containing the most influential factors (possibly acting as a driver, barrier, or both) as well as their relationships.

2.3.1 Classification of Factors in Drivers and Barriers

This paragraph is characterized by a "reverse structure" as it starts by showing the results of the analysis and then provides an explanation of them. A summarized version of **results** is contained in Table 2.7 where a list of 31 factors (on the rows) has been identified from the analysis of 19 academic studies (on the columns). To ease the reading process of the table, the identified factors have been divided according to their meaning into **six macro-categories**: technological, informational, economic, organizational, regulatory, and finally, environmental. This division does not directly come from literature but rather has been adopted to have a clearer understanding of the main typologies of drivers/barriers that can characterize UIS. The colours assigned to each category have been used in paragraph 2.3.2 to provide a graphical representation of relationships between the factors.

On the bottom of Table 2.7 there is a bar containing the number of factors (frequency) discussed within each paper. As it can be noticed, most authors tend to consider just few actors. The only cases in which the number of factors per paper increases are those in which authors strictly focus on the discussion of drivers or barriers for UIS.

On the other hand, by counting the number of "X" contained in the rows it is possible to verify the frequency of each single factor. If a factor has been repeatedly analysed by multiple authors, its relevance might be higher with respect to factors that have been analysed less. As for the **explanation of factors**, two elements have been discussed namely according to which perspective it has been analysed and what are the main considerations found in literature about it, and what the relationships between the different factors are.

Table 2. 7 Identification of Factors (potential D&B) with references per paper.

Category	List of Factors	References																		
		(Chertow 2000)	(A. Neves et al. 2020)	(Chen et al. 2012)	(Lenhart, Van Vliet, and Mol 2015)	(Guo et al. 2016)	(Z. Liu et al. 2018)	(Geng, Tsuyoshi, and Chen 2010)	(G.-F. Liu and Chen 2013)	(Fang et al. 2017)	(Sun et al. 2017)	(Yedla and Park 2017)	(Sacirovic, Ketin, and Vignjevic 2019)	(Satoshi Ohnishi et al. 2018)	(Liang Dong et al. 2017)	(Fujii et al. 2016)	(Hashimoto et al. 2010)	(Park et al. 2008)	(Liang Dong et al. 2016)	(Cao et al. 2018)
Technological	Waste Composition			x										x						x
	Technology availability					x				x									x	
	Standardization Level									x		x								
Information	Information sharing through IT											x							x	
	Communication					x						x							x	
	Awareness											x						x		
Economic	Volume exchanged			x																
	Supply Volatility											x			x					x
	Infrastructure (energy, utility and transport)											x	x							
	Price of VRM, energy and labor cost					x					x			x		x				
	Site Specificity								x											
	Revenues generation											x	x							
	Investment opportunity											x	x							
	Employment opportunity											x	x							
	Property value and area development												x							
	CAPEX					x														
	Transaction costs								x											
	Quality related to production																			x
	Long term impact											x								
	Geographical location			x	x							x								
Organizational	Cooperation and coordination	x	x		x								x							
	Firm commitment											x								
	Multiparty involvement					x						x								
Regulatory	Green regulations											x								
	Incentive schemes									x									x	x
	Hazardous Materials											x								
	Community approval							x												
Environmental	Waste reduction																x			
	Resources Conservation																x			
	Landfilling																x			
	Health and air quality						x						x	x			x			

Waste Composition: intended as the heterogeneity or homogeneity of the waste resource, i.e. the degree at which the waste is characterized by the presence of just one material. If the waste is heterogeneous, this factor will act as a barrier and vice versa. The composition of waste determines the suitability, transportation cost, and value of recycled products (Chen et al. 2012). Therefore, it is crucial to verify the composition of waste to better address its recovery process, since the outcome could vary deeply. As examples, plastic-rich waste would be efficient for incineration with energy recovery and food-rich waste would be effective for operating methane fermentation plants. The composition of waste, then, should be considered for refinement of the model (Satoshi Ohnishi et al. 2018).
Relationship with other factors: On the one hand, the more heterogeneous the waste is the more the recovery process is costly (affecting revenues/profits generation) and new complex technologies are needed (they might be not even available) (Satoshi Ohnishi et al. 2018). On the other hand, if technologies (ex. Recycling, disposing, producing, collecting) are available and standardized, companies are incentivized to optimally separate the waste and its composition will be more homogeneous (resulting in an increase of the transactions value both for the producer of the waste and for the user) (Fang et al. 2017)**,** (Yedla and Park 2017).

Technology Availability: intended as whether all the necessary communication (IT), production, collection, recycling, and disposal technologies to ensure a correct implementation of UIS are available. On the one hand, for UIS implementation technology-intensive and various advanced technologies are required, and in case of lack of the state-of-the-art technologies (in addition to a limited financial support, as well as the lack of the related useful information) it is difficult to find an ideal undesired material to substitute the raw materials with high costs and/or to achieve the utilization of those wastes with high disposal costs (Guo et al. 2016)**,** (Liang Dong et al. 2016). On the other hand, effective and efficient technologies always provide a fundamental basis for formulating innovative strategies, in the sense that key available technologies for circular economy (as well as quality standards thresholds) act as guidance for waste generators (Fang et al. 2017). Therefore, technology could be either a strong barrier, when there is not the possibility to match the requirements of the different industrial and urban actors, or a powerful driver, when most part of them have the possibility to access the latest and most efficient technological machineries and knowhows.

Relationship with other factors: The availability of new effective technologies might guarantee higher quality standards (Fang et al. 2017), and could be applied on a larger basis if their standardization level were high (Yedla and Park 2017). However, even if the technology were available, the CAPEX required to possess them might act as the real barrier (Guo et al. 2016)**,** (Liang Dong et al. 2016). The technology availability also relates by definition to the IT information sharing enabling UIS.

Standardization level: To ensure proper UIS development the level of standardization of different aspects such as technologies (communication (IT), production, collection, recycling, and disposal) and waste composition should be strongly considered. The more actors produce, collect, recycle, dispose, and communicate in "standardized" ways, the easier it is to implement UIS. Nevertheless, companies have different knowhows, and have their own manufacturing processes. Thus, on the market there are thousands and thousands of different products (even products that might address similar needs), and not all of them are able to be recycled/disposed/collected with the same techniques. In consequence of this, there are not unified international standards (Yedla and Park 2017) and this represents a sound barrier hindering the match between demand and supply of waste. Relationship with other factors: mainly three things should be standardized to make UIS easier: key technologies for recycling and processing the waste, quality and waste composition for the input material as guidance for waste generators, and databases (e.g. multi-regional IOTs) which could provide a basis for wise environmental decision making and enhance communication in various regions (Fang et al. 2017).

Communication and Information sharing through IT: The fact that IS involves many stakeholders/multiparty and that different industries are subjected to different regulations of environmental emissions makes this ‘‘communication’’ across firms a tricky and difficult task. Therefore, forums and platforms, where inter-firm communication and collaboration is facilitated, play an important role, as well as trust among firms, in organizing inter-firm exchanges of energy and material (Guo et al. 2016; Yedla and Park 2017). The local governments should facilitate the development of a feasible IS/UrS network or platform for information exchange, as it already happens in some areas (ex. NISP (G.-F. Liu and Chen 2013)). In addition, a government-university-industry partnership should be established so that each party can play necessary roles in the development of such network (Liang Dong et al. 2016). Once functioning, the IT system could extremely foster the advancement of UIS practices and Circular Economy culture.

Relationship with other factors: by definition, communication and information sharing are the basis of cooperation and coordination among actors, which in a UIS perspective should last in the long-term (according to the definition of IS network, i.e. "the collection of long-term, symbiotic relationships (G.-F. Liu and Chen 2013)). In addition, as specified before, communication and information sharing thought platforms might strongly ease the multiparty involvement related to UIS and, thus, lower the transaction costs (Yedla and Park 2017).

Awareness: intended as the knowledge (at first) and the perception (then) about UIS practices and its potentialities. The advantages of eco-industrial development are not always straightforward and there might be problems in the quantification of benefits, especially of environmental and social type. In addition, in most cases the benefits manifest themselves in the medium/long term and actors tend to be informed less when benefits are not promptly tangibles. Here, the role played by governments and public institutions is key for revealing the bright side of UIS (Park et al. 2008)**.** Multi-pronged awareness-raising initiatives overcome the lack of awareness. (ex. development of training materials for industrial workers; using popularity modes of advertising for the use of ‘‘green goods’’ and public participation in ‘‘greening of industries’’ initiatives..) (Yedla and Park 2017)**.** For instance, in the case of Kawasaki some societal benefits have been achieved, such as improved public awareness by encouraging IS (Hashimoto et al. 2010)**.**

Relationship with other factors: actors tend to neglect initiatives not able to generate short term benefits and incentives/regulatory schemes might help raising interest and awareness in companies (Park et al. 2008)**,** (Yedla and Park 2017). Awareness is also related to geographical location (see below what "regional learning" means).

Volume exchanged: intended as the volume of resources transferred during the exchanges (also named project scale (Chen et al. 2012)). The amount of exchanged volume can be compared to the virgin material savings (as an indicator of the quantity saved) and to the operating rate (as an indicator of operational performance), namely the ratio of the number of treated wastes to the planned amount. Regarding material savings, the total amount of waste treated, and VMS (virgin materials savings) are statistically correlated, i.e. the eco-towns treating more wastes are likely to have more savings of virgin materials. As far as operational aspect is concerned, on average, facilities located in large eco towns are likely to have higher operating rates. In addition, as the facility's scale increases, the operating rate becomes more stable and stays in a relatively high range (Chen et al. 2012). Relationship with other factors: the volume of waste exchanged is influenced by the price of VRM, since the more the price of VRM is convenient the less actors are incentivized to reutilize the waste to replace them. In addition, the presence of sharp fluctuations ("Supply Volatility") in volumes exchanged over time might compromise the stability and the conveniency of the symbiosis, causing a negative composite effect.

Supply Volatility: intended as the rate at which material and waste flows are stable/unstable over time, and it is at the basis for the establishment and management of UIS (Liang Dong et al. 2017). In presence of sharp fluctuations and potentially insufficient amount risk, the economic feasibility and convenience of UIS could be compromised (Cao et al. 2018). Therefore, there is a dire need for regulations which could avert the risk of an industry running short of input stock that comes from multiple sources of resource recycling. However, regulations "forcing" the industries to provide a stable supply will increase the risk of not establishing symbiotic links, since companies would not sign contracts if they are too much constraining (also due to risk of relocation of companies which could compromise the conveniency given by proximity) (Yedla and Park 2017).
Relationship with other factors: Firm commitment is crucial to increase the efficiency of the transaction and to guarantee a more stable/secure supply, however usually contract are made according to long-terms agreements that can increase the risks for the involved parties (Yedla and Park 2017). Thus, supply volatility could not be the main barrier but perceived so when the real reason why the supplies are not stable is that the firms do not want to get committed to each other because of the associated risks (for example the risk of supplier relocation or bankruptcy). In addition, if two actors were geographically close the risk of having high supply volatility would be lower (Yedla and Park 2017) because of the lower transportation time/cost and the better communication established thanks to proximity.

Infrastructure: intended as: (1) Energy infrastructure (substations, public lighting, electrical and other connections), (2) Utility infrastructure (water supply and water storm installations, water and sewerage, connection to outdoor installations, etc.), (3) Transport infrastructure (access roads—roads in the zone, telephone, and other terminals, etc.). The local economy provides sources of raw materials, materials, parts, and services to companies in the park. Water and sewerage, energy, solid waste, and transportation infrastructure usually are under the jurisdiction-administration of local authorities. Usually, the presence of an infrastructure allows and entails the existence of industries and urban units nearby and vice versa (Sacirovic, Ketin, and Vignjevic 2019). Whether on the one hand this could lay the ground for the UIS development and its flourishing, on the other it could impede its proper functioning when some parts of the infrastructure are missing or deficit from providing a minimum level of service.

Relationship with other factors: The presence of a good infrastructure might boost the investment opportunities in the nearby area, the benefits of sharing a common one are especially tangible for all the cluster of similar industries coexisting within a geographical location, nevertheless the other actors revolving (multiparty of actors) around that same location could reciprocally take advantage and exploit the services provided by others. Hence, a key role is played by municipalities (government bodies responsible for providing civic service) which should guarantee an efficient and fair access to the public infrastructure (avoiding moral hazard and lower the transaction cost), so as to foster the development of a "private" network in which UIS exchanges are embedded. It must be denoted that financially the municipalities might not have enough resources to bear the costs of a proper infrastructure, in fact public–private partnerships may be attempted (Yedla and Park 2017).

Price of RM, energy, and labour cost: The economic convenience of exchanges directly depends on the price of RM, especially when the substituted materials are expensive, and the disposal costs of the recycled wastes are very high. Consequently, in order to receive high economic benefit intensity, both the substitution of raw materials with high market prices and the utilization of wastes with high disposal costs should be promoted. In fact, if the prices of natural resources (such as natural clay, limestone, natural gypsum, natural sandstone etc.) is too cheap, the involved industrial enterprises could hardly achieve economic benefits because there would no economic advantages in substituting VRM with waste, which impedes potential IS activities (regulators could use as a tax on natural resources or increase their price (Guo et al. 2016). In addition to direct costs, also overhead ones should be considered. The energy savings often account for the largest part of the benefits when adopting UIS practices, because many of the production processes happen to be energy intensive; thus, the selling price of electricity has a large influence (Satoshi Ohnishi et al. 2018). Even if less typical when talking about UIS, labour cost too can have a considerable weight and can be deemed as an important aspect for an actor who wants to evaluate the possible benefits of UIS practices (averting production of new materials and use the workforce to remanufacture/recycle the waste ones) (Fujii et al. 2016). All these three aspects could be either a driver or a barrier depending on the geographical location and the availability of sources, and can directly affect the conveniency of the investment. For instance, China gains a lot from lower price of natural resources, but also suffers from significant ecological loss: as a world factory it has failed on internalizing the ecological impacts into the economic system (apply proper resource tax, carbon tax, ecological compensation policies to better internalize the ecological externality), so that the market price of natural resources can be more close to their "real price" (Sun et al. 2017). This at demonstration of the fact that the role played by governments can significantly affect the attractiveness of UIS practices, both negatively and positively.

Relationship with other factors: these three factors might vary according to the specific site considered (Sun et al. 2017), therefore by definition they might affect the conveniency of the investment on that site and the capability of generating revenues/profits (Satoshi Ohnishi et al. 2018). Regulators can try to control those three factors by using taxes or incentives mechanisms, as well as promulgating green regulations in order to boost resource conservation (Guo et al. 2016).

Site's specificity: Site specificity refers to the fact that in different places and on different levels (continental, countries' national, regional etc.) conditions differ in thousand ways. For example, launching a national wide IS programme in China like it has been done in UK's NISP is impracticable. Other than geographical area differences compared with developed countries, China's urban symbiosis development is focused on Eco-industrial Park, while developed countries have shifted to urban or regional level and mainly develop a symbiotic relationship by seeking business opportunities (G.-F. Liu and Chen 2013). Therefore, it is impossible to have an empirical tested methodology of UIS development, and it becomes difficult to grasp and consider all the differences between different sites when assessing it.

Relationship with other factors: See Price of RM, energy, and labour.

Revenues generation, Investment opportunity, Employment opportunity: Regarding the former, by-products have market value and can be sold rather than disposed, regulatory penalties for waste wrong discarding can be avoided, and market share could be improved through products' eco-labelling (Yedla and Park 2017) . The concept of Extended Producer Responsibility is spreading, and regulations might push companies to take care themselves of their by-products. As for Investment opportunities, waste producers could have the opportunity to vertically expand their scope and enter new businesses generating in this way a positive externality on the third aspect (Yedla and Park 2017). As a matter of fact, the workforce of the eco-industrial parks mainly comes from nearby cities and may require the training of local educational institutions. New employees in this area have a need for housing in the local community. This would trigger a process of human resources improvement and education, for instance cooperative education program in the vicinity of the UIS area. It would result into better trained people, higher employment rate, and lower training costs (Sacirovic, Ketin, and Vignjevic 2019).

Relationship with other factors: explained in the other factors' comments: see Waste composition, Geographical Location, price of RM, labour and energy, and Incentive Scheme comments to understand relationships of Revenues Generation. See price of RM, labour and energy, Property Value and Infrastructure comments to understand relationships of Investment Opportunity. See Property Value and Community Approval to understand relationships of Employment Opportunity.

Property value and area development: intended as the attractiveness of having a property in a specific area (a house, a building, a shop, a land etc). This factor considers the variation of attractiveness consequent to area development. As a consequence of UIS the attractiveness of the area would increase and so would the value of such properties (bringing further benefits not only to the UIS actors but also to the broad community). Relationship with other factors: all the positive externalities consequence of the infrastructure development, the increased attractiveness due to novel investment opportunities, and the new opportunities for employment, may engender additional opportunities for area development disjointly from the industrial world. As a matter of fact, existing properties would strengthen their market value, new buildings would rise, and the income of urban units would increase in all its fields (food, transports, entertainment, real estate etc.) (Sacirovic, Ketin, and Vignjevic 2019).

CAPEX and transaction cost: In this case there is no need to further define what CAPEX and transaction cost are since they are unequivocal. On the one hand, in particular for governments and industrial players, the amount of capital required to unlock the possibilities

offered by UIS is massive. In fact, whether the formers have to bear most part of the infrastructure creation cost, the latter have to be compliant with requirements of other players and they often must invest in state-of-art technologies to do so (Yedla and Park 2017). On the other hand, transactions involve information asymmetries and moral hazard, which especially in case of long path distances cause the risk of flows interruption, lower quality than expected, slower diffusion, not respected payments and so on. All these negative aspects make weaker the ties among the potential involved players and discourage the spread of UIS (G.-F. Liu and Chen 2013).
Relationship with other factors: explained in the other factors' comments: see Incentives, Technology Availability, Infrastructure comments to understand relationships of CAPEX. See Incentives, Geographical Location, Infrastructure, Communication and Firm Commitment comments to understand relationships of Transaction Cost.

Quality related to production: intended as the lower quality that might arise from the re-utilization of by-products/waste in production to replace fresh new RM. For instance, surrogates/blended products coming from recycled materials might have quality problems and might have difficulties in meeting the specifications required (Cao et al. 2018) Relationship with other factors: explained in the other factors' comments: see Technology Availability and Hazardous Materials.

Long term impact: Long term impact particularly refers to two aspects: the first one is the fact that, both in terms of environmental and economic benefits, the UIS does not immediately pay off its cost. The second one, more important, is that UIS ties players up to each other through long-term supply contracts. Long term contracts are needed to tackle potential undersupply and to homogenise the waste, however, they are subjected to the risk of future relocation of the proposed partners, which poses a major challenge connected to the supply security (of the by-product and waste product streams) and economic stability of the exchanges (Yedla and Park 2017).
Relationship with other factors: explained in the other factors' comments: see Supply Volatility, Awareness and Communication.

Geographic location: One of the most highlighted elements to enable UIS is geographic proximity, or the locational advantages through which place-based resource exchanges are facilitated in close proximity for environmental/economic benefits (Chertow, 2000, 2007; Van Berkel et al., 2009). However, not all the materials flow necessarily require proximity. On the one hand, wastes that are costly to transport and have relatively low market value, such as MSW, debris, wood, and sludge, are mostly collected from the city where the recycling facility is located, as well as energy/heat carriers so as to avoid degradation during the exchange. On the other hand, metal, waste electrical and electronic equipment (WEEE), plastics, paper, automobile shred (containing metals), and oil are mostly collected from longer distances (Chen et al. 2012). On the basis of what has just been explained, recycled products that are costly to transport and of low value are usually delivered across short distances, whereas high-value products that are relatively cheap to transport are delivered over long distances (see matrix in figure 2.12). In addition, when most of the recycled products become inputs for particular categories of industrial producers (e.g., construction materials and feedstock for iron and cement production), the transportation distances also tend to be short, since in such cases, the demand for recycled products is spatially more concentrated than the generation of wastes.

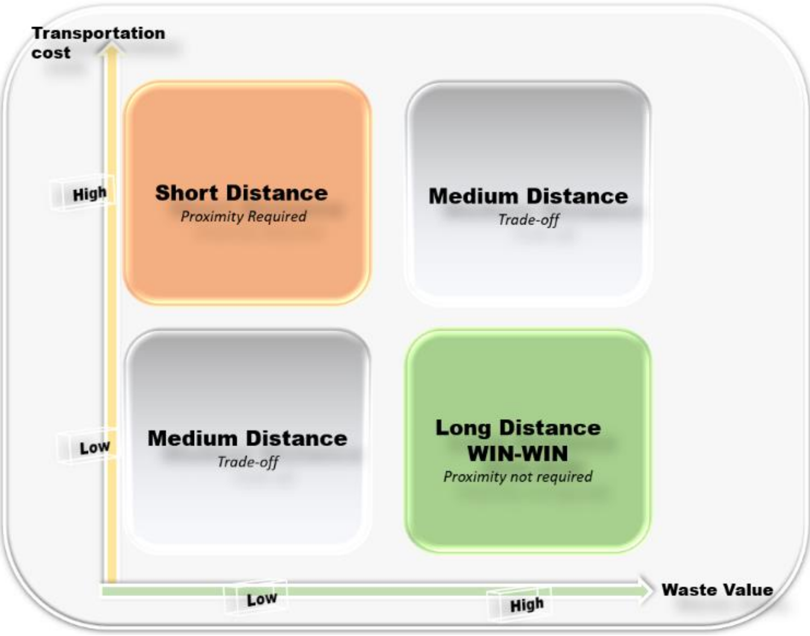


Figure 2. 11 Transportation Impact Matrix

<u>Relationship with other factors:</u> According to has just been said, locating close to customers is more likely to reduce transportation and transaction costs (and consequently to make more exchanges that improve revenues) (Chen et al. 2012). It must be said that geographic proximity can also facilitate social relationships, enhancing trust between different actors to support resource exchanges (Chertow, 2000; Ohnishi et al., 2012). Another positive

phenomenon (able to stimulate awareness) especially enabled by geographical proximity is called regional learning, wherein partners exchange knowledge on how to develop a local symbiotic system (Baas and Boons, 2004; Baas and Huisingh, 2008; Mirata and Emtairah, 2005; Lenhart, Van Vliet, and Mol 2015). See also above the relationship with security of supply and waste composition.

Cooperation and coordination: Urban symbiosis projects are characterized by a high level of complexity as they involve multiple stakeholders (e.g., citizenships, companies producing and using wastes, government, companies collecting wastes) that have usually different interests (Sun et al., 2017). In this regard, two studies in particular show that strong cooperation among all the above-mentioned stakeholders is a *conditio sine qua non* for the effective implementation of IS projects (A. Neves et al. 2020 ; M. R. Chertow 2000). What makes Kalundborg a model is that its participants allowed and continued to encourage interaction; Local engagement is the glue that binds organisations together, facilitating access to information. This requires personal and professional relationships, common interest, and ownership. Social relations among participants at inter-organisational levels may explain why certain symbiotic exchanges, especially those with minor short-term economic gains and long-term strategic value, persist (Heeres et al., 2004; Jacobsen, 2006). Open and frequent inter-organisational communication and dialogue not only generate trust and transparency but encourage learning and enable knowledge spill-overs (Lenhart, Van Vliet, and Mol 2015; Sacirovic, Ketin, and Vignjevic 2019). However, problems occur when many different actors, belonging to different sectors, have to interact (see "Multiparty involvement").

Firm Commitment & multiparty involvement (connected with "Cooperation and Coordination"): With the involvement of many public and private actors, eco-industrial networking implementation requires commitments, i.e. the stipulation of contracts that make depend one firm on the other with the creation of a link. This link is crucial to have a more stable/secure supply and increase the efficiency, however, benefits of a symbiotic link between firms are not uniform among the participating units and that poses a major barrier for the negotiation process. Thus, ensuring equitable benefit sharing holds the key for the successful establishment of a symbiotic link.

Relationship with other factors: considering the involvement of many different actors (both private and public) and the associated transaction cost, the planning and coordination make it a big challenge for UIS linkages (Yedla and Park 2017). It happens especially because some analyses indicate that IS activities have not been fully promoted because the senior managers of the tenant industrial enterprises did not pay enough attention. Thus, it is critical to increase the awareness of all the stakeholders involved (Guo et al. 2016). See also Supply volatility and Infrastructure comments to understand all the relationships.

Green regulations & Incentive schemes: The action of regulatory institutions can significantly reduce or increase the probabilities of UIS success. The first “weapon” that regulators can use are the green regulations: ban on disposal and hazardous materials, high tipping fee and environmental levy such as climate change fee. For instance, in UK regulators encourage the industries to understand the real value of resources, to try for innovation and take up by-product reuse, cutting down carbon emissions and improving the health and air quality (Yedla and Park 2017). The second “weapon” are well aimed incentive schemes. In fact, after having identified the hot-spot carbon emitters of a region (through CF assessment methodologies) policy makers could set the proper incentives to achieve concrete reduction goals (Fang et al. 2017). Economic instruments such as tax and financial subsidies, in addition to the green regulations, are critical for improving the local stakeholders' awareness and understanding of IS/UIS potentialities (Liang Dong et al. 2016) and internalize the positive externalities of the urban ecosystem (Cao et al. 2018). Relationship with other factors: incentive scheme might be a very good driver to overcome the high CAPEX, to reduce the transaction cost and to stimulate the interests of investors by increasing their awareness.

Hazardous materials: It is defined as waste material, such as an industrial by-product, that is potentially damaging to the environment and harmful to humans and other organisms. Some governments regulate treatment, storage, and disposal of wastes as a mean to avert risks stemming from improper management of hazardous wastes. Therefore, laws set for handling such waste insist on a set of protocol for hazardous waste handling and treatment, which leaves little scope for the reuse of by-product elsewhere as a feedstock. Therefore, on the one hand it can be a driver to lower the pollution and to ease the recyclability of products, while on the other hand it can pose a limit to the quality of products itself (Yedla and Park

2017).

Relationship with other factors: the restriction on **hazardous materials** enhance the effectiveness of “green” regulations and can help improve health and air (as well as land, water etc..) (Z. Liu et al. 2018). Conversely, the possibility of not using hazardous materials might cause a lower quality of products (Yedla and Park 2017) since the choice of manufacturers about RM would be restricted to a shorter list.

Community approval: intended as the perception that the broad community has about UIS practices, and whether they would easily accept them or not. Thus, in this case, the community could be seen as an “unofficial regulator” which approves or denies the UIS development. On the one hand, many aspects of UIS are beneficial for the broad community (employment, property value etc.). On the other hand, urban communities often consider incineration facilities, landfills, and heavy industries as sources of pollution and oppose local placement of new plants. As a result, new incineration plants, landfilling sites and heavy industries are often located in less populated areas. Because demand for heat in such areas is limited, a large amount of heat generated these incinerators is not efficiently used and, also, the transportation costs increase (Geng, Tsuyoshi, and Chen 2010).

Relationship with other factors: UIS might be in favour of the community since it discourages landfilling and tries to avoid incinerators as long as it is possible, because the incineration process would impede the reuse and recycling of many valuable solid wastes that could be substituted for raw materials (Geng, Tsuyoshi, and Chen 2010). In addition, UIS is able to create employment opportunities which would surely be beneficial to the community, as discussed above in Employment Opportunity.

Waste reduction, resources conservation & landfilling: UIS systematically considers the various types of waste, including industrial and municipal waste, as well as all stakeholders’ concerns; therefore, various environmental benefits could be gained by readdressing the waste purposes, such as conserving natural resources and reducing the solid waste volume and thus reducing the burden on local landfills. In addition, UIS can significantly reduce both virgin material consumption and CO2e emissions (Hashimoto et al. 2010).

Relationship with other factors: see Green Regulations for all the three factors; see price of RM, energy, and labour for Resource Conservation; see Community Approval for Landfilling.

Health and air quality: UIS has the potentialities for guaranteeing a sustainable cohabitation between industries and urban environment, contributing to dilute the toxic gases, reduce hazardous waste and restore water to reduce the concentrations to non-harmful levels for environmental health (Hashimoto et al. 2010; Z. Liu et al. 2018; Sacirovic, Ketin, and Vignjevic 2019).

Relationship with other factors: See Green Regulations and Hazardous Materials.

2.3.2 "The ball" of Factors relationships

In this paragraph **the relationships** between different factors emerging from previous comments have been summed up. It must be said that only those having literature's "acknowledgement" have been considered, i.e. the relationship has been reported in the new framework only if it was directly or indirectly discussed by the selected papers; indirectly means that two factors are intrinsically related by definition, i.e. they are intertwined according to the definitions given to them. In addition, it must be said that many other relationships could exist and some of them might also be obvious. In furtherance of graphically displaying what factors (barriers and drivers) mutually influence each other, a specific new tool called **"the ball"** (figure 2.12) has been used. On the circumference the rectangles containing the factors can be found. These are coloured in different ways in accordance with the macro-category in which they have been placed by basing on their meaning (see table 2.7). These rectangles are connected by arcs, which represent a relationship or mutual influence between the different aspects. If the comments factor by factor are not fully explicative for the intentions of the reader, in the appendix ("D&B references") it is possible to find the full matrix where the references of each relationship/arc have been placed. Moreover, to make the visualization more friendly, the same colours as the rectangles have been used to paint the arcs representing the relationships between factors (in accord with what done for the macro-categories, also here the colour of the arcs have been assigned considering the meaning of factors and of their relationships): blue arcs correspond to mainly technological-related (involving technologies) relationships; orange arcs correspond to mainly information-related (involving the exchange of information) relationships; white arcs correspond to mainly economic-related (affecting economic conveniency) relationships; purple arcs correspond to mainly organisational-related (involving organizational decisions) relationships; red arcs correspond to mainly regulatory-related (involving regulations/regulators) relationships; and green arcs correspond to mainly

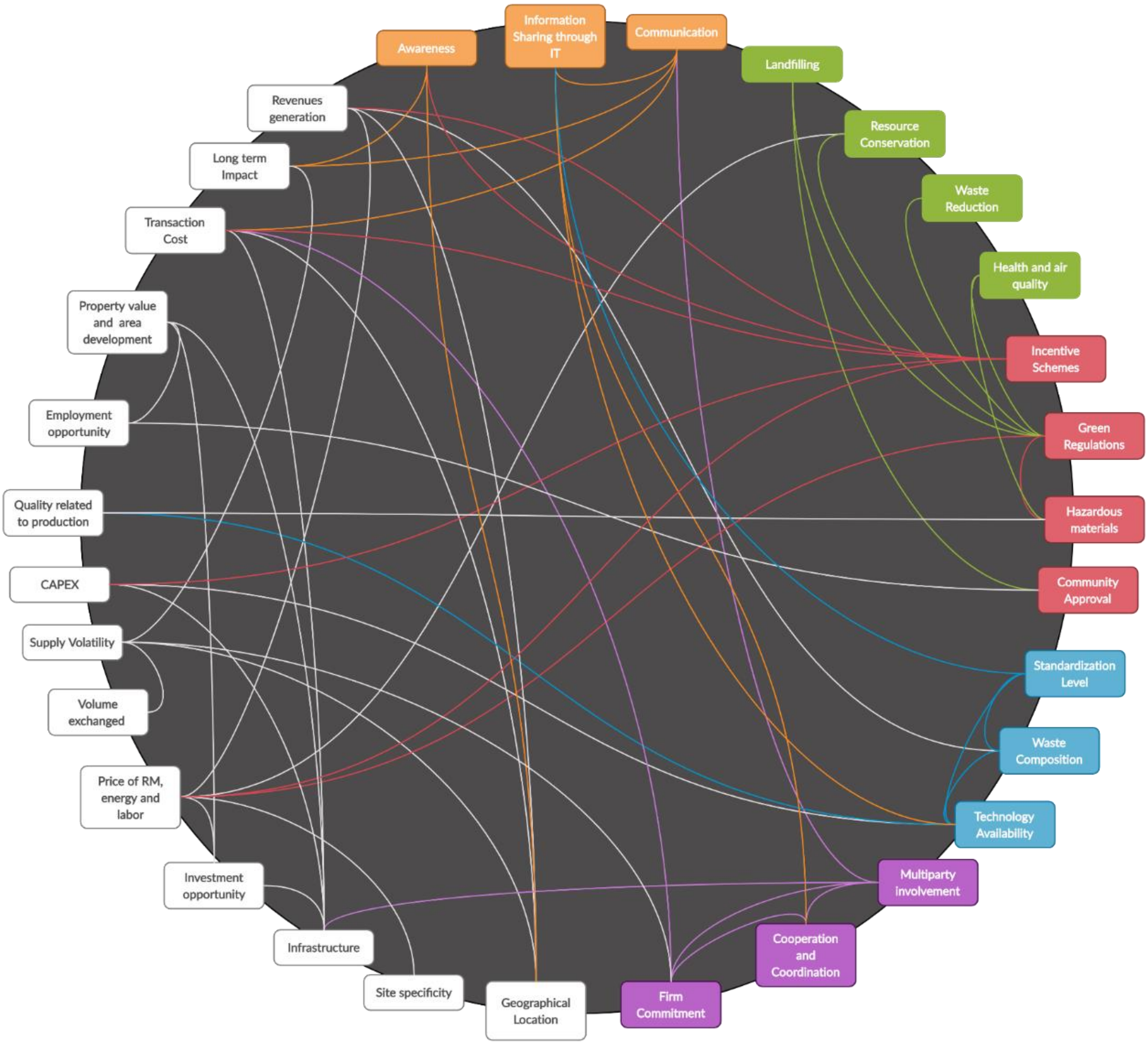


Figure 2. 12 "The ball of relationships" explaining the interconnection between different factors.

environmental-related (concerning environment) relationships. “The ball” has been used in Chapter 4 as a basis for a deeper analysis of the relationships between UIS drivers and barriers: according to the Italian experience, the present arcs will be investigated and further discussed.

2.4 Development of IS-URS (UIS)

In keeping with G.-F. Liu and Chen (2013), there are two primary models in building and developing an urban symbiosis network (as well as IS networks): **Top-down** planning and **Bottom-up** planning. The first one is a goal-directed way (Planned) and the second one is a self-organization method (Spontaneous). Then, there is a combination of the two called **Middle-out** approach, for instance it has been used for the NISP in UK, which is an interactive process that is able to integrate managers (top-down) and workers (bottom-up) contributions to network development. There is an exhaustive literature discussing advantages and disadvantages and providing examples of the three models, therefore it is not intention of this study to talk about it. Just one thing deserves to be specified: the "facilitated" or middle-out approach will probably be the dominant mode for the development of urban symbiosis in the future, since it can avoid top-down planning's disadvantages such as lack of flexibility, overly concern about environmental benefits and difficult to achieve optimal allocation of resources while also solving the problems of bottom-up planning such as market failure, communication difficulties and slow development. The purpose of this paragraph is more precisely related to what could be the stages of the development and what could be the developmental role of each stakeholder belonging to the system. In furtherance of this, the literature proposed before can be a very good starting point.

2.4.1 UIS development Phases

Most of papers discuss UIS already in operation and mainly focus on the benefits/results generated. As previously seen, some papers talk about factors for UIS functioning and development. However, just a few papers talk about stages of UIS and, sadly, there is not a clear background on what is **"the path"** that an area goes through when UIS process starts up. As reported by Fujii (et al. 2016), the transition from present to future will be driven by UIS: in this study the current system is defined as based on fossil resources, where the generated waste is headed for landfills; the future system as a system where the industries and the society are ultra-low carbon, thanks to the penetration of renewable sources and circularity; in the middle there is a **transitional system**, based on the so called hybrid industries and urban symbiosis, where only part of the waste is incinerated or landfilled and where waste becomes rather a resource more than a burden.

"A hybrid industry is an industry whose processes use not only fossil resources but also recycled and renewable resources to the highest extent possible. A hybrid industry has multiple functions: not only the original function to manufacture a product, but it also has additional functions such as waste treatment and supplying energy for surrounding residential areas" (Fujii et al. 2016). Because of their capacity to generate significant environmental benefits, hybrid, and multi-functional industries together with urban symbiosis are expected to be a **transitional system** that will promote low-carbon industries and cities in the future. In fact, in densely populated cities located nearby heavy industries the additional cost of sorted collection and pre-treatment to produce recycled raw materials and fuel is relatively low, therefore, it could be very convenient recycling by utilizing the already existing industrial facilities so as to reduce the incinerators use and have both environmental and economic benefits.

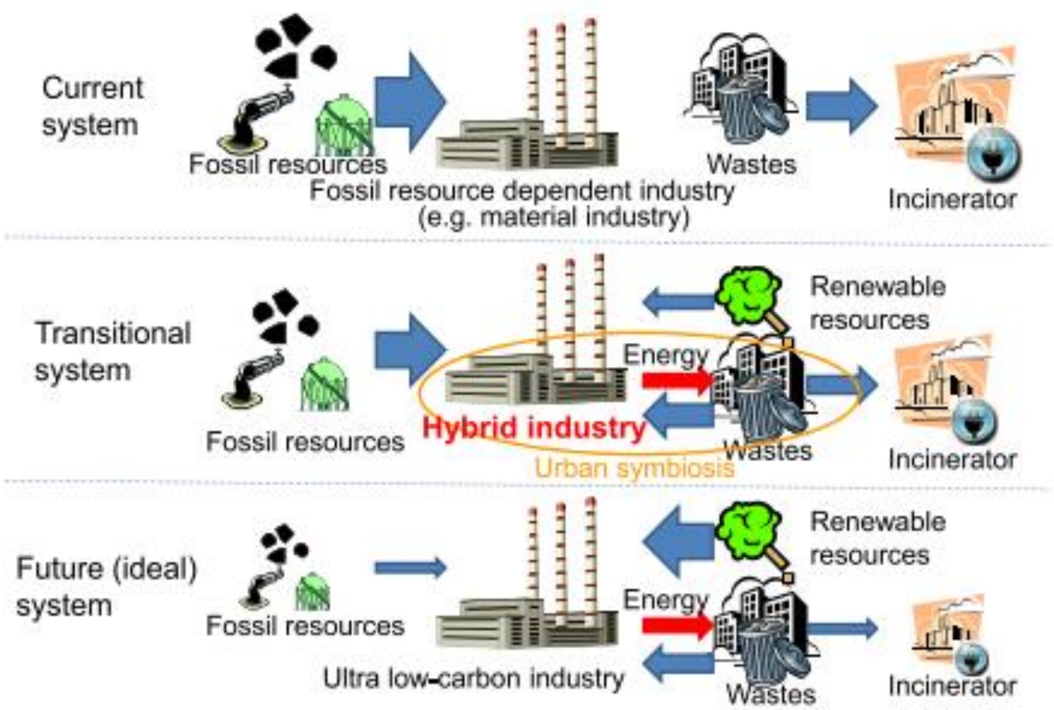


Figure 2. 13 . Transition stages from current system to a future ideal system. Taken from Fujii (et al. 2016)

Therefore, the "hybrid industry" condition could be very helpful to understand what the intermediate phase of UIS development would be like: through the concept of hybrid industry and of urban symbiosis it is possible to explain the transition between a system without UIS and an ideal system with UIS. It is like taking a picture of a dynamic district in evolution towards an ideal system. It embodies all the principles necessary to implement

UIS practices and, thus, it shows what the intermediate phase after the implementation of UIS could be like. In fact, as showed in the figure 2.13, the hybrid industry combined with the urban symbiosis principles characterize the middle phase where the system is undergoing a transaction.

What changes when moving from the current system to the transactional system?

To further clarify what the difference between a current system and a transactional system is, the main differences are here highlighted. As a starting point, the system is in the first condition called **"current system"** which represents most parts of current industrial and urban areas in the world: based on fossil fuels and where waste generated is heading for landfills/incinerators. When an area based on the "current system" incipiently meets UIS, it starts the transaction towards the second condition. During this first transaction, the very managerial practices change more than the area structure itself. It means that in most cases there is no need to build new recycling facilities, since in the initial stages the industrial ones can be exploited to provide for the service required. Therefore, what truly changes are the managerial practices ruling the functioning of industries and the waste logistics, as well as the culture of the actors involved who put more effort in waste re-routing. For example, in Japan incinerators are getting older and a major revision of the waste management plan is required, including the elimination and consolidation of inefficient incinerators (typical of first stage). In second stage, utilizing existing industrial and waste treatment facilities has the potential to be an economically attractive solution, especially in large cities and surrounding regions near industrial complexes. This better exploitation of existing facilities should be simultaneously combined with a more efficient and organized waste separation and sorted collection (as for instance happens in China according to Fujii (et al. 2016)). The main problems to overcome during the first transition (from the current system to the transactional one) relate to the likely needs to revamp and upgrade the industrial facilities in order to let the waste recycling process work; that is where government should act through incentives so that financial burdens do not completely fall on industrial players' heads, in coherence with the principles of the middle-out approach.

Hitherto, the three main statuses characterizing a system undergoing a development process have been pointed out (current system: no UIS, transactional system: hybrid industries + urban symbiosis and future system: UIS) and it has been explained what their main characteristics are. Since the UIS literature does not offer more than what just discussed, it is necessary to dig into the IS literature and UrS literature to find some more papers describing the development paths and stages of industries and cities.

As far as concern urban context, Fang (et al. 2017) points out four stages of development (poverty stage, production stage, consumption stage and eco-city stage) thanks to which it is possible to further breakdown the system conditions. Thanks to M.Chertow and Ehrenfeld (2012) it is possible to understand the industrial development dynamics in each stage: a three-stage model of development for IS is promoted. Stage 1 is defined as **"Sprouting"** where firms engage in individual resource exchanges on a random basis for a variety of reasons. Then, the positive network externalities created may change decision analysis in firms such that new exchanges become desirable. On this pathway, the industrial district reaches stage 2 **"Uncovering"** where the exchanges become known or "uncovered" and benefits (also environmental) start to be tangible. In addition, at this stage both goals and range of membership broaden thanks to "regional learning" and "knowledge spill overs". Finally, the firms reach stage 3 called "**Embeddedness and institutionalization"** where, in supplement to self-organization, further expansion of the network becomes intentionally driven by an institutional entity created at an earlier stage that becomes more deeply established during this stage.

Despite the differences of the three mentioned studies [(Fang et al. 2017), (Fujii et al. 2016) and (M. Chertow and Ehrenfeld 2012)], in accordance with the four stages proposed by Fang (et al. 2017) and in combination with the insights provided by Fujii (et al. 2016) and M. Chertow and Ehrenfeld (2012)**,** four stages (more appropriate names for UIS have been given) characterizing UIS development path have been identified: the first one called "No UIS" where the system does not exploits UIS, the second one called poverty stage where UIS has just started its route, the third one called economically viable stage where the system starts benefitting from UIS, and the fourth where the city/area becomes economically, environmentally and socially sustainable, i.e. eco-area. In figure 2.14 it is possible to notice a summary of what the stages and their variables are and how value qualitatively varies across time when implementing UIS practices from scratch; value is intended as the sum of all the benefits concerning economics, environment, and social context.

Stage 1- No UIS (current system): the first stage refers to the condition of current system defined by (Fujii et al. 2016), where the economy is based on fossil fuels and there are no alternatives to landfills or incinerators. Basically, it is the conditions in which cities would be without UIS. Here, it is assumed that the "grounding infrastructure" (i.e. roads, energy, water etc.) already exists. This is also the situation that characterizes most cities in the world.

Stage 2 – Poverty Stage (Transitional system): at the dawn of UIS implementation, the system starts leaning towards the "sprouting" condition (M. Chertow and Ehrenfeld 2012) and towards the hybrid industry (Fujii et al. 2016) but benefits are still "poor" (poverty stage from Fang (et al. 2017)): there is a re-definition of collection and separation system able to increase the efficiency of urban-industrial metabolism and already existing industrial facilities start to be exploited for recycling waste materials that before where destinated to landfills or incinerators. This does not imply that UIS is always triggered by the transformation of normal plants into hybrid industries even if it can be considered as a facilitator (section 2.4.2). At this stage, the economic benefits of the UIS are not visible yet, especially due to the high capital expenditure and organizational effort required to adequate industrial plants to the new procedures. Incentives are necessary to let some players overcome financial barriers. In addition, there are difficulties related to coordination and cooperation among actors since there is not a consolidated network or a platform able to reduce the transaction costs. In fact, players might not promptly trust each other due to information asymmetries and moral hazard risks, thus the volume exchanges are low. Furthermore, environmental benefits are still very low since the economy is almost totally dependent on fossil fuels, and being the UIS practices not stable yet, the emission reduction due to waste reutilization and avoided landfilling/incinerating is still ineffective.

Stage 3 – Economically Viable Stage (Transitional system): it corresponds to "production" and "consumption" stage from Fang (et al. 2017) and at this stage the benefits start to be "uncovered" (M. Chertow and Ehrenfeld 2012): the UIS has started to be effective, new structures and facilities might have been built or old plants might have been transformed either by companies or governments that act as facilitators, and the communication network rode its way. Players can exchange materials and sufficient volumes to obtain good economic returns, and through IT technologies transaction cost has lowered. Economic incentives could be necessary just for industries where the volatility of the flows is higher or where structural factors related to energy or RM price hinders the UIS take-off. The main efforts in terms of expenses are related to investment in more advanced technologies which could further improve the efficiency of the transactions and expand the margins. Also, environmental benefits due to the resource and energy saved start to emerge. The penetration of renewables is not strictly related to UIS, however the combination of the two could create a powerful synergy for the decarbonization process and for the environmental restoration process.

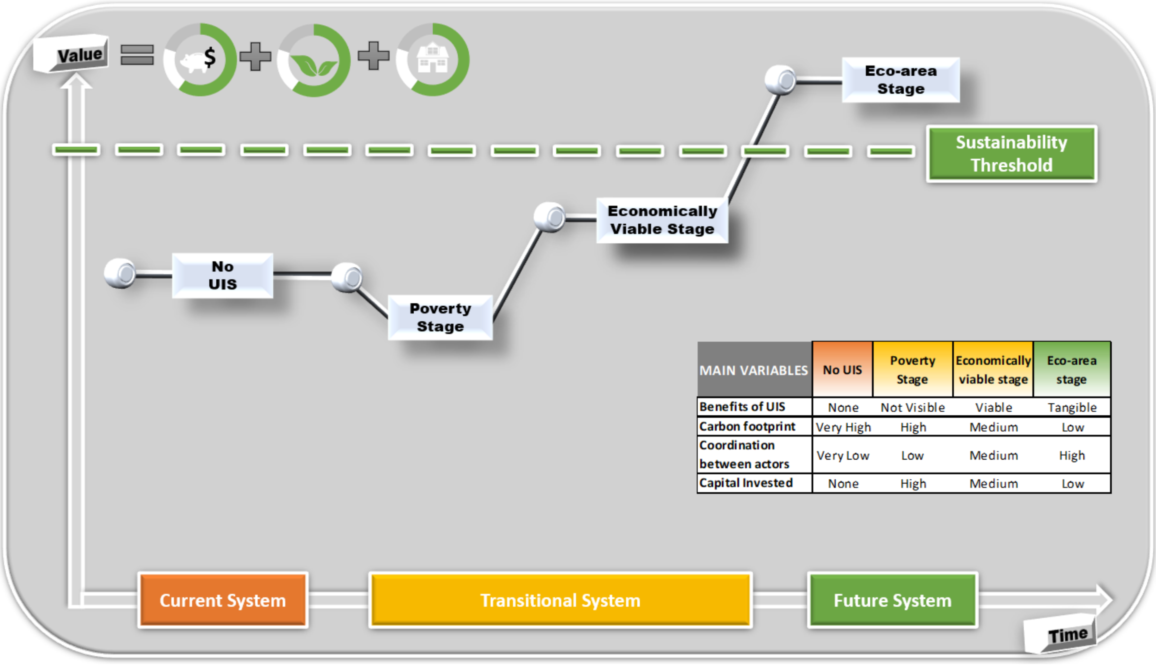


Figure 2. 14 UIS development stages and characteristics.

Stage 4- Eco-Area (Future System): the last stage refers to a "institutionalized" self-sustaining environment (M. Chertow and Ehrenfeld 2012), called eco-area (or eco-city in Fang's). Being 100% self-sustaining could be utopic, nevertheless the phenomenon of "urban mining" in accord with UIS principles could be able to satisfy a good share of human settlements needs. At this last stage, environmental, economic, and social benefits are tangible and UIS practices are very well consolidated. Examples of social benefits are cleaner air and improved health from the new balance between urbanization and nature, property's value increase, new opportunities for employment etc. The existence of a centralized IT network favours exchanges of any kind and just a small fraction of waste heads for landfills or incinerators. The investment costs have reduced to maintenance and R&D costs, while the incentives could be turned into governmental control of the waste market, by fining the actors who do not respect the correct reutilization/disposal procedures.

In an eco-area, it is also expected to have a high share of renewable energy sources, which in theory should overcome the fossil ones for an ultra-low carbon economy.

In conclusion, the UIS could be a powerful ally to push cities over the “threshold” of sustainability, i.e. where human settlements are, at least in theory, able to self-sustain themselves.

2.4.2 Role of the different UIS actors in development

When talking about development, it is important to know what are the actions that should be taken by each actor and when. Liu and Chen (2013) describes the duties of China’s urban symbiosis members in a government promoted model. In addition, Yedla and Park (2017) list some measures to undertake on different levels to foster the development of Eco Industrial Parks: national level, industrial level, firm level, city level, and social measures. By combining these frameworks, and by classifying both duties and measures according to the 4 development stages, a new framework (table 2.8) has been drafted. To outline the actors involved the **social-legal classification** proposed in paragraph 2.3.1 has been used; when talking about development it is important to know the social and legal role of the actors with respect to the decision that they can take. In the table, the main tasks that each actor should accomplish have been divided stage by stage.

Role of Government (both local and central): Most measures that have been classified as national level measures by Yedla and Park (2017) fall in this category. These measures are founded on the same pillars: long-term vision, involving both businesses and different ministries in the realization of a EIP master plan to coordinate actions and relying upon independent actors, and institutions or research units to facilitate cooperation and develop a replicable model. Based on these pillars the following measures have been included in the newly created table 2.8: in the initial stage, where UIS has not been established yet, the government should guarantee flexible waste management regulations that let industries and collectors slowly adapt to the incipient changes. During the transition, instruments like incentives, landfill taxes, emission caps and landfill bans could be helpful to catalyse the transition by giving, at the same time, the requested financial support. In case governments do not have enough resources themselves to give initial financial support to develop the infrastructure needed for the exchange of resources, by-product, and waste, public–private partnerships may be attempted to provide much needed support for the infrastructure development. In addition, government could enhance the use of ‘‘eco-friendliness’’ of products as a market driver (ex. eco-labelling). Once UIS has been well proven, the role of the government is manly related to review purposes by checking companies’ practises and engagement in the symbiosis and by setting up a fining system for those not respecting the correct practices.

Government agencies (commissions): A government agency may be established by either a national government or, in case of USA, a state government within a federal system. In relation to UIS, the first pillar of national policies is related to involving businesses and establishing a network and consequently these agencies have a key role when the development of UIS is top-down: in the first part their objective is to analyse and approve projects based on potential benefits generated; then, their role evolves into helping private organizations in setting up a recycling system, and ultimately into fostering the development of an exchange network (for instance through an online platform). Therefore, a channel of communication and coordination among inter-industrial clusters plays a key role in achieving ‘‘wider networking options’’ which could further minimize social losses in the system. National government may establish research units in support of eco-industrial development by providing the necessary drivers such as research grants and infrastructure. Such an initiative can promote collaboration between the industrial clusters and research Institutes (Yedla and Park 2017).

Public Organizations (e.g. industry associations): state-owned enterprises play a key in the development of UIS too, especially when it is top-down. Their objective is to promote the establishment of a symbiosis network and handle the relationships and coordination between public and private actors. For instance, Multi-pronged awareness-raising initiatives overcome the lack of awareness. (e.g. development of training materials for industrial workers; using popularity modes of advertising for the use of ‘‘green goods’’ and public participation in ‘‘greening of industries’’ initiatives). In addition, when UIS starts to be consolidated, these organizations may try to standardize their practices: eco-industrial development involves resource recycling, and such recycling does not have unified international standards. This could have a negative effect on their international trade performance, which would have a serious implication on national economy of any country. Therefore, there is a need to institutionalize, internationally, such eco-industrial networking initiatives (G.-F. Liu and Chen 2013).

Private Associations (e.g. NGO such as Ceres): they might catalyse the process in uncovering of synergies and opportunities related to sustainability, as well as bridge the gap between business and governments (G.-F. Liu and Chen 2013).

Universities: the role of universities is key throughout the development process. In the first part they ought to help highlighting economic, environmental, and social opportunities, while later they can foster the improvement of waste management technologies through R&D. While industries are better equipped to carry out such need-based R&D, national government should ensure to promote collaboration between industrial R&D and research institutes by fostering such collaboration with various incentives (G.-F. Liu and Chen 2013).

Business Enterprises (firms): The role of industrial companies directly involved into the business is crucial. In the initial stage, they might be not aware of the opportunities and they might hinder the development process. In fact, many times they try to renegotiate with regulators the restrictions related the recycling and disposal of products (e.g. restriction on hazardous materials use and disposal). In the poverty stage, their involvement as active partners and collaborating actors is the soul of UIS; if the different enterprises cannot establish connections the UIS will probably never take-off, in spite of all the efforts made by the other players. Potential bilateral and multilateral agreements dealing with recycling of resources, by-product, and waste streams need to be institutionalized (among the major limitations of material exchange, the risk of not meeting the requirements of input material of the recipient firm stands out as prominent). Once the UIS practices start working, they can embark on to EPR (extended producer responsibility): EPR ensures the involvement of industries in handling solid waste and improve material recycling (Yedla and Park 2017).

Community: the role of communities is proportionally influenced by culture of the society: in the first part, habits such as correct waste differentiation and collection, as well as green consumerism, might ease the “graft” of symbiosis practices. In the transition stages, the communities are responsible for integrating urban enterprises (agricultural or husbandry) within the symbiosis boundaries and then for managing the collection and recycling of waste (G.-F. Liu and Chen 2013).

Table 2. 8 Role of Actors involved in UIS per each stage of development.

	No UIS	Poverty Stage	Economically viable stage	Eco-area stage
Government	Flexible waste management regulation, Building the Infrastructure	Incentives, Landfill taxes, Eco-labelling	Emissions caps, Landfill bans, Eco-labelling	Control and maintenance, fines, Eco-labelling
Government agencies	Project analysis and approval	Set up Recycling sysetm	Building communication platform for enterprises	Expand the links of the collaboration platform
Public Organizations	Promoting the establishment of symbiosi network	Coordinating and monitoring the activities of members, bridge between business and government	Partecipating in establish national standards	Partecipating in establish internationals standards
Private Associations	Assisting in uncovering of synergies	Feedaback between business and government, assisting in establishing new synergies		
Universities	Assisting in uncovering of synergies: data collection, MFA, CF and economic assessment	R&D in waste management technologies	R&D in waste management technologies, Monitoring governmental policies and business strategies	R&D in waste management technologies
Business Enterprises	Attempt to renegotiate with the regulations that restricts recycling of waste and by-products within firms and with other firms.	Keep close relations with other enterprise, create more symbiotic opportunity, feedback information to community and local government	Feedback of economic and environmental advantages of partnerships, Embark on to EPR (extended producer responsibility).	
Community	Call for human waste collection and differentiation, Promoting green consumerism	Integrating local enterprises like urban agriculture, urban animal husbandry	Manage recycling vendor, Manage fixed collection point	

2.5 UIS/IS in Italy

Hitherto, it has emerged that in **Asia** a number of urban-industrial symbiosis initiatives have been reported, with the highest number of cases in China, largely due to constraints on carbon dioxide emissions and the numerous plans and policies that have been implemented to foster circular economy practices. In Japan, there have been cases of industrial symbiosis and industrial and urban symbiosis across several cities, driven by the Japanese Eco-Town Programme that encourages the use of industrial, municipal, and commercial waste in industrial applications, with the aim of boosting the economy and reducing waste disposal. Angela Neves (et al. 2019) describe the situation in **Europe**, where numerous applications of industrial symbiosis are spread across different countries: most of the cases reported in the literature are in northern and north-western Europe, with the United Kingdom reporting the highest number of cases. Finland also has several cases of industrial symbiosis, largely arising from the strong presence of the pulp and paper industry, which has driven the creation of synergy relations, as well as Denmark with Kalundborg. Differently from Chinese and Japanese cases, in EU the symbioses studies tend not to envelop the urban context within the analysis. In this section a look is taken on what are the current case studies conducted in **Italy** and what are their main contents/aspects analysed, by answering the last remaining research question related to the LR.

2.5.1 Case studies previously conducted in Italy.

At the best of this study knowledge, up to November 2020, in Italy only one study (A. Simboli, Taddeo, and Raggi 2019) discusses the potential UIS in the province of Pescara. However, by enlarging the scope towards industrial symbiosis and, more broadly, towards industrial ecology, it was possible to find new literature cases that can help investigating and evaluating the presence, the diffusion, and the potential of symbioses on the Italian field. As Table 2.9 - readapted from Angela Neves (et al. 2019) – shows, the focal topic of Italian case studies is the industrial world. Some authors discuss the requalification of existing industrial districts or brownfields through the use of IS practices (D'Amico et al. 2007; Susur et al. 2019) others try to detect and propose new synergistic possibilities offered within the studied area (Ardente et al. 2010; Marchi, Zanoni, and Zavanella 2017; Notarnicola, Tassielli, and Renzulli 2016; Alberto Simboli, Taddeo, and Morgante 2014, 2015), others attempt to discuss the creation of a platform to favour IS linkages creation in Marche (Marconi et al. 2018) and Sicily (Luciano et al. 2016) and, last but not least, one author (Iacondini et al. 2015) aims to describe all the European, national and regional regulations that have fostered the adoption of IS practices.

Table 2. 9 Summary of IS/UIS studies conducted in Italy.

City	Region	Sector	Waste Considered	Approach	Type of Analysis	Focal Topic	Objective	Source
Murano	Veneto	Glass Manufacturing	Chemicals	BATTER tool, direct measurement	Quantitative	Industrial District	Requalification of an existing industrial district	(D'Amico et al. 2007)
Brancaccio, Carini, Termini Imerese	Sicily	Automotive	Plastics and rubber	Questionnaire and interviews, LCA	Quantitative	Eco-industrial Cluster	Detect&Propose a solution to create an "open recycling loop"	(Ardente et al. 2010)
Val di Sangro	Abruzzo	Motorcycle	Industrial Scraps	Questionnaire, interviews, site visits, and focus groups	Quantitative	IS	Detect&Propose IS strategies and explain the role of the key drivers	(Alberto Simboli, Taddeo, and Morgante 2014)
Fucino Upland	Abruzzo	Agriculture and Manufacturing	Paper,Plastics and rubber, and wood	On-site survey and interviews	Quantitative	Agri-food Clusters	Detect&Propose IS strategies and appraise the impact of reparing instead of racycling/incinerating	(Alberto Simboli, Taddeo, and Morgante 2015)
Pescara	Abruzzo	Agriculture, Manufacturing, Water&Waste, Construction	Organic, metallic, non-metallic, paper, plastics and rubber, waste heat and steam, and water and wastewater	Input-Output Analysis	Qualitative	UIS	Detect&Propose potential UIS strategies	(A. Simboli, Taddeo, and Raggi 2019)
Macrolotto of Prato	Tuscany	Wool Production	NA	Interviews & Questionnaires	Qualitative	EIP	Explain how the EIPs can unfold over the traditional industrial production systems	(Susur et al. 2019)
Ponte a Egola	Tuscany	Industrial Production System						
NA	Emilia-Romagna	Variety of actors beloning to the region						
NA	Marche	WEEE	Mixed plastic and copper from electrical cables	Creation of a platfrom. Interviews and LCA	Quantitative	IS	Creation of a web platform that can be used to characterize, classify information, match partners and generate IS linkages	(Marconi et al. 2018)
NA	Emilia-Romagna	NA	NA	Interviews	Qualitative	IS	Analysis of the european,national and regional initiatives/regulations to foster IS	(Iacondini et al. 2015)
NA	Sicily	NA	NA	interviews, NISP approach, focus groups	Qualitative	IS	Promoted by ENEA with the objective of implementing an industrial symbiosis platform in Sicily	(Luciano et al. 2016)
Brescia	Lombardy	Industrial Production System, wood ,caviar	Energy	Swot, Material waste analysis	Qualitative	IS	Evaluate current and potential synergies of creating an industrial symbiosis network in a specific Italian district (focus on energy utilization)	(Marchi, Zanoni, and Zavanella 2017)
Taranto	Puglia	Industrial production system	Steel, fly ash,heat,BFS and BOFS scraps	Material and energy analysis	Quantitative	IS	Detect&Propose new possible interactions for IS	(Notarnicola, Tassielli,Renzulli)

The research question regarding the Italian Case studies consists of describing the current situation: what studies have been conducted and where. To do so, the process for analysing the Italian context is based on a regional description of related papers and main contents. In the pie chart it is possible to notice how many case studies have been conducted in each Region. In all the other not mentioned regions studies have been never conducted.

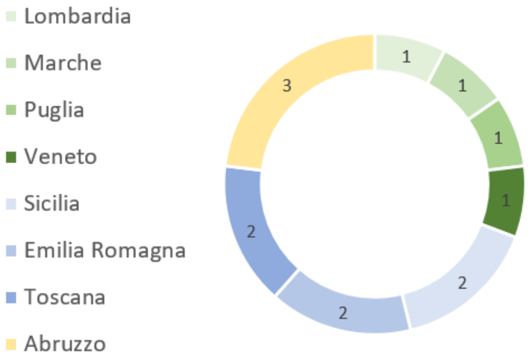


Figure 2. 15 Frequency of studies previously conducted in Italy per region.

Abruzzo: This is the region in which most case studies have been conducted, probably due to the presence of the "Industrial Symbiosis Lab of Università di Chieti-Pescara". The first article published (Alberto Simboli, Taddeo, and Morgante 2014) is focused on the manufacturing sector only, it analyses the issues in a local industrial network which the CISI (Consorzio Italiano Subfornitura Impresa), a Consortium of 18 SMEs, and the Honda Italia Atessa production plant (HIA), both located in the Val di Sangro Industrial Area. After having identified them, some IS strategies have been proposed and, in accordance with what discussed in paragraph 2.3.1, the role of four key drivers (geographical location, regulations, heterogeneity of waste and stakeholders' participation) has been examined.

The second article (Alberto Simboli, Taddeo, and Morgante 2015) related to the agri-food clusters (AFC), i.e. development of local agglomerations of companies consequent to agricultural activities, describes of the most representative Italian AFCs, the Fucino upland in the Abruzzo region. The aim is to analyse the features of the AFC and the flows of auxiliary material wastes, identifying solutions for their efficient management from an eco-industrial perspective. The focus is especially on "agricultural plastics", i.e. auxiliary materials used for agricultural activities: film mulches, drip irrigation tape, row covers, tunnels, silage bags, hay bale wraps, plastic trays, pots, and containers. The most-used plastics are polyethylene (PE) and polypropylene (PP), followed by ethylene vinyl acetate (EVA), polyvinyl chloride (PVC), and to a lesser extent polycarbonate (PC) and polymethyl methacrylate (PMMA). This study could offer more precise insights on plastics recycling with respect to the options proposed in paragraph 2.2.2.

The third and most recent article (A. Simboli, Taddeo, and Raggi 2019) appraises the main flows and potential synergies among the residential and the neighboring rural and industrial dimensions (UIS perspective) by offering an integrated framework through an input-output placed based approach. The analytical framework proposed concerns those "hybrid" and small-scale urban contexts in which residential, rural, and industrial dimensions are strongly integrated. It also presents the evolution of the Pescara proving throughout the years from 1960 (large industrial complexes) to 1970 (small and medium sized industrial areas) until today (9 main industrial settlements where the rural, residential, and industrial areas exist together).

Sicily: In Sicily two studies have been conducted. The first research (Ardente et al. 2010) well embeds the principles of UIS even if it is generally addressed as a study on industrial ecology. In fact, it expands the scope to three Sicilian towns and considers the production of building and furniture components. It follows a top-down approach, beginning with an extended **data survey** and progressively focuses on a detailed analysis of the companies and processes. A feasibility study of industrial symbiosis in several Sicilian locations is carried out, where interlinked companies share subproducts and scraps, services, structures, and plants to reduce the related environmental impact. In particular, the research focuses on new recycling solutions to create open recycling loops in which plastic subproducts, and scraps are transferred to external production systems.

The second study (Luciano et al. 2016) has been promoted by ENEA and entails the project for the development and implementation of the first Italian Platform for Industrial Symbiosis in Sicily. Following the NISP approach (G.-F. Liu and Chen 2013), companies were asked to fill in input– output data sheet before the meeting and to indicate resources to share within the proposed approach. Resources included: (a) materials, (b) energy, (c) services, (d) skills. Several criticalities emerged:

- Participating **companies can show more interest in offering their residues** (outputs), **rather than in demanding** alternative inputs (e.g. waste to be used as raw materials) for their activities. This was certainly determined by the lack of knowledge, among the companies, on the technical chances to replace the supply of traditional raw materials with residues from other production cycles.

- A second critical issue is represented by the companies' concern of a potential increase in controls exercised by the **control and authorization system** still anchored in traditional logics and reluctant to the change in the procedures.
- A third critical issue regards the **typologies of declared (input–output) resources** and consequentially the potential matches. First of all, resources declared were mainly packaging (plastics and plastic products), and paper and paperboard. The market of these materials in Italy is managed through national consortia which are no-profit private systems with a social character established and regulated by law operating in order to achieve the recycling objectives concerning all types of packaging.
- Finally, a fourth critical issues consist in the **size of the company**. Bigger companies have spontaneously started some symbiosis paths addressed to their residues valorisation and reuse while with smaller companies, where economic advantages are less evident but environmental returns could still be high, the provision of proper incentives could be useful.

Emilia-Romagna: Two studies refer to this region: the first one (Iacondini et al. 2015) is an analysis of European, National and Regional regulations to foster IS. It will be useful when exploring the regulatory framework in the next Chapter. The second one (Susur et al. 2019) explains how EIPs can unfold over the traditional industrial production systems by employing a qualitative multiple case study. It qualitatively analyses the experimentation within two cases from Tuscany and one from Emilia-Romagna and particularly examines the Green Economy and Sustainable Development Project started in 2013 by the latter. In this case, the brownfield experimentation did not identify a specifically bounded industrial production system and aimed to involve variety of industrial actors located in Emilia-Romagna region. It started through a top-down manner and continued in the form of facilitation aiming to boost the EIP practices among the located companies, research and development centres, and other regional formal and informal actors. The experimentation was started over the existing synergistic composition between the industrial actors producing industrial waste and the technology developer advancing the biomass treatment (Susur et al. 2019).

Tuscany: the two cases regarding Tuscany (Susur et al. 2019) differ from the other case as they concern a specifically bounded industrial production system, the "Macrolotto of Prato" and “Ponte a Egola”. The first, **Macrolotto of Prato,** specializes in wool production and has been an important economic hub for the development of Tuscany region since 1990. It represents one of the main Italian EIPs considering its history of continuous environmental improvements under the influence of the district EMAS (Eco-Management and Audit Scheme) initiative, i.e. a special recognition for the clusters that implement EIP management models (Susur et al. 2019). It started with the EEPA (Ecologically Equipped Productive Areas) programme, i.e. the first initiative introduced by the Italian Government in 1998 to search for a new industrial production model based on the IE principles**,** but it was abandoned before becoming certified. Its main EIP characteristics are related to the centralized environmental services, its wastewater recycling plant and the reputable performance of its management body as a facilitator of the EIP practices. The brownfield experimentation in this case has evolved through a combination of top-down and self-organised EIP practices. **The second, Ponte a Egola,** is an older and smaller industrial production system in Tuscany, which was established in 1970. As in the first case, the emergence of the brownfield EIP experimentation has been observed as a combination of top-down and self-organised approaches. The EIP experimentation has been highly influenced by the EMAS-certificated Tannery District to which Ponte a Egola pertains. Under the vision of the Tannery District, many efforts have been put into the recovery and reuse of by-products and the use of shared facilities. The EEPA process started in 2013 and the qualification was obtained in 2016. It is the first and only certified EEPA in Tuscany. In all three cases (Susur et al. 2019), **broad networks** have been observed where fundamental roles have been played by the management bodies, the governmental institutions, intermediary organisations, universities and research centres, and the private companies. The **intermediary organisations**, especially the agency of the management body can be claimed to play the central role in the unfolding EIPs as they have been coordinating and/or providing shared services and infrastructure, facilitating interactions among the network members, identifying synergies, creating awareness, scaling up existent EIP practices and designing new ones. The analyses of three cases have shown that, relatively, the more there are homogenous industrial production systems composed of SMEs the more likely it is to develop the EIP practices.

Veneto: The one study related to this region (D’Amico et al. 2007) investigates the requalification possibilities for the industrial (mainly glass production) district of Murano, Venice, which comprises about 187 firms, 84 of which work directly on fusion and glass moulding; others engage only in part of the production cycle. Companies operating in Murano are suffering from increased costs compared to those on the mainland because of logistical problems. The adopted approach is called BATTER, namely BATs (Best Available Techniques) for a territory. The most rated solutions were to use a centralized water treatment plant and the use of fabric filters and basic chemicals to reduce dust, heavy metal, and acid chemical concentration.

Marche: Marconi (et al. 2018) proposed an approach based on the implementation of **a web platform** to characterize and classify information. Stakeholders can rely on this platform to establish an efficient IS model. In addition, they study the AS-IS case of a WEEE treatment centre (A) in Marche region and then, after having pointed out several favourable conditions for symbiosis, propose some synergies with two more companies, a material recycler (B) and a compound producer (C). The conditions that eased the exchanges are: both Company A and Company B belong to the WEEE market sector and while the first one realizes pre-treatments and disassembly of WEEE, the second one is specialized in material recycling; the three abovementioned companies are located in the same production district (Marche Region) at a distance of about 50 kilometres; the output materials (mixed plastic from electrical cable insulation) of Company A are very similar to the input materials (plastic and rubbers scraps) of Company B. Company B has the necessary equipment (pulverisers) to treat the scraps of Company A; company C is currently using fillers (rubber and mineral powders) to realize its PP based compounds. Economic assessments have been realized to understand the feasibility and convenience of the identified industrial symbiosis scenario for each involved partner. In addition, by considering material savings and reuse, transport and energy consumptions, environmental assessments have been carried out by using the Life Cycle Assessment methodology.

Lombardy: The only study on the Lombardy region (Marchi, Zanoni, and Zavanella 2017) aims at creating an industrial symbiosis network in a specific Italian district, considering the geographical area of Brescia. It is focused on the development of solutions for the reduction of the energy utilization (both electrical and thermal), qualitatively considering the opportunities introduced through synergies involving industrial system and public service facilities (public-private partnerships) enabled by geographical proximity. The different companies considered are (figure 2.16): one Italian multi-utility company (leader in the energy, environment, heat and networks sectors), 5 steelmakers, one important cement producer, one company treating solid waste and biomass, one company specialized in the production of wood chips from wasted wood, one company responsible for the treatment of the car fluff, a company leader in the field of road asphalting, road embankments, excavations and earthmoving and the world leader in the production of caviar obtained from sturgeons bred. When the study was conducted, almost all the waste produced were disposed in landfill site; only a limited share of them was recycled and reused. Heat from the cooling of the fumes produced by both steelmaking and cement producers could be used to provide thermal energy to other actors. Heat can also be converted into electricity to be supplied into the utility network. In this case an investment is needed as heat is used to power the turbine of an ORC cycle containing silicone oil that traps pollutants. Regarding raw materials, the main flows identified leading to a reduced amount of traditional fossil fuels are: excess sludge, waste wood and car fluff flows from the manufacturers to companies that implement products treatments. From sludge and waste wood it is possible to produce fuels through drying, gasification and pyrolysis techniques rather than dispose them in landfills. Finally, the black slag, i.e. residue of steelmaking processes generated during the melting of iron scrap, has better physical and mechanical properties with respect to valuable inert materials such as basalt and porphyry normally used for road funds.

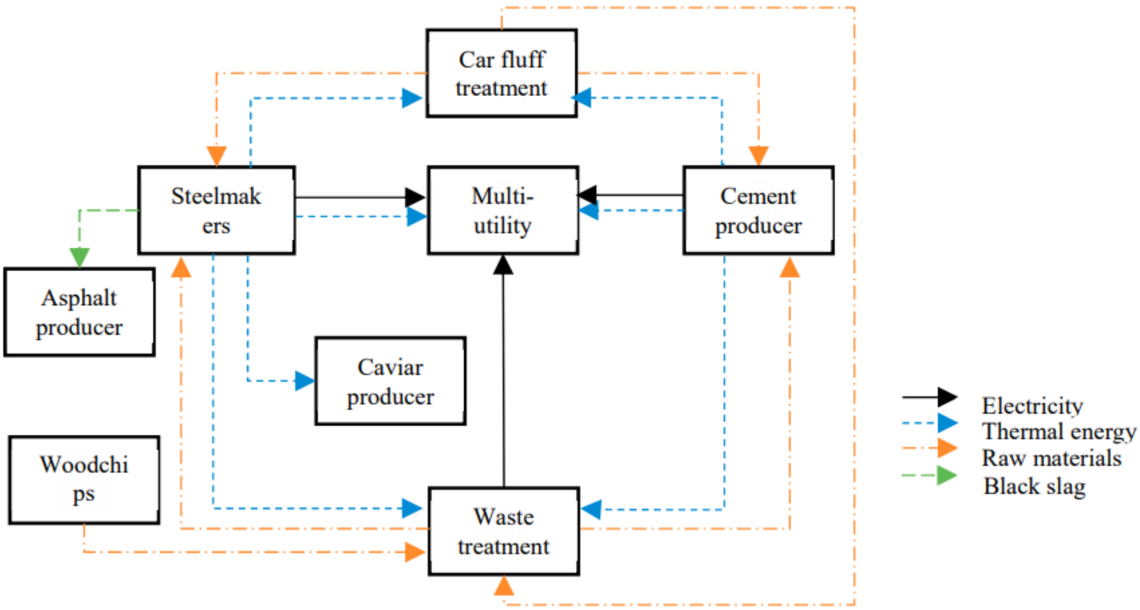


Figure 2. 16 Energy, RM, and black slag flows potentials in the IS network. Taken from Marchi, Zanone e Zavella (2017).

Puglia: An IS case study (Notarnicola, Tassielli, and Renzulli 2016) has been conducted also in the Taranto Industrial District. The strategy for the industrial development of southern Italy brought a series of districts containing large industrial complexes into existence. The Taranto Industrial District includes the Ilva integrated steelworks (the largest in Europe of its kind), a crude oil refinery, three power plants, the third largest naval port in Italy (including a military dockyard), a cement factory and a large beer factory. The nature of the integrated steelmaking process guarantees a continuous flow of waste material and energy that makes **steelmaking plants fulcrums around which symbiotic districts can develop** as for example in the UK Humber region, the Jinan district in China or the Japanese eco-town of Kawasaki. This district though, since 1990, has been declared an area with a high risk of environmental crisis because the heavy alterations of the ecological balances of the ground, water and air surrounding the district represent a serious risk for the environment and the health of the local population. A material waste analysis (quantitative) was performed as a means of identifying the main quantities of waste produced, disposed and recovered. The main synergies occur between the steelworks, the refinery and their respective power stations. Other noticeable exchanges regard the cement factory Cementir that makes use of 15% of the total blast furnace slag produced by the Ilva steelworks and the metal scraps collected from around the province and used by the steelworks. As a conclusion, the IS interactions in the district that are already spontaneously occurring between the larger industrial developments are centred around the steelworks plant and are a positive factor. However, the study confirms, as already highlighted by Mirata (2004) and Boons (et al. 2011), that industrial symbiosis can occur spontaneously up to a certain point but then **needs to be driven** to express its full potential.

2.5.2 Comparison between Italian and rest of the world literature cases.

In this paragraph the Italian UIS/IS literature has been compared with the one on UIS considered in paragraph 2.2.1 and the new emerging possible actors, materials exchanges, factors, and development paths have been pointed out.

Based on everything mentioned in previous paragraphs, it is possible to build a framework (Table 2.10) displaying which **actors** (excluded governments according to the reasoning made in paragraph 2.2.1) are mentioned and analysed into the Italian context. Out of eleven studies considered, the three that were not mentioning actors/flows have been coloured in light grey (columns 6,8 and 9), while the remaining 8 were eligible and are part of this analysis. The number of studies analysed is much lower with respect to the ones related to the rest of the world (table in paragraph 2.2.1), in fact the frequencies are much lower if compared to those and some sectors are not even considered (such as Rubber, Ceramic, Biofuels Mines, Hotels/Restaurants and Offices). However, it is possible to see how Italian studies consider the actors that were most frequent in the rest of the world, belonging to such industries such as Cement, Municipal and Industrial Waste Treatment, Iron & Steel, Chemicals, Paper, C&D, Energy Generation and Farming.

Table 2. 10 Actors considered by the Italian Case studies on IS/UIS

		(D'Amico et al. 2007)	(Ardente et al. 2010)	(Alberto Simboli, Taddeo, and Morgante 2014)	(Alberto Simboli, Taddeo, and Morgante 2015)	(A. Simboli, Taddeo, and Raggi 2019)	(Susur et al. 2019)	(Marconi et al. 2018)	(Iacondini et al. 2015)	(Luciano et al. 2016)	(Marchi, Zanoni, and Zavanella 2017)	(Notarnicola, Tassielli, and Renzulli 2016)	Freq.
I	Industrial waste Collectors		X			X						X	3
I	Rubber Producers												0
I	Chemical Producers				X			X					2
I	Cement producers										X	X	2
I	Iron & Steel Mill		X			X					X	X	4
I	Ceramic Producers												0
I	Biofuel Producer												0
I	Paper Mill					X							1
I	Glass Producers	X											1
I	Automotive		X	X							X		3
I	Brewery											X	1
B	Farmers		X		X	X							3
B	Mines												0
B	Power Plants		X			X					X	X	4
U	MSW collectors		X			X		X			X		4
U	Hotels/Restaurants												0
U	Wastewater Treatment Plants	X				X							2
U	C&D companies		X			X							2
U	Residentials/ Offices		X										1

Furthermore, it is noticeable that out of 8 eligible studies, Italian ones consider the most Power Plants, Iron & Steel companies and MSW waste. This aspect underlines the strong presence of these kind of actors on the Italian territory and testifies that Italy could be a country suitable for establishing symbioses. On top of that, it is possible to see from the table that Italian cases also considered three additional actors (highlighted in yellow within the table) belonging to Automotive, Glass Producers and Brewery industry. In that direction, the additional **material flows exchange** that could be added to the table 2.6 (containing all the possible synergies) are the reuse of car fluff or various components (mainly made of metal and plastics) and marc and dregs from the wine production that can be reprocessed in distilleries. Note that no additional flows were found around glass since the study by D'Amico (et al. 2007) focuses on emissions abatement (filters) and wastewater treatment and not materials reutilization.

About **drivers and barriers and development**, the Italian case studies do not add much to what already analysed in the rest of the world. The only studies examining some of the factors are from Alberto Simboli, Taddeo, and Morgante (2014) in Abruzzo and Luciano (et al. 2016) in Sicily, while the only study analysing development (but not strictly focused on IS/UIS) is from Susur (et al. 2019), explaining how the EIPs can unfold over the traditional industrial production systems.

2.6 Key Gaps and Limitations of LR

Throughout this chapter an analysis on existing literature regarding UIS has been conducted. Multiple studies have been analysed with the objective of clearly defining most common stakeholders, characterizing factors and their relationships, defining drivers and barriers and development process, as well as understand under which lens has UIS (but IS too in this case) already been analysed in Italy.

However, during the LR several **gaps and limitations** have been identified and pointed out. Despite the two being almost synonyms, a clear distinction has to be made. On one side, a limitation is an aspect that might limit the accuracy of the research and of UIS benefits' estimation. On the other side, gaps are hereby intended as aspects that have been totally/partly unexplored by authors in the present literature. The two have been separated as from the point of view of this study, gaps have been examined more in the LR, while limitations have been considered more as a hurdle to overcome in the field search. However, both gaps and limitations might create troubles for the subsequent search in this field, therefore it is better to specify what the associated problems are and how this research project is going to try to solve them.

As far as this Thesis is concerned, not all the gaps or limitations have been investigated (e.g. social value created by UIS) and, thus, the objective of this section is to **summarize just the ones that this study has helped to further shed light on**.

Table 2.11 shows the two main gaps and limitations that have been considered. The first one is related to factors, one of the topics mostly analysed in this Thesis. On this matter, it has been noticed that literature randomly and indirectly discusses the **composite effect** and the relationships between drivers and barriers and that there is no study aiming at explaining how they might worsen or enhance each other. The composite effect of factors should not be neglected since actors might not realize the reasons why they are not able (or they are able) to implement UIS. For instance, technology may be considered as the main barrier while in reality, lack of awareness is what is holding them back (this happens especially for SMEs). For transparency's sake, this is a gap that no other author pointed out before but is believed to be relevant for the forementioned reasons. The gap has been further investigated both in the LR (2.3.2) and throughout the fourth Chapter.

The second gap is more related to **"geographical" unbalance** of studies, as almost all of them were conducted in eastern countries such as China and Japan. This leaves European and Italian countries behind with respect to the eastern ones in terms of UIS academic research, since the urban context is hardly ever included in the boundaries of analysis and case studies refer to mere IS. As a concurrent cause, but also as consequent problem, UIS practices are scarcely spread across Europe with respect to China and Japan. In fact, although the globalization has brought academic research to open up and share articles across multiple continents, case studies suffer from specificity problems in the sense that if economies are based on different activities in different countries, it is difficult to locally apply the results of a case studies conducted in a very far part of the world. As for the purpose of this Thesis, the possible problem related to the differences between two contexts has been addressed in paragraph 2.5.3, where the Italian UIS/IS case studies have been compared with the ones on UIS (rest of the world) and differences in terms of actors, materials exchanges, factors, and development paths have been pointed out. In keeping with this, A. Simboli (et. al 2019) have, for the first time in an Italian case study, started moving towards the inclusion of urban context in the symbiosis.

Concerning limitations, on the other hand, the first one characterizing most of the analysed studies is related with **overlooking transportation activities**. As a matter of fact, especially when a symbiosis needs big volumes and far distances in order to happen, transportation might influence the viability of exchanges (see Transportation in paragraph 2.3.1). Authors themselves tend to admit in their studies that not involving transportation in computations might undermine the capability of computations to mirror the reality.

A second limitation which characterizes the studies conducted in Italy so far is the fact that **quantitative computations** of environmental and economical savings are missing (unlike Chinese and Japanese studies). In this way, studies remain in their theoretical sphere and neither potential benefits nor performances are clarified. As a consequence, the true potentialities of urban-industrial symbiosis might be underestimated by companies and regulatory institutions. With the intent to break this trend and quantitatively measure the potentialities of UIS, in this study it has been decided to appraise the order of magnitude of transportation impact and to explicitly compute savings associated to potential symbioses (Chapter 4), at least on a very high-level.

Table 2. 11 Key Gaps/Limitations and associated problems

	Key Gaps	Associated Problems	Notes
1	The literature randomly and indirectly discusses the relationships between factors, but there is not an analysis focusing on their interactions.	Drivers & Barriers might have composite effects: drivers helping overcoming barriers, barriers fostering other barriers etc. This could create problems during UIS implementation.	Considered in this study (2.3.2)
2	The UIS literature is mostly focused on China and Japan.	In different countries where the economies are based on diverse activities the most common stakeholders and resource flows might be unlike.	Considered in this study (2.5.2)
	Key Limitations	**Associated Problems**	**Notes**
1	The impact of transportation is overlooked in most of the studies.	Neglecting transportation both entails to ignore a part of the emissions and to misrepresent the real economic viability of resource exchanges.	Considered in this study (chapter 3)
2	In the studies already conducted in Italy on IS the quantification of economic and environmental savings is missing.	Without quantitative benchmarks, the UIS performance and potentialities are hard to be appraised in a real world scenario.	Considered in this study (chapter 3)

3 Macro analysis: estimation of UIS potential in Lombardy around C&D

Based on the contents of LR, in this chapter the objective is to conduct a **high-level** quantitative analysis, named “macro”, on UIS in Lombardy region centred around the C&D supply chain. The objective of this macro-analysis is, thus, to compute the possible associated **UIS benefits on a regional level**, built around the **C&D supply chain**. It is important to remark upfront that the purpose of this macro-analysis is just to give the order of magnitude of the UIS benefits and not to give a 100% accurate description. This choice is mainly related to the fact that there are not sufficient publicly available data to perform a detailed analysis and to the fact that this is the first study of this genre conducted in Lombardy, thus there are no other authors to rely on. In this way, on a high level, it is possible to give a first appraisal of UIS potential within the boundaries of Lombardy region.

It is also important to underline upfront that most part of this chapter relies on the previously analysed LR studies, for instance in terms of categories of actors, flows selected and thus possible synergies to establish.

Based on the results of this analysis, the research questions from 6.1 to 6.3 set in paragraph 1.2 have been answered. Specifically, it has been explained:

- What are the actors generating the bulkiest **volumes** in Lombardy around the C&D supply chain (RQ 6.1)
- What are the synergies that provide the most **economic and environmental savings** (RQ 6.2)
- What is the order of magnitude of **transportation impact** in Lombardy (RQ 6.3)

The contents of this chapter have been structured as follows: at first, the methodology used for collecting the data is pointed out (3.1). Then, the methodologies used for roughly estimating the environmental and economic benefits are clarified and explained (3.2), as well as the one used to appraise transportation impact (3.3). Lastly, the findings of the macro-analysis are displayed (3.4) and discussed (3.5).

3.1 Data Collection

3.1.1 Volumes and Substitution Factors

This paragraph discusses the logics behind the Lombardy waste data collection process (volumes of regional waste) and the search of the substitution factors (SF) displayed in table (in findings), whereby SF it is intended the percentage of raw materials that can be substituted by utilizing waste instead. However, as a very first step preceding the actual data collection process it is explained how the use of the flow chart developed for the C&D based on the LR (2.2.3) has helped identifying the presence and characteristics of the relevant flows (and actors).

Since the aim was to find as many data as possible in relation to the actors and the flows displayed in the flow chart, the data search process started by going through national and regional publicly available reports that might contain that information. The most explored websites have been ISTAT (Istituto Nazionale di Statistica) and **ISPRA**[1] (Istituto Superiore per la Protezione e la Ricerca Ambientale) , but also more specific ones such as AITEC (Associazione Italiana Tecnico Economica del Cemento) and FEDERACCIAIO (Federacciaio) have been investigated. Despite containing a lot of data on national level, ISTAT, AITEC and FEDERACCIAIO have not been very useful for the purpose of this study. On the other hand, ISPRA database contains regional data of aggregate waste from many production processes and therefore it has been more utilized. Actually, on the website the data (to now) are available from 2014 to 2018 and since the purpose of this analysis is to estimate the order of magnitude of UIS benefits in Lombardy, the average quantities have been considered. It is important to underline that for the macro-analysis, a very small part of the information has been retrieved from direct interviews with companies, such as the prices of metals waste from C&D. However, the data from interviews have been mostly used and explained in chapter four.

At the end, the actors for which the data were available are quarrying producers, non-ferrous metals producers, C&D companies, municipal waste collectors, incinerators, and Iron & Steel companies, while the actors excluded from this macro-analysis because of data lack

[1] Catasto Nazionale Rifiuti - ISPRA

are rubber, paper and chemical producers. To give a better evidence of what are the actors and flows involved in the macro-analysis with respect to the one found in the LR, the flow chart from paragraph 2.2.3 has been here reproposed with some circles highlighting the ones included. Thus, starting from public databases and LR findings it has been possible to draft a list of 27 possible IS and UIS synergies revolving around the C&D supply chain (see table 3.3 in findings). For the benefit of clarity, it must be specified that the possible synergies could be many more of the ones considered, however at the best of our knowledge these are the most significant.

Table 3.1 Summary of waste considered, quantities, sources and assumptions

Synergy Number	Code on ISPRA	Waste from	Aggregate Volume [kt/y]	Waste as resource	Disaggregared Volume [kt/y]	Aggregated Data Source	Source for disaggregating Data	Source for SF
1	-	Quarrying	523.85	Magnetic Fraction	523.85	Estimated from Maffei	Maffei	Assumption
2	23	Non-Fe Metals	219.98	White and colored marble sawing	65.99	ISPRA	Assumption	Assumption
3				White marble sawing	65.99	ISPRA	Assumption	NA
4				Granite and soliceous sawmill	44.00	ISPRA	Assumption	NA
5				Mixed (granite+marble) sawmilland siulicatic	44.00	ISPRA	Assumption	Assumption
6	41.42.43	C&D	10224.98	Iron	988.81	ISPRA	(Dahlbo et al. 2015)	(Dahlbo et al. 2015)
7				Aluminum	494.40	ISPRA	(Dahlbo et al. 2015)	(Dahlbo et al. 2015)
8				Brass	41.20	ISPRA	Assumption	Copper Dev. Association Inc.
9				Copper	123.60	ISPRA	Assumption	Assumption
10				Concrete and mineral waste	2136.31	ISPRA	(Dahlbo et al. 2015)	(Dahlbo et al. 2015)
11				Wood containing iron pieces	1186.57	ISPRA	(Dahlbo et al. 2015)	(Dahlbo et al. 2015)
12				Wood	3361.94	ISPRA	(Dahlbo et al. 2015)	Based on HHV comparison
13				Miscellaneous Waste	1220.75	ISPRA	(Dahlbo et al. 2015)	HHV
14				Unsorted Mixed Fraction	671.41	NA	NA	NA
15	3	Waste collectors	317.48	Waste plastic	100.48	ISPRA	Giancarlo Ugazio (Dei and Urbani n.d.)	Based on HHV comparison
16				Organic Waste	217.00	ISPRA	Giancarlo Ugazio (Dei and Urbani n.d.)	Based on HHV comparison
17	-	Incinerators	140.68	Coal Fly Ashes	136.10	Estimated from ISPRA	(Luciano et al. 2020)	Assumption
18				Sand	1.94	Estimated from ISPRA	(Luciano et al. 2020)	Assumption
19				Ferrous metals	2.64	Estimated from ISPRA	(Luciano et al. 2020)	(Dahlbo et al. 2015)
20	24	Iron and steel	1862.97	GBS	755.53	ISPRA	(Luciano et al. 2020)	Assumption
21				ABS	17.57	ISPRA	(Luciano et al. 2020)	Assumption
22				Basic Oxigen Slag (BOS)	296.07	ISPRA	(Luciano et al. 2020)	Assumption
23				EAF-C	487.20	ISPRA	(Luciano et al. 2020)	Assumption
24				EAF-S	90.94	ISPRA	(Luciano et al. 2020)	Assumption
25				EAF-S	13.75	ISPRA	(Luciano et al. 2020)	Assumption
26				Steelmaking slag	27.12	ISPRA	(Luciano et al. 2020)	Assumption
27				Steelmaking slag	174.79	ISPRA	(Luciano et al. 2020)	Assumption

Subsequently, after having identified what are the actors involved and the sub-category, it has been possible to ascribe a definite waste volume to the specific synergy identified. After having identified the volumes for each flow of interest, through a substitution factor the amount of resource that it is possible to substitute has been estimated. To have a clearer sub-category, it has been possible to ascribe a definite waste volume to the specific synergy identified. After having identified the volumes for each flow of interest, through a substitution factor the amount of resource that it is possible to substitute has been estimated.

To have a clearer overview on the volume data collection process, on the search of SFs and on the various assumptions made, in a unique chart (table 3.1) all this information has been assembled: the first column shows the synergy identification number[2], useful to keep track of the synergies during the reading process. In the second column, it shows the sector producing the waste and its type, as well as the source of the aggregate data with the associated code on ISPRA. Afterwards, it shows the source where the necessary information to disaggregate the data were found and the source for the substitution factor (or HP in case hypotheses were used). To provide higher transparency, it is here explained sector per sector what has been the data collection process and the eventual assumptions made:

Quarrying companies: about quarrying companies, ISPRA shows just the quantity of "others extraction activities from mines and caves", which does not include the processing of the mined minerals (excluding crushing, grinding, cutting, washing, drying, sorting and mixing). Therefore, an estimate of the total waste produced has been done by using data coming from a specific company named Maffei Group. In a study from University of Turin (Gruppo and Maffei 2008) it is stated that annually Maffei Group treats, on average, a quantity equal to 300 kt/y of quarry scraps. Now, considering that Maffei Group has 13 productive sites spread around Italy (most of them are in the North), it is possible to appraise that, on average, for each site the quantity of quarry scraps yearly treated is 23.08 kt/y. Thus, since according to ISTAT there are 454 sites (caves and mines) in Lombardy, it is possible to have a rough estimate of the total aggregate of quarry scraps annually treated. On this aggregate, according to the study on Maffei Group the 60% is a by-product known commercially as F60P (quartz feldspar mixture) that is used to make ceramics, the 23.33% is Sand usually used to make cement, and the remaining 16.67% is called **magnetic fraction**, which could be destined for less demanding markets with lower mineralogical purity requirements, but strongly in need

[2] The synergy number is the ID number of each synergy. It is useful to trace each single synergy back to the table 3.3 (first column), where all of them are listed.

of natural raw materials (ex. industrial floors). Whether the first two are not properly waste, the magnetic fraction is usually landfilled, therefore in this study just the last one has been considered as possible new synergy. The hypothesis, based on a comparison with the usual composition of slag cement, is that 30% of Magnetic fraction produced will be reused to replace limestone in cement production. Here, the SF is assumed to be 1, since on a production of a certain amount of concrete the magnetic fraction could substitute in a 1:1 ratio part of its RM (es. Limestone). To better explain this 1:1 ratio assumption a numerical example is considered: in the case of magnetic fraction the volume is 523.85 kt/y, which means that with a fraction of 30%, over a production of 1746.16 kt/y of cement it is possible to replace 523.85 kt/y of Limestone.

<u>Non-ferrous metals producers:</u> in this case the aggregate waste is taken by ISPRA, but since studies analysed did not reveal the typical composition percentages of the waste, some assumptions have been made: on the total aggregate, it has been assumed that 30% is **white and coloured marble sawing**, 30% is **White marble sawing**, 20% is **Granite and siliceous sawmill** and the remaining 20% is **Mixed (granite+marble) sawmilled silicate**. The second and the third have not been considered as proper synergies since the white marble sawing can be used as an additive in plastics but does not substitute a resource and the granite and siliceous sawmill can be only used for backfilling. The first and the fourth have a SF equal to 1: since the first can be used, among the many options, for RM substitution in cement production (same reasoning of 1:1 ratio as before) while the fourth can be used to build 100% sawmilled silicate tetrapod in replacement of concrete.

<u>C&D companies:</u> from ISPRA it is possible to know the aggregate waste produced by C&D companies in Lombardy in one year. Then, in accordance with the typical % of waste composition from Dahlbo (et al. 2015) the C&D aggregate has been divided in five main sub-categories of waste: **metal waste, concrete and mineral waste, wood, miscellaneous waste** and **unsorted mixed fraction**.

The **metal waste** has been further categorized in iron, aluminium, copper and brass in keeping with the main types of waste produced by Lagalla and, after discussing with them in a direct interview, it has been assumed that on the total metal waste generated 60% is iron, 30% aluminium, 7.5% is copper and 2.5% is brass. The substitution factors have been explicated by Dahlbo (et al. 2015) for iron and aluminium, while by Copper Development

Association Inc (Copper.org 2015) for brass. For copper it has been assumed that all of it can be recovered (SF=1). Also in line with what specified by Dahlbo (et al. 2015), about **concrete and mineral waste** a 90% recovery efficiency has been considered and of the remaining part a substitution factor of 99.5%. Regarding **wood**, seen its multiple reuse options, it has been assumed that 30% is used to recover nails, angle irons and metals parts (50% of it is estimated to be made of metals (Dahlbo et al. 2015)) while the remaining 70% plus the wood remaining after the metals extraction is assumed to be used for energy recovery. The SF of wood for energy production, i.e. its capability to replace fossil fuels (coal as a reference), has been estimated with respect to the HHV (higher heating value): dividing the HHV of wood by the one of coal, it is possible to know how much coal I save if use wood instead, i.e. the SF. By **miscellaneous waste** it is intended SRF (solid recovered fuel) consisting of 80% bio-based materials (Dahlbo et al. 2015), and its substitution factor has been determined by comparing the HHV of bio-waste with the one of coal. Lastly, the **unsorted mixed fraction** cannot be used in any synergy (except for backfilling) so there is no need to further specify anything.

<u>Waste collectors:</u> about MSW, its composition (%) has been found on the www in a study from Giancarlo Ugazio (Urbani) while the total MSW produced in Lombardy on ISPRA. Combining the two the total waste for each type of MSW category has been obtained. In this case, the MSW categories considered are **waste plastics** and **organic waste**, which can both be used for replacing coal in cement kiln. Here, it is assumed that, potentially, the 20% of these wastes could be used for that purpose. The SF have been here valued according to the HHV of the waste with respect to the one of coal usually used in cement kilns.

<u>Incinerators:</u> as incinerated waste, it has been considered just the waste coming from the urban context. In this direction, the total MSW minus the differentiated MSW (from ISPRA) gives the quantity of **MSW** that is usually incinerated (18% on the total in 2019). From the aggregate, after having turned the quantities of incineration by-products given by Luciano (et al. 2020) in percentages, it has been possible to obtain the disaggregated quantities of waste coming from incineration activities. Here, the SF is assumed to be 1 since the waste could substitute in a 1:1 ratio part of RM (e.g. **limestone, clinker, and iron**).

<u>Iron &</u> steel companies: for Iron & Steel, staring from ISPRA's aggregate scraps and projecting them on percentages of metallurgic waste composition from Luciano (et al. 2020)

, the quantities of disaggregated waste have been estimated, also considering the efficiency in recovery: for **GBS, ABS, BOS and SMS integrated works** the recovery efficiency is estimated to be 100%, while for **EAF-C slag, EAF-S slag and Steelmaking slag EAF** the efficiency is estimated to be around 75%. About SF, for metallurgic waste the reasoning is the same as the one adopted for incinerated waste (1:1 substitution ratio with RM).

3.2 Data Analysis

3.2.1 Evaluation of Environmental savings

Broadly speaking, there are three major methods to account for carbon footprint, including accounting based on Intergovernmental Panel on Climate Change (IPCC) recommended emission inventory and factors (hereafter IPCC method), life cycle assessment (LCA), and input–output analysis (IOA). In studies from Fang (et al. 2017) and Huang (et al. 2016) the advantages and disadvantages of the three are explained. However, the purpose of this study is to give just the **order of magnitude** about emissions saved for each flow, therefore a strict procedure covering the whole lifecycle [such as in papers from H.Dong (et al. 2014) and S.Ohnishi (et al. 2017)] was not required and so neither of the three methodologies has been adopted.

The approach here followed to estimate the environmental savings is the same as the one used in several studies belonging to the analysed articles from the LR (Liang Dong et al. 2014, 2016, 2017; Li, Dong, and Ren 2015; Ong, Ie, and Ang 2016; Sun et al. 2017). To ease the readability process, in this study the avoided energy consumption will be called "Energy savings", the reduction in virgin RM consumption will be called "Q sub.RM" and the recovered waste will be called "Q waste" (instead of respectively naming them EnvG, R and M). Starting from the aggregate data, it is possible to estimate the quantity of resource substituted through the use of a substitution factor (SF) that accounts for the fact that, due to the nature of some industrial processes, a higher number of recycled materials may be needed to obtain the same results as the one that would have been obtained by using virgin resources. In this case, this factor highly influences the amount of product that can be effectively substituted without altering the characteristics and capabilities of the finished product and consequently the economic and environmental savings.

By multiplying the SF of resource times the quantity of waste, it is possible to estimate the **amount of the resource substituted** (formula 1).

$$1)\ Q\ sub.RM = SF * Q\ waste$$

After gaining the resource avoided consumption in terms of quantity or energy/fuel saved, it is possible to calculate the CO_2e emission reduction (ER) through the difference between the CO_2e emission factors of the resource substituted and of the waste. By EF it is intended the amount of CO_2e generated for a ton of a specific material (used, produced, landfilled, or incinerated depending on the specific case). The difference between the EFs of substituted material and waste is called **REDUCTION emission factor** (△EF), it accounts for how much tCO_2e might be reduced when replacing 1 t of virgin RM/fuel with waste. Be aware that in some cases the △EF will be given by literature and authors, in other cases it needs to be estimated by starting from the single EFs of RM and wastes (all the EF, their sources and the estimations can be found in the annex "EF and Prices").

$$2)\ \triangle EF = EF\ resource\ substituted - EFwaste$$

The general formula used for computing the **total emission reduction** (ER) is:

$$3)\ ER = \triangle EF * (Q\ sub.RM - Qwaste) + EFwaste\ disposal * Qwaste$$

Be conscious of the fact that the calculation of carbon emission reduction through UIS is based on same principles and on the same formula, but different IS and UrS types might require slight changes in calculation methods. The main limitations of this methodology are related to its simplicity and to the fact that it does not consider transportation emissions, as well as the main advantage is the ease of use. However, considering that the purpose of this study is to give just the order of magnitude, the computations have been quite accurate, and transportation could not be included since the data considered do not refer to specific companies with a precise geographical position.

3.2.2 Evaluation of Economic savings

As for the computation of UIS economic savings, in the literature there are studies adopting different positions and point of views. For instance, Van Berkel (et al. 2009) states that economic evaluation of symbiotic exchanges is not possible as price data are considered commercially sensitive and that, to establish the economic significance, an attempt can be done using statistical data collected by various government agencies and industry associations. In another study (L. Dong et al. 2013) economic gains were defined as the revenue streams or avoid costs through the reduction of virgin materials consumption, waste generation or by-product/waste reuse and recycle. There the calculation of economic gains is based on the analysis of the material exchange in the symbiosis network, but it does not consider the waste sales income. Instead, the approach used by Guo (et al. 2016) appears to be the most complete among the ones analysed in the LR and, in this Thesis, the same approach has been adopted to evaluate economic savings of resource flows associated to Lombardy.

Basically, the economic benefits are derived from three positive revenues streams, i.e. **cost saving of raw material purchase, cost saving from avoided disposal and waste sales income**. As a negative revenue stream, it must be considered also the **cost of waste treatment** which erodes part of the positive economic benefits generated. As the target of this study is to express the hypothetical benefits of symbiotic activities, the investment cost for facilities were not emphasized, even though investment is a vital part for the establishment of industrial symbiosis.

The formulas used are:

1) $Savings\ of\ RM\ purchase \left[\frac{€}{y}\right] = Q\ sub.RM \left[\frac{kt}{y}\right] * P\ sub.RM \left[\frac{€}{kt}\right] - Qwaste * P\ buying\ waste[€/kt])$

Formula 1, where “Q sub.RM” (as before) is the quantity of RM that can be substituted by using “Q waste” instead, “P sub.RM” is the price of buying a certain quantity of such raw material while “P buying waste” is the price at which the company buys waste. Keep in mind that, usually, the price of waste is lower than the price of fresh new RM and that generates an economic gain for the company.

2) $Savings\ from\ avoided\ disposal \left[\frac{€}{y}\right] = Q\ waste \left[\frac{kt}{y}\right] * P\ waste\ disposal\ [€/kt]$

Formula 2, where “P waste disposal” is the price that usually companies pay to get rid of that waste. However, it might happen that waste has a market value, and so companies do not pay anything to dispose the waste or better they can gain a price on it (“P selling waste”), in fact, the next formula (3) considers the economic benefit gained from selling the waste. Obviously, formulas 2) and 3) are mutually exclusive.

$$3)\ Waste\ sales\ income\ \left[\frac{€}{y}\right] = Q\ waste \left[\frac{kt}{y}\right] * P\ selling\ waste\ [€/kt]$$

So far, all the formula accounted for a positive gain from the symbiosis, however there can be cost associated with treating/recycling the waste before reusing it that influence the economic savings deriving from the symbioses. Therefore, as a fourth formula it ought to be considered the cost of recycling the waste to enable the correct RM substitution:

$$4)\ Cost\ of\ waste\ treatment\ \left[\frac{€}{y}\right] = Q\ waste \left[\frac{kt}{y}\right] * P\ treatment\ [€/kt]$$

Where “P treatment” denotes the price paid by companies to have the waste reused correctly.

At the end the total economic benefits have been computed as follows:

$$5)\ Tot.Economic\ Benefits\ \left[\frac{€}{y}\right] = (1) + (2) + (3) - (4)$$

In this case the main limit of the methodology is the fact that prices are a commercially sensitive data and, moreover, their value can be dynamic. However, always from the perspective of this study, the simplicity of this methodology has made it the best choice to give the order of magnitude about UIS in Lombardy from an economic standpoint.

3.2.3 Transportation Impact

Normally, assessing the impact of transportation is a very difficult operation since it is strongly dependent on many factors that are not easily foreseeable such as distance of transportation and waste transportation cost and emission factors. For this reason, many authors of the studies analysed in the LR have overlooked the computation of transportation impact. However, it is often stated that transportation impact might affect the conveniency of resource exchanges and it is better to embed them when possible.

In this Thesis it is proposed an easy way to **roughly estimate the impact that transportation** could have at regional level on the exchanged flows. It must be said that due to its low accuracy, this approach is not suitable when information such as the distance between companies is available. However, seen that the logic behind this macro-analysis does not provide specific geographical locations neither for companies that generate waste nor for the ones that reuse it, the only way to take into account the transportation impact is to assign fictitious distances between the categories of actors involved.

Distances Matrix	Non-fe metals producers	Urban Players	Quarrying	Power Plants	Industrial Players	Landfills
Non-fe metals producers	S	M	M	M	S	M
Urban Players		S	L	M	M	L
Quarrying			S	M	M	S
Power Plants				S	M	M
Industrial Players					S	M
Landfills						S

Figure 3. 1 Reference Matrix for Transportation distances (Legenda).

In the matrix (figure 3.1) it is possible to see that to each type of actor it is assigned a letter **(S=small distance, M=medium distance, L=long distance)** that corresponds to the distance existing between the different categories. The "grouping" process has been based on the different functions that companies perform assuming that if they run similar/complementary activities it can be more likely that they are in proximity to each other. In this case, industrial players can be cement, iron & steel and chemical producers; urban players can be C&D and waste collectors while power plants also include incinerators. Obviously, this is extremely unprecise and surely not a way to estimate the real transportation impact, it is a way to averagely appraise what the impact of transportation on a regional level could be.

The criteria behind the assignation of distance to the different letters has been based on the distances existing between some cities in Lombardy. As an example of short run it has been considered the distance between Milan and Pavia, as a medium run the one between Lecco and Cremona, and as a long run the one between Varese and Mantova, which are the cities located on opposite sides of the region (figure 3.2).

Transportation Distance	KM travelled	Example
SHORT (S)	50 KM	Milano-Pavia
MEDIUM (M)	150 KM	Lecco-Cremona
LONG (L)	250 KM	Varese-Mantova

Figure 3. 2 Real examples used to calibrate distances.

Once having qualitatively assigned one of the three letters (S, M or L) to the distance between different kinds of actors, it is possible to roughly estimate what are the benefits/liabilities coming from the transportation.

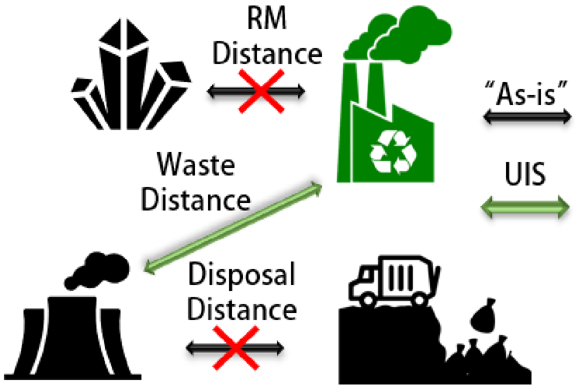


Figure 3. 3 AS-IS (without UIS) and To-BE

Basically, when applying UIS it is possible to avoid the shipping of fresh new RM and the transferring of waste to the disposal facility; the only distance travelled is for the waste to the facility where it will be reused (figure 3.3).

The formula on transportation impact (1) clearly shows how the different distances contribute to the transportation impact into the UIS scenario: the sign of the sum of the three terms will determine the transportation impact, i.e. it will be positive if the transportation benefits of avoided distances is greater than the liabilities from transporting the waste, and vice versa. Therefore, the transportation could either increase or decrease the convenіency of a symbiosis.

$$1)\ Transportation\ Impact = Avoided\ Distance\ (RM + Disposal) - Travelled\ Distance(Waste)$$

A very simple calculation has been done to estimate the EF of Transportation and the transportation cost for carrying 1 kt of material for 1 km: from Ong, Ie and Ang (2016) it is known that that to transport 1 kt of material for 1 km 78.2 litres of diesel are needed, thus by knowing the amount of ktCO2 stemming from the use of 1 litre of diesel (from EPA (2018) 0.002670 tCO2/litre) it is possible to compute the average EF diesel per kt.km (0.00021 ktCO2/kt.km). About the cost, by multiplying the litres of diesel needed to move 1kt for 1km times the avg. price of diesel (avg. value in Italy 1.32 €/litre), it is known that a proxy[3] of the cost of transportation is around 103.22 €/kt.km.

Just to show an **example** (table 3.2) of how transportation impact has been appraised, the synergy number 1 (from table 3.1) has been considered: according to the figure 3.2 the distance from quarrying to quarrying that Limestone (RM) would travel is short (S), the distance that the waste from quarrying to landfill is medium (M) and the distance from quarrying to cement that the waste travels in case of symbiosis is medium (M).

Table 3. 1 Example of Transportation Impact computation.

Hp			Transp Emissions			Transp Cost [M€]		
Avoided Distance for RM	Avoided Distance for Disposal	Distance travelled by Waste	RM transp	Disposal Transp	Waste transp	RM transp	Disposal Transp	Waste transp
50	150	150	5.52	16.57	16.57	2.70	8.11	8.11
50	150	150	0.70	2.09	2.09	0.34	1.02	1.02

On the basis of that, it is possible to compute the associated savings. In this case, since avoided distance for disposal and distance travelled by waste are both "M", the two offset themselves and the resulting savings are just associated to the avoided transportation of RM. It is important to remark that the evaluation of transportation impact is very basic, eventual transport stations and truck loads have not been considered as variables of computations: the more waste can be loaded into a truck, the less trucks would be needed to transport a specific volume of waste resulting in lower costs and emissions overall.

3.2.4 Identification of Best Synergies

Hitherto, the data collection process and the methodologies for the evaluation of savings have been described. In this paragraph, the approach used to determine what are the "best synergies" is explained. By **best synergies** it is intended the ones it would be convenient to

[3] It is a proxy since it just considers the cost of necessary fuel, therefore the real transportation cost might be higher than that.

start from seen their profitability, which is evaluated according to three criteria: amount of waste volume, environmental savings (aggregate or specific) and economic savings (aggregate and specific). By aggregate savings it is intended the whole amount of money/CO2e that can be saved thanks to each synergy per year ([M€/y] or [ktCO2e/y]), while by specific savings it is intended the aggregate savings normalized by the volume of waste ([M€/kt waste] or [ktCO2e/kt waste]).

To discuss and combine the three perspectives altogether, a simple qualitative approach is used. The results of the computations (showed afterwards in the findings section) will be ranked from the largest to the smallest according to **5 different criteria**: by volume of waste generated, by aggregate environmental and economic savings (transportation included), by specific environmental and economic savings. According to their position in the ranking, several points will be assigned to each synergy from 10 (if largest) to 1 (if smallest). Based on the table 3.5 containing the rankings, the final output table (3.6) containing the points assigned to each synergy will be drafted: it will display the number of each synergy, the number of times that it appears in the five rankings (frequency), the number of points assigned (for each of the rankings and total) and the relative weights for the different rankings.

The main **assumption behind the assignation of the weight** is that, when trying to identify the best synergies, the data on economic and environmental savings are much more important than the amount of volume generated (5% weight). The explanation is that it might happen that synergies involving large volumes (thus big logistics effort) bring to low savings. Since their rankings are different, a further separation between aggregate and specific savings has been done. Note that the transportation impact has not been included in the specific savings since, being transportation impact just an approximate value, it might have altered to much the specific savings of the synergies with low volumes, and in turn the rankings of specific savings. Based on this consideration, the weight assigned to the specific savings (17.5%) is lower than the one assigned to the aggregate savings (30%).

3.3 Findings

In this paragraph the aim is that to provide a **description of the Macro-analysis results**. In the table above it is possible to see the overall results: starting from the left, the first eight green columns discuss the possible symbiosis identified, i.e. which waste can be converted in which RM, what are the sectors involved, the area of reference (in this case it is all referred to Lombardy) and the type of flow according to what already explained for table 2.6 in paragraph 2.2.2. As you could notice, the layout of the table is the same as the one used in the LR. What changes here is the fact that all the volumes refer to the Lombardy region, and that the economic and environmental savings for each single symbiosis have been estimated. In addition to the savings, there is also reported in % (as additional emissions and economic benefits) the impact of transportation. The methodologies for calculations of those have been explained respectively in paragraphs 3.2.1 and 3.2.2. To better characterize the findings of this macro analysis, it is possible to have a more specific outlook on volumes (3.3.1), savings (3.3.2 & 3.3.3), comparison between savings (3.3.4) and transportation impact (3.3.5) that at the end will lead to the identification of best synergies (3.3.6).

Table 3. 2-part 1 Overall Findings of Macro-Analysis.

	Symbiosis	Waste as resource	Reused for/resource substituted	From	To	UIS/IS	Type of flows	Area	Volume of waste [kt/y]	SF	Volume of resoruce substituted [kt/y]	Environmental Savings [ktCO2e/y]	Addition al%Transp Emissions	Economic Savings [M€/y]	Addition al%Transp Cost
1	Replace Limestone in Cement production	Magnetic Fraction	Limestone	Quarrying	Cement	IS	M	Lombardy	523.85	1	523.85	230.49	2%	€ 20.78	13%
2	Replace Limestone in Cement production	White and colored marble sawing	Limestone	Non-Fe Metals	Cement	IS	M	Lombardy	65.99	1	65.99	29.04	2%	€ 0.42	82%
3	Production of plastics in polypropylene	White marble sawing	Plastics	Non-Fe Metals	Chemical	IS	M	Lombardy	65.99	-	-	0.00	-	-	-
4	It can be used to fill voids	Granite and soliceous sawmill	Backfilling	Non-Fe Metals	Restoration	IS	M	Lombardy	44.00	-	-	0.00	-	-	-
5	It can be used to produce tetrapods instead of using concrete	Mixed (granite+marble) sawmilland siulicatic	Concrete	Non-Fe Metals	Tetrapod Producers	IS	M	Lombardy	44.00	1	44.00	44.96	3%	€ 4.77	14%
6	Metal scraps can be recycled in the EAF	Metal scrap	Iron	C&D	Iron & Steel	UIS	M	Lombardy	988.81	0.94	929.48	669.22	8%	€ 127.87	19%
7	Metal scraps can be recycled in the EAF	Metal scrap	Aluminum	C&D	Iron & Steel	UIS	M	Lombardy	494.40	0.76	375.75	581.42	4%	€ 582.07	2%
8	Metal scraps can be recycled in the EAF	Metal scrap	Brass	C&D	Iron & Steel	UIS	M	Lombardy	41.20	0.8	32.96	84.71	2%	€ 164.77	1%
9	Metal scraps can be recycled in the EAF	Metal scrap	Copper	C&D	Iron & Steel	UIS	M	Lombardy	123.60	1	123.60	322.60	2%	€ 741.52	0%
10	After being pre-treated at site and then treated the materials can be recovered	Concrete and mineral waste	ıcrete and mineral wa:	C&D	C&D	Recycling	M	Lombardy	2,136.31	0.995	2125.63	47.95	47%	€ 223.78	5%
11	Wood containing nails, angle irons	Wood	Iron	C&D	Iron & Steel	UIS	M	Lombardy	1,186.57	0.5	593.28	390.38	6%	€ 96.25	13%
12	Wood chips to replace heavy fuel oil in a heat boiler	Wood	Coal	C&D	Heat Generation	UIS	E	Lombardy	3,361.94	0.705	2369.63	-586.74	0%	€ 189.22	0%
13	SRF (solid recovered fuel) consisting of 80% bio-based materials can to replace natural gas in a co-combustion plant	Miscellaneous Waste	Natural Gas	C&D	Power Generation	UIS	E	Lombardy	1,220.75	0.211	257.60	632.40	0%	€ 36.66	0%

Table 3. 3-part 2 Overall Findings of Macro-Analysis.

	Symbiosis	Waste as resource	Reused for/resource substituted	From	To	UIS/IS	Type of flows	Area	Volume of waste [kt/y]	SF	Volume of resoruce substituted [kt/y]	Environmental Savings [ktCO2e/y]	Additional%Transp Emissions	Economic Savings [M€/y]	Additional%Transp Cost
14	It can be used to fill voids	Unsorted Mixed Fraction	Backfilling	C&D	Restoration	UIS	M	Lombardy	671.41	-	-	0.00	-	-	-
15	Replace coal for cement kiln supply	Waste plastic	Coal	Waste collector	Cement Producers	UIS	M/E	Lombardy	100.48	1.532	153.96	248.46	3%	€ 5.07	67%
16	Replace coal for cement kiln supply	Organic Waste	Coal	Waste collector	Cement Producers	UIS	M/E	Lombardy	217.00	0.419	90.91	392.88	2%	€ 24.70	15%
17	Use fly ashes to replace clinker	Coal Fly Ashes	Clinker	Incinerators	Cement Producers	IS	M	Lombardy	136.10	1	136.10	64.07	7%	€ 2.23	95%
18	Sand from incineration can be used to produce Cement	Sand	Limestone	Incinerators	Cement	UIS	M	Lombardy	1.94	1	1.94	0.87	2%	€ 0.08	13%
19	Ferrous metals deriving from incineration can be used to replace RM in Iron & Steel	Ferrous metals	Iron	Incinerators	Iron & Steel	UIS	M	Lombardy	2.64	0.94	2.48	1.79	4%	€ 0.34	11%
20	Slag replacing a fraction of clinker in cement production	GBS	Clinker	Iron and steel	Cement producers	IS	M	Lombardy	755.53	1	755.53	370.21	2%	€ 12.35	32%
21	Slag replacing a fraction of clinker in cement production	ABS	Clinker	Iron and steel	Cement producers	IS	M	Lombardy	17.57	1	17.57	8.61	2%	€ 0.29	32%
22	Used to substitute concrete in Road Ballast	Basic Oxigen Slag (BOS)	Concrete/Asphalt	Iron and steel	C&D	UIS	M	Lombardy	296.07	1	296.07	106.59	9%	€ 4.84	95%
23	Slag replacing a fraction of limestone in concrete/asphalt	EAF-C	Limestone	Iron and steel	C&D	UIS	M	Lombardy	487.20	1	487.20	175.39	3%	€ 7.97	32%
24	Slag replacing a fraction of limestone in concrete/asphalt	EAF-S	Limestone	Iron and steel	C&D	UIS	M	Lombardy	90.94	1	90.94	32.74	3%	€ 1.49	32%
25	Slag replacing a fraction of clinker in cement production	EAF-S	Clinker	Iron and steel	Cement Producers	IS	M	Lombardy	13.75	1	13.75	4.95	3%	€ 0.22	32%
26	Slag replacing a fraction of clinker in cement production	Steelmaking slag	Clinker	Iron and steel	Cement Producers	IS	M	Lombardy	27.12	1	27.12	9.76	3%	€ 0.44	32%
27	Slag replacing a fraction of limestone in concrete/asphalt	Steelmaking slag	Concrete/Asphalt	Iron and steel	C&D	UIS	M	Lombardy	174.79	1	174.79	62.92	3%	€ 2.86	32%

3.3.1 Volumes

At first, it can be understood where volumes come from, so what are the actors that generate the highest amount of waste and what are the sectors in which it will be reused to substitute RM. In this macro-analysis, six are the categories of actors considered as **“waste generators”**, i.e. C&D, Iron & Steel, Cement Producers, Quarrying industry, Incinerators and Municipal Waste Collectors, and four are the categories considered as **“waste users”** to substitute RM, i.e. C&D, Power Generators, Iron & Steel and Cement companies. About the “waste users” and the first five among the “waste producers” the logic behind the choice is quite straightforward, since as they are industrial players, and they can directly produce waste (or reuse it to replace RM). About Municipal Waste collectors companies (that typically offer services), there is the need to further clarify why they have been considered as such. Basically, they are the actors responsible for most part of the waste stemming from the urban environment (e.g. plastics, organic, paper etc.), and the economic and environmental benefits associated strongly depends on how those companies manage that waste. In fact, MSW is usually either collected and recycled/landfilled or collected and incinerated (this depends on waste composition and this topic is better discussed in section 4.3.2), therefore, when considering Municipal Waste collectors among the “waste generators”, it is meant that they are responsible for handling and disposing the waste coming from the urban environment.

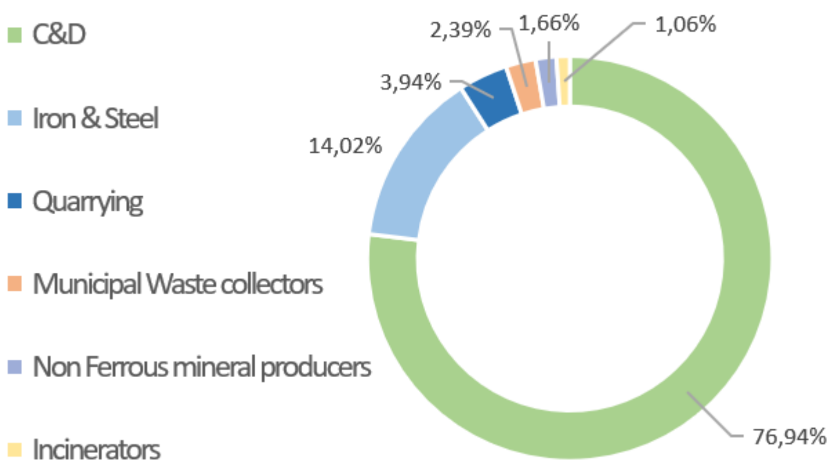


Figure 3. 4 Percentage of Waste Volume produced per each considered actor type.

From figure 3.4 it is possible to notice how, in relative terms, each actor type contributes to volumes of waste generated. The **C&D leads by far** in the generation of waste (76.94%), against the 14.02% of the Iron & Steel and the 3.94% of quarrying. All the others account for a very small fraction of waste generated. To check the concentration with respect to the different synergies, it is possible to order them from the largest to the smallest in terms of waste of volume and it emerges that the 50.56% of waste comes just from the first three synergies (wood (synergy number = 12), concrete and mineral waste (10) and miscellaneous waste (13)) and that 81.6% comes just from eight synergies (previous three from plus wood containing angle irons (11), metal scrap (6), GBS (20), unsorted mixed fraction (14) from and magnetic fraction (1) from quarrying). Except for the GBS that comes from Iron & Steel and for the magnetic fraction coming from quarrying sector, all the others are C&D waste: this fact stand at confirmation of what said in the introduction, since this industry contributes massively to almost all types of pollution: air pollution, drinking water pollution, landfill wastes, not to mention the noise pollution and the resource depletion. ‘The residual 18.4% is given by the remaining 19 synergies, where also non-ferrous metals producers, waste collectors and incinerators are involved.

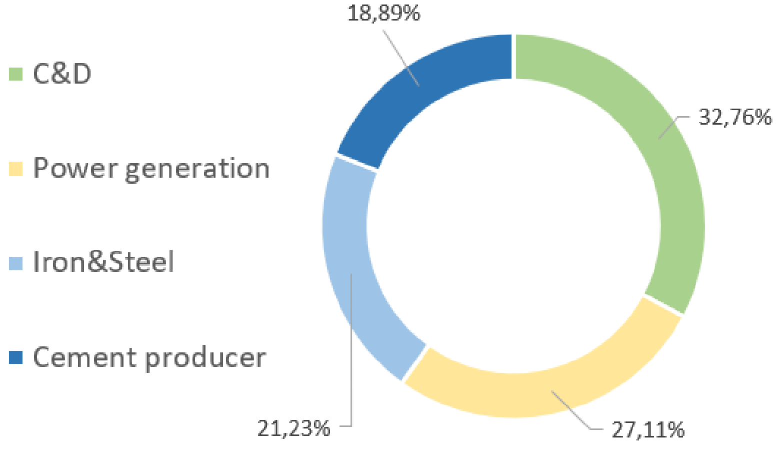


Figure 3. 5 Percentage of waste reused in the four destination sectors.

In figure 3.5 it is showed where the waste produced is recovered. From this analysis it emerges that the overall recovery efficiency of waste materials to be reused as RM substitutes is 72.91%, at least on a theoretical level. The remaining 26.09% goes landfilled or used for backfilling in caves. **Out of that 72.91%**, the most part (33.76%) can be reused in C&D sector. The other sectors that can benefit from reusing waste are Power Generation (21.23%), Iron & Steel (21.23%) and Cement Producers (18.89%).

3.3.2 Economic Savings

About the economic savings it is possible to **distinguish from economic benefits for waste producers and for waste users**. As previously explained in the evaluation of economic savings, the waste producers will benefit from selling the waste and not having to dispose it, while waste users will benefit from paying less the input materials (waste replacing RM) but, at the same time, will bear the cost of recycling/treating. The results of these calculations show that waste producers could save up to 1,042 M€/y (49%) and waste users up to 1,094.M€/y (51%) for a total of 2,150 M€/y of savings/year (including transportation). As it is evident, the benefits are almost equally distributed among the two, but to have a clearer understanding of savings distribution for waste producers and for waste users, it is possible to characterize results by using pie charts:

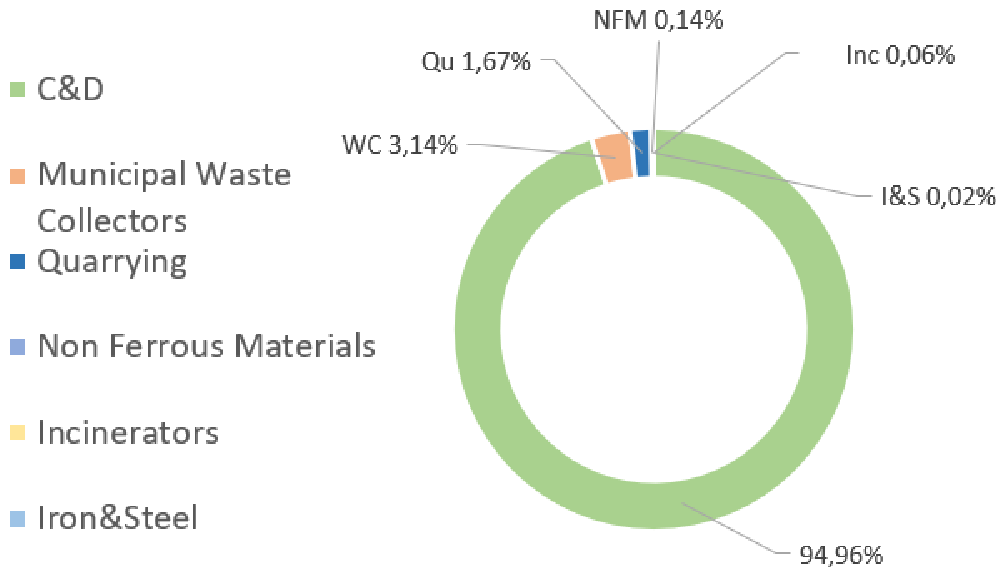


Figure 3. 6 Economic Savings Associated to Waste Generators.

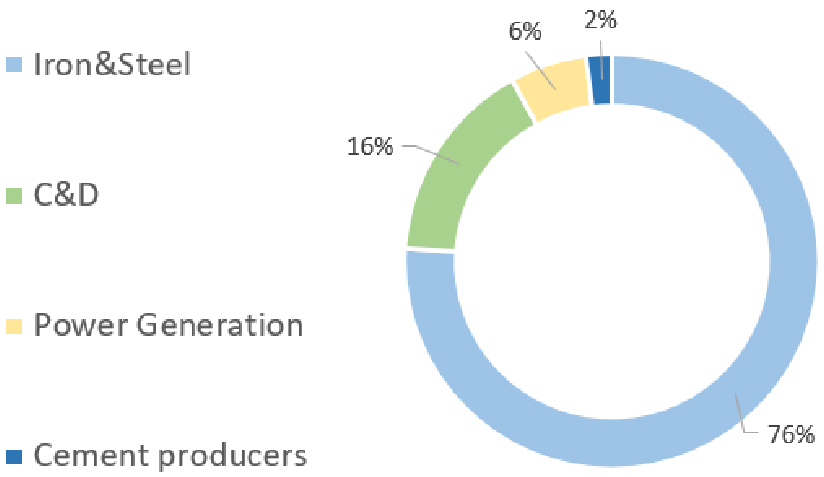


Figure 3. 7 Economic Savings Associated to Waste Users.

Through the pie charts (figure 3.6 and 3.7), it is possible to check how these economic benefits are distributed across actors generating the waste and across sectors in which they are utilized. About the former, the first pie chart (figure 3.6) shows that most of economic benefits are achievable by reusing waste coming from C&D sector (almost 95% of savings). Note that the synergy number 12 (Wood from C&D used to replace heavy fuel oil in a heat boiler) has not been included in those charts, since despite having a very high volume and a good economic saving it showed a very bad performance in terms of environmental ones: the reason is that the lower HHV of the wood with respect to fossil fuels causes a negative environmental impact. Moving forward, the value of waste produced by Iron & Steel, non-ferrous metals and incinerators is almost null if compared to the economic impact of the C&D waste, while for Quarrying and Waste Collectors the percentage is slightly higher but still very small. On the other hand, in the second pie chart (figure 3.7) where it is showed what actors types benefit the most when reusing the waste coming from other sectors, the best results are achieved by the Iron & Steel one (76% of savings), followed by C&D (16%), Power Generation (6%) and Cement Producers (2%).

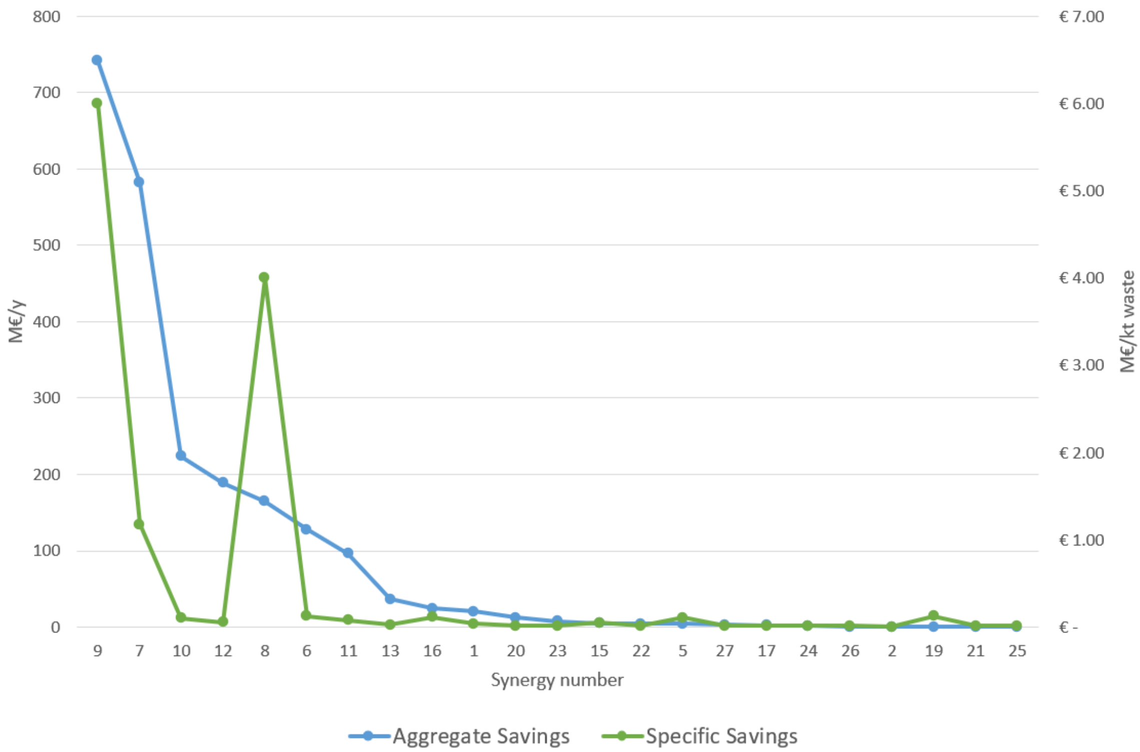


Figure 3. 8 Economic Savings (aggregate and specific) per each synergy.

Another perspective to represent the economic savings, which gives the overview of what are the most profitable synergies, is to show (figure 3.8) the **aggregate savings** (blue line) per synergy and the specific savings (green line) per synergy (the difference between aggregate and **specific savings** has been previously specified in paragraph 3.2.4). The number on the x axis refers to the "synergy number" contained in the very first column of the table 3.3. Note that the aggregate savings have been ordered from the largest to the smallest, while the specific savings have positioned themselves accordingly.

3.3.3 Environmental Savings

As far as environmental savings are concerned, there is no need to show the results separately for waste producers and waste users, since the benefits towards the environment have been computed considering **emission factors referred to the CO_2e emissions of the whole lifecycle** and there has not been a distinction between emissions of waste producers and emissions of waste users.

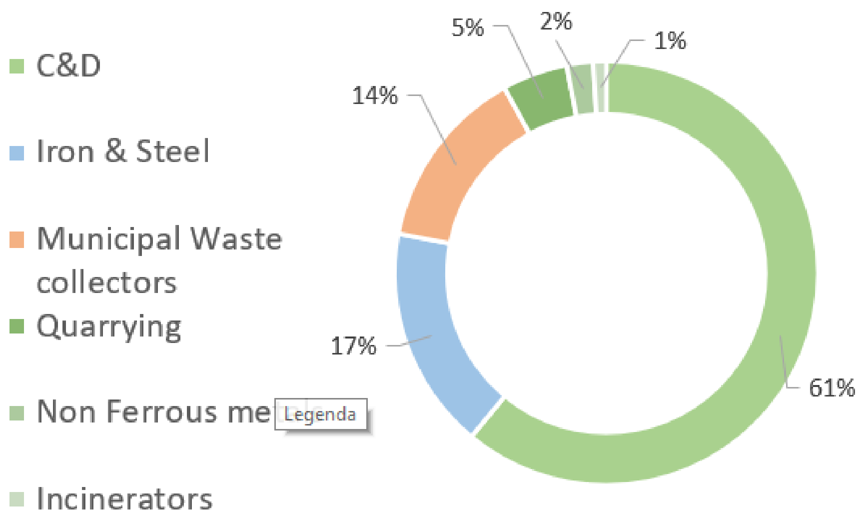


Figure 3. 9 Environmental Savings Associated to Waste Producers.

From the pie chart (figure 3.9), it is possible to notice that most part of environmental savings comes from the reutilization of C&D waste (61%), followed by Iron & Steel (17%), Waste Collectors (14%), Quarrying (5%) and others. The data used to make the pie chart can be seen also in table 3.4, where it is showed that the total amount of potential environmental savings generated is equal to 4,693 ktCO2e/y (including transportation). In pragmatical terms, this number corresponds to the emissions generated in one year from 2,720,780 cars who run 15,000 km, or 52,269 F1 racing cars, or 22,3 incinerators or 3,5 steel producers. To compute how much a car emitts in one year, it has been assumed that it runs 15.000 km/y, while for the F1 cars the data has been taken from the F1 website. About incinerators the indicative data have been taken from a journal article (Inquinamento e cambiamenti climatici: l'impatto degli inceneritori) while as a reference steel producer Arvedi has been considered.

Table 3. 3 Comparison of emissions savings with other polluting entities.

Table of Emissions Equivalents					
	Env. Savings [ktCO2e/y]	# Class B Car	# F1 car	# Incinerator	# Steel Producer
Total	**4,693**	**2,720,780**	**52,269**	**22.3**	**3.5**
C&D	2,857	1,656,314	31,819	13.6	2.2
Incinerators	71	41,304	793	0.3	0.1
Iron&steel	797	462,066	8,877	3.8	0.6
Non ferrous-metals	76	44,110	847	0.4	0.1
Quarrying	236	136,821	2,628	1.1	0.2
Waste Collectors	656	380,164	7,303	3.1	0.5

By shifting the perspective, also for environmental savings it is possible to have an overview of **aggregate** and **specific savings** generated per each single synergy (figure 3.10). Also in this case, the aggregate savings have been ordered from the largest to the smallest.

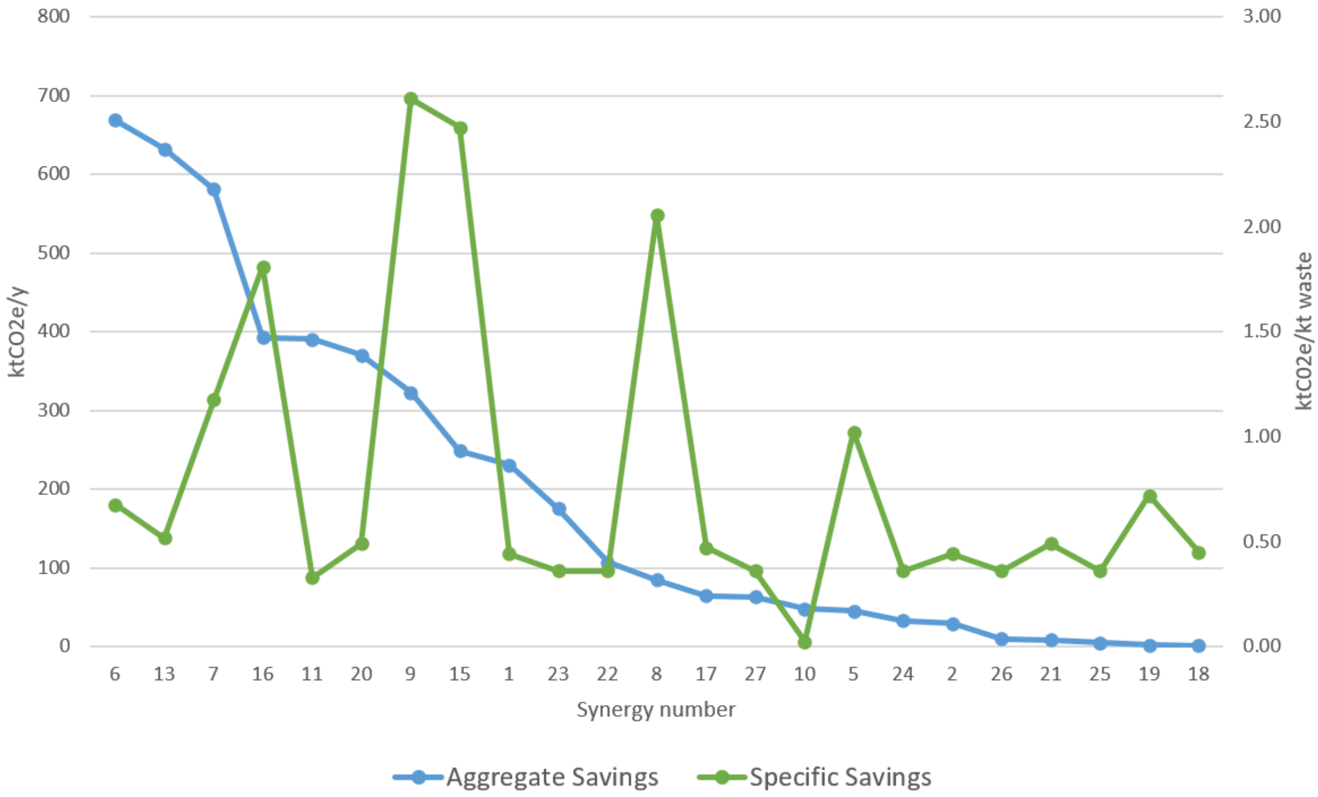


Figure 3. 10 Environmental savings (aggregate and specific) per each synergy.

3.3.4 Comparison between Economic and Environmental savings

In figure 3.11, it is possible to visualize by synergy **the capability to generate both aggregate economic and environmental benefits**, thus it is possible to point out what are the synergies capable of creating good economic benefits against the environmental ones, and vice versa. On the "left" y axis the yearly environmental savings are displayed, while on the "right" y axis the yearly economic savings.

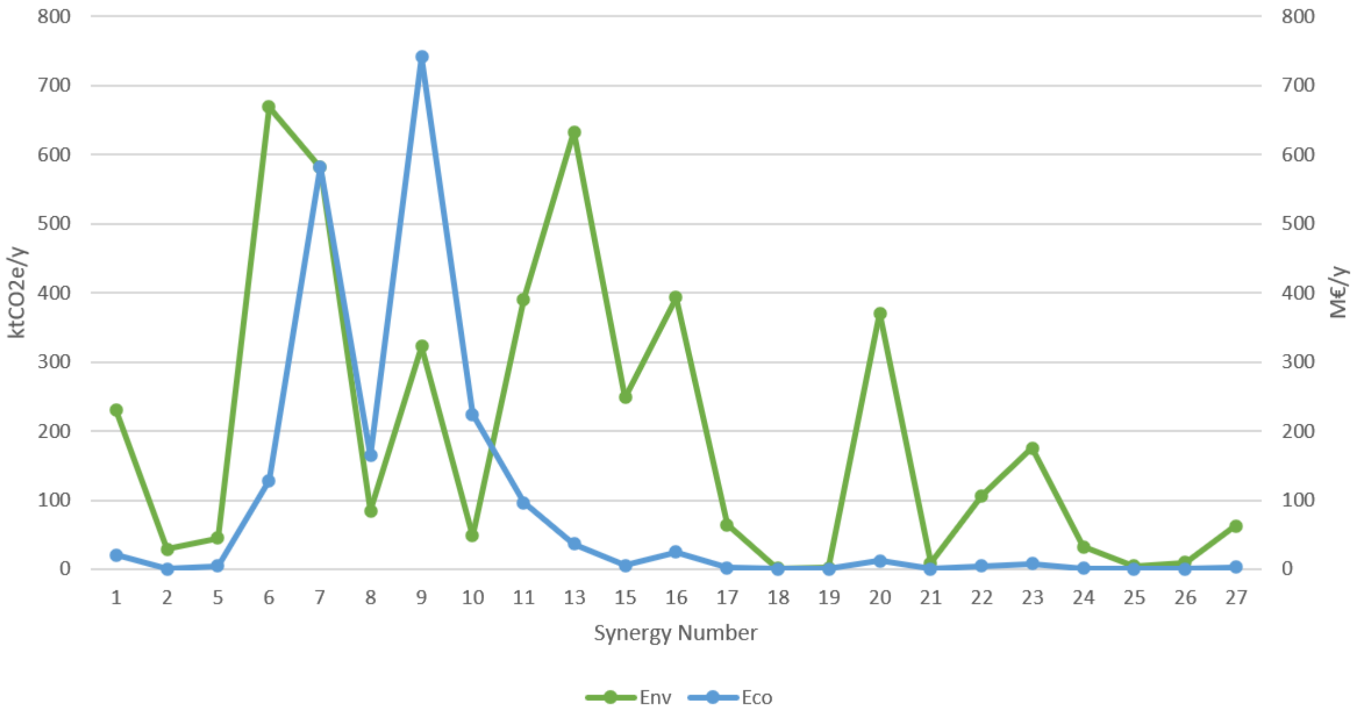


Figure 3. 11 Comparison between aggregate economic and environmental savings per synergy.

For instance, the synergies from 6 to 11 (iron, aluminium, brass, copper, concrete and mineral waste, wood containing iron pieces coming from C&D sector) are the most interesting ones from the economic standpoint and entail very good environmental savings (WIN-WIN). The synergies number 1 (magnetic fraction from quarrying), 13 (miscellaneous waste from C&D), 15 (Waste Plastics from MSW), 16 (Organic from MSW), 17 (coal fly ashes from incinerators replacing clinker), 20 (GBS from Iron & Steel), 22 (BOS from Iron & Steel), 23 (EAF-C from Iron & Steel), 27 (Steelmaking slag used for concrete production) show high environmental aggregate benefits but low economic ones. The synergies number

2 (marble sawing), 5 (mixed sawmilled silicate), 18 (Sand from Incineration), 19 (Ferrous metals from incineration), 21 (ABS from Iron & Steel),24 (EAF-S),25 (EAF-S),26 (Steelmaking replacing a fraction of clinker) shows medium/low environmental aggregate benefits and low economic ones.

3.3.5 Transportation impact

Since as showed in paragraph 3.2.3 the computations on transportation are not related to real distances, to consider transportation impact on the single synergies would be meaningless. However, if considered on the aggregate savings, the computed value could be an indication of how much transportation would (indicatively) weight on the total. Both in the just discussed economic and environmental savings the additional benefits coming from avoided transportation were already included: on the totals showed before, the transportation accounts for the **4.12% (88 M€/y)** with respect to economic savings and for the **3.85% (180 ktCO2/y)** with respect to environmental savings.

3.3.6 Best synergies identification

As anticipated in paragraph 3.2.4, based on all the results emerged so far, the best synergies have been identified by combining five different criteria. The table 3.5 shows the synergies numbers ranked from 1st to 10th place in relation to each criterium. For instance, according to the Volume, the synergy number 10 (concrete and mineral waste) is the one with the highest quantity, followed by synergy 13 (Wood containing iron pieces-2nd), 11

Table 3. 4 Synergies Rankings according to the five selected criteria.

		Top Ten Rankings				
Points Assigned	Ranking	Volume waste	Env Agg	Eco Agg	Env Spec	Eco Spec
10	1st	10	6	9	9	9
9	2nd	13	13	7	15	8
8	3rd	11	7	10	8	7
7	4th	6	11	8	16	6
6	5th	20	16	6	7	19
5	6th	14	20	11	5	16
4	7th	1	9	13	19	5
3	8th	7	15	16	6	10
2	9th	23	1	1	13	11
1	10th	22	23	20	20	15

(Miscellaneous waste-3rd) and then all the others. Applying this logic to the results of the analysis according to each criterium, it is possible to obtain the 5 distinct rankings as showed in the table 3.5.

On the basis of those five distinct rankings, the final table 3.6 containing the frequency (# of times that the single synergy is present in one of the rankings), the assigned points, the weights and the total score has been obtained:

Table 3. 5 Total weighted score per each synergy.

Synergy Number	Frequency Top Ten	Volume waste	Env Agg	Eco Agg	Env Spec	Eco Spec	**Best Synergies**
		5%	30%	30%	17.5%	17.5%	
1	3	4	2	2	0	0	**1.4**
5	2	0	0	0	5	4	**1.575**
6	5	7	10	6	3	7	**6.9**
7	5	3	8	9	6	8	**7.7**
8	3	0	0	7	8	9	**5.075**
9	4	0	4	10	10	10	**7.7**
10	3	10	0	8	0	3	**3.425**
11	4	8	7	5	0	2	**4.35**
13	4	9	9	4	2	0	**4.7**
14	1	5	0	0	0	0	**0.25**
15	3	0	3	0	9	1	**2.65**
16	4	0	6	3	7	5	**4.8**
19	2	0	0	0	4	6	**1.75**
20	4	6	5	1	1	0	**2.275**
22	1	1	0	0	0	0	**0.05**
23	2	2	1	0	0	0	**0.4**
Grand Total	50						

From table 3.6, it is possible to notice how there are synergies present in many rankings and synergies present just in a few (frequency column). This aspect underlines that not all the synergies show good result in each of the criterium used to estimate their attractiveness. Obviously, the more are the times that a synergy is present in rankings, the higher will be its total score because there are more addendums to consider. By total score it is intended the weighted sum of the points assigned for each synergy in each ranking. The synergies ending up having the highest weighted sum (green coloured=**very high priority**) are basically the ones related to metal scraps from C&D, i.e. the number 7 (aluminium) and the number 9 (copper), followed by synergy number 6 (iron) and 8 (brass). Other synergies showing a good overall result (coloured in yellow=**high priority**) are number 16 (Organic waste from

MSW), 13 (Miscellaneous Waste from C&D) and 11 (Wood from C&D containing iron pieces), followed by 10 (concrete and mineral waste from C&D), 15 (Plastics waste from MSW) and 20 (GBS from Iron & Steel). The ones left in white have a lower priority **(medium)** with respect to the ones previously discussed, but still are worthy to be mentioned and investigated, while the synergies not appearing in this table are the least attractive ones, and it would be better to consider them in a second moment **(low priority)**. These results are better characterized below in figure 3.12, where it is possible to understand the impact that each criterium (for simplicity the contribution of aggregate and specific savings has been integrated for economic and environmental savings) had on the total score.

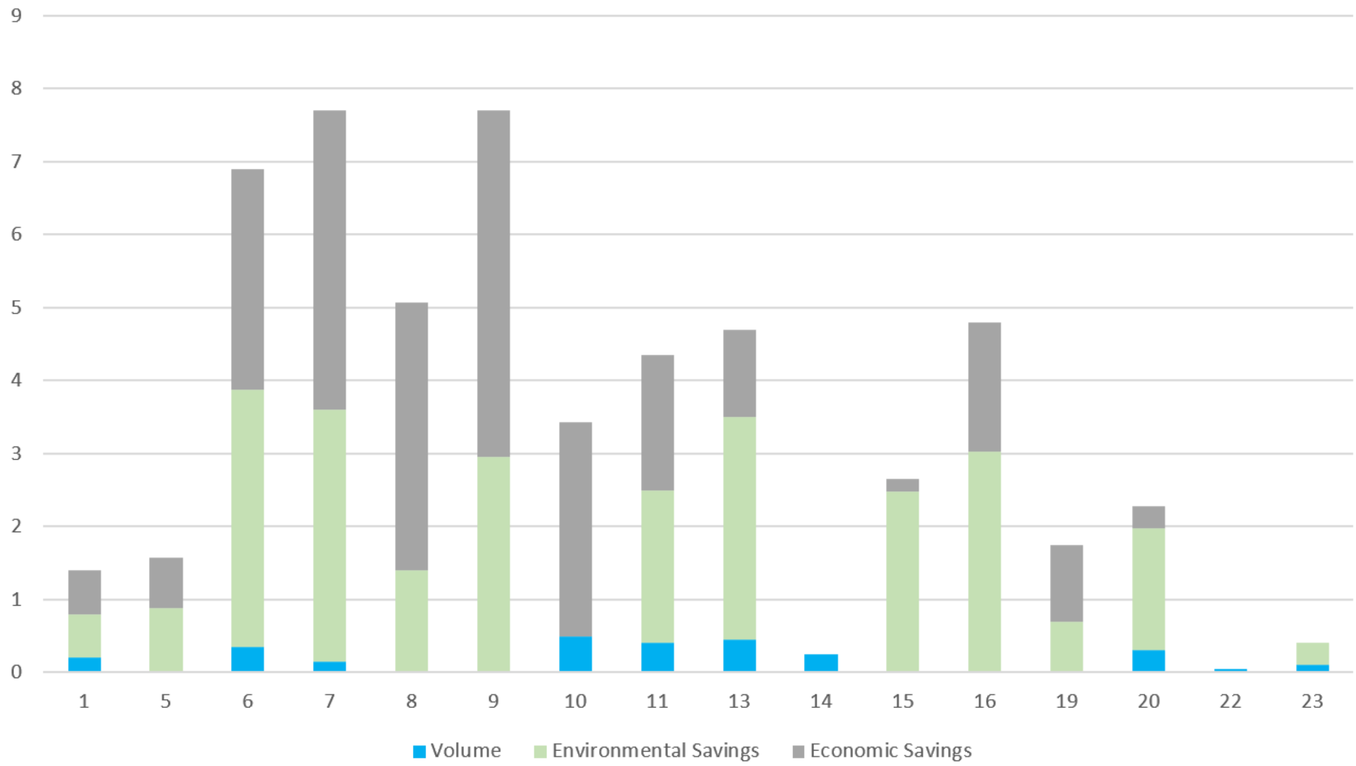


Figure 3. 12 Characterization of total weighted sum per each synergy according to the selected criteria.

3.4 Discussion of Findings

3.4.1 Volume

The first RQ answered by the macro-analysis is the 6.1: **“What are the actors generating the bulkiest volumes? Is the supply stable?”**. Thanks to the findings, the answer to part of RQs number 6.1 is very straightforward: the most part of volumes generated around the C&D supply chain comes from the C&D sector itself, followed by the Iron & steel one (figure 3.4). To answer the second part of the question, it must be underlined that it is fundamental to know the quantity of volume exchanged in a synergy (or the so called “project scale”) since volume is the first proxy of flows importance: firstly, as also specified in the literature (Chen et al. 2012)**,** the total amount of waste treated and VMS (virgin materials savings) are statistically correlated. Secondly, the stability of the supply is important to have long lasting benefits. At confirmation of what said in the literature, it is possible to notice that the coefficient of correlation between volumes and environmental savings is of 0.46, while the correlation between volume and economic savings is much lower (0.159). From the findings it has emerged that most part of waste is produced from C&D (76.94%) and Iron & Steel (14.02%). Starting from these data, it is possible to make considerations about the stability of supply: by knowing that C&D sector does not suffer seasonality in demand, it is possible to assume that the C&D interventions and the iron & steel production are pretty much continuous throughout the year. In keeping with this, it is possible to conclude that also most part of volumes generated will not suffer from a strong supply volatility, therefore it would be possible to build up those synergies without risking to much of having a short supply flow. However, having high volumes does not necessarily means that the synergy is profitable. It all depends by the value and by the emission factors of the raw materials and waste involved, which brings us to RQs number 6.2.

3.4.2 Best sectors and synergies

To answer the question 6.2 **“What are the best sectors and synergies in terms of environmental and economic benefits?”**, in the first place it is necessary to split the environmental from the economic part. Therefore, this RQ can be slit in four sub-questions: in the answering to the first sub-question it is explained what are the sectors and the synergies that could generate the most economic savings, in the second sub-question the same is done from an environmental perspective, in the third sub-question the two perspectives are merged and in the fourth and last sub-question the best synergies are pointed out.

Sub-question 1: What are the sectors and the synergies that could generate the most economic savings?

From the analysis of findings (figure 3.6), it emerged that for waste producers, most part of the economic value is generated from C&D sector. This happens because of the value that C&D waste has with respect to the waste produced by other sectors. For instance, by bearing in mind the synergies related to C&D metal scrap, i.e. number 6 (iron), number 7 (aluminium), number 8 (brass), number 9 (copper) and number 11 (wood containing metals), it must be considered that their selling prices are much higher with respect to other wastes' selling prices, such as GBS, ABS, Sand, Plastics waste and so on. Furthermore, there are wastes which do even have a value or worse that have to bear a disposal cost. This, jointly with the fact that most part of the volume comes from C&D, explains the fact that 95% of economic value for waste producers is generated in C&D sector. The opposite happens when taking the position of waste users (figure 3.7): from this standpoint, the actors that will be mostly able to achieve economic benefits are the ones whose RM cost the most, since they can enjoy greater advantages if replacing them. In fact, in keeping with this consideration, the Iron & Steel actors are the ones that enjoy the 76% of economic savings created by the here deemed symbioses. Actors such as Cement producers, whose RM materials have a much lower price with respect to the one of metals, benefit just from 2% of economic savings.

From figure 3.8, comparing the specific and the aggregate economic savings, it is possible to notice that not always the synergies providing greater aggregate savings are the ones able to give the greater specific savings. To cover the discussion of all the possibilities, it is possible to analyse one representative case for each. As an example of synergies that present high aggregate and high specific savings the number 9 (copper from C&D) could be used. In fact, copper waste has a very good price on the waste market (around 3000 €/t) and its recycling costs are relatively low. In addition, a company in needs of copper could save almost half of its RM price if buying waste copper instead. Therefore, under the light of all these considerations, despite having a quite low volume the synergy number 9 shows excellent specific and consequently aggregate savings. As an example of synergy showing high aggregate savings but low specific ones are number 10 (concrete and mineral waste from C&D). The large aggregate savings are directly related to the fact that the volume of waste is big, however the intrinsic value of concrete and mineral waste is very low, as well as its market value (usually C&D companies pay to dispose debris). Therefore, economically speaking it is more convenient to recycle them internally. Lastly, as a third possibility, there are synergies showing very high specific savings but low aggregate ones. It is the case of synergy number 8 (brass from C&D), since brass is a very valuable material used in modest quantities. Usually, in C&D brass is used in little pieces such as doorknobs or parts of radiators, thus the volumes associated are not very high if compared to the deployment of other materials. However, seen its very high specific value, it is worthy to collect and reuse it when dismantling a house.

In conclusion, it is possible to conclude that some resource flows need a very large quantity to be economically worthy (minimum critical mass), while for waste materials having a high intrinsic value (such as metals) the minimum critical mass is much lower.

Sub-question 2: What are the sectors (and the synergies) that could generate the most environmental savings?

From figure 3.9 in the findings it is noticeable that by reutilizing the waste coming from the C&D sector most environmental savings are generated (61%), followed by Iron & Steel (17%) and Waste Collectors (14%). This aspect depends on several elements: in keeping with what discussed for economic savings, the quantity plays an important role in the definition of aggregate savings, while the EF value delineates the specific ones: the higher the RM production and Waste disposal EFs are, the higher will be the environmental benefits associated with the symbioses. On the other hand, the higher is the EF of waste recycling (or combustion in case of energy recovery), the higher will be the part of savings offset. In the synergies analysed by us (except number 12 which has been thus excluded), the savings generated outweigh the necessary emissions to recycle the waste.

The C&D waste is the first one in terms of aggregate savings generated from reutilization, however it must be considered that not all the waste created shows high specific savings (figure 3.10). In the case of synergies such as number 10 (concrete and mineral waste), number 13 (miscellaneous waste), number 11 (wood containing iron pieces) and number 6 (iron) the volumes are very consistent: in the case of number 10, despite the large volume, the aggregate environmental savings are not great due to low environmental impact that this material bears in production, reutilization, and disposal, because most part of it is recycled internally. Miscellaneous waste (80% biomass made), Wood and Iron can bring to “medium” specific savings, and so, if combined with reliable volumes can bring to very good environmental impact. On the other hand, there are waste materials coming from the C&D sector which have lower volumes but much higher specific savings, such as the metal scraps. In fact, aluminium (synergy 7), brass (synergy 8) and copper (synergy 9) have considerable lifecycle EF and consequently they are the ones among the resources considered in this study showing the highest specific savings.

About Iron & Steel players, the reutilization of the waste is more convenient from an environmental than from an economic standpoint. For synergies 20 (GBS replacing clinker in cement), 23 (EAF-C replacing limestone in concrete for C&D) and 22 (BOS used to substitute concrete in road ballast) the volumes are quite consistent, and so are the aggregate environmental savings associated. Yet, the fact that the aggregate savings for these three synergies are good depends on the fact that the volume is high and not from the fact that specific savings are. For other synergies associated to waste coming from Iron & Steel, i.e. 27 (steelmaking slag to replace concrete in C&D), 24 (EAF-S replacing limestone in concrete for C&D), 26 (steelmaking slag to replace clinker in Cement), 21 (ABS replacing clinker in cement) and 25 (EAF-S replacing clinker in Cement), the volume is not big and due to the medium/low specific savings the aggregate ones are not giant.

As far as Waste Collectors are concerned (as stated before, it is intended those players that after having collected the waste have to readdress or dispose it), the good % of environmental savings associated is related to the types of synergies considered. As previously mentioned, (3.2.1), among the many types of waste collected just two types have been considered for this study, i.e. plastics (synergy 15) and organic waste (synergy 16). The reason behind this choice is also that by reusing this kind of waste as a coke coal substitutes in cement kilns, very high environmental savings can be generated. This is mainly due to the fact that coal coke has an enormous EF and, in comparison, the usage of plastics and organic materials pollutes less. Alongside with the great specific savings achievable, these two synergies show excellent aggregate ones even though the volumes are much lower in terms of quantity with respect to C&D waste.

Sub-question 3: Are there synergies economically valuable but not environmentally or vice versa?

This question can be easily answered by looking at the figure 3.11 and by considering what has emerged so far from the discussion: it has been seen how C&D players can, economically speaking, take advantage from selling their waste to other sectors (especially Iron & Steel), and, oppositely, how the waste generated from Iron & Steel players could generate very good environmental benefits if reused in other sectors (such as Cement Production and C&D). In the first case, good environmental benefits are generated alongside the economic ones, while in the second case very poor economic benefits are generated alongside environmental ones. The point is that for those synergies whose environmental savings are good but economic return is low, incentives from third parties (e.g. state, regional governments) should be granted to push waste reutilization.

Sub-question 4: what are the synergies where actors should start from?

The paragraph 3.3.6 in Findings answers the question since it shows the synergies having very high, high, medium, and low priority with respect to the weighted sum result achieved. It can be added that the results of this final qualitative analysis perfectly align with what previously discussed/explained into the sub-questions. In fact, in figure 3.12 it is possible to visualize what is the impact that volume, environmental savings and economic ones have on the priority coefficient (weighted sum) of each synergy. It well summarizes all the considerations done for the synergies having both good environmental and economic performance, synergies having good environmental performance but bad economic ones and vice versa. In addition, also the contribution given by volumes is showed in accordance to the answer given for research question 6.1.

3.5.3 Transportation

The last question answered in the macro-analysis is: “What is the order of magnitude of transportation impact?”. About transportation, the very simplistic computations and the methodology utilized is not suitable for analysing the impact that it has on each single synergy. In fact, the transportation impact has been included in the aggregate economic and environmental savings during the findings discussion. In other words, in this analysis transportation can be seen as an adjustment coefficient that increases of a certain % the aggregate savings, which on average is **4.12%** with respect to economic savings and **3.85%** with respect to environmental savings. These % on the total, can be a good approximation of transportation order of magnitudes since the km travelled, the cost of fuel (proxy of transportation cost) and the volumes transported have been calibrated on Lombardy region.

3.5 Limitations of macro-analysis

The main limitations of the macro-analysis have been mentioned all along the paragraphs, however, to provide greater transparency they have been here listed and shortly commented:

- The main limitation concerns the volumes of Lombardy region and the substitution factors. About the former, since on ISPRA website there were only aggregate data, it has been necessary to search for ways to disaggregate them either based on previous studies or on assumptions. About the latter, as well as for volumes, some assumptions have bene made due to data lacks (as explained in 3.1.1).

- For some resource flows prices and EF data have been taken from Chinese/Japanese studies (from LR), thus there can be some slight variations with respect to the Italian actual prices and EF. An example can be the prices of Iron & Steel waste (GBS,ABS,BOS, EAF) taken from Guo (et al. 2016) or the EF of Limestone taken from Li,Dong and Ren (2015). Note that all the Prices and EF used with the associated references can be found in the appendix ("EF and Prices with References for Macro-Analysis"). Furthermore, the considered Prices and the EF are just a proxy of the real economic and environmental advantages, since other exogenous factors (such as technological breakthroughs, prices volatility, market trends and others) might influence them dynamically. In relation to this, to have a more precise approach also those influencing factors should be accounted for. However, in accordance with the mere purpose of this macro-analysis, they could be overlooked.

- The costs related to the sorting and processing of the wastes before their use has been estimated but, due to lack of data, in many cases assumptions that might limit the accuracy of results were necessary.

- The methodology to estimate transportation impact is very simplistic and might not display the real impact that transportation has on the single synergies. The justification is that, as far as this research is concerned, the objective was just to give the order of magnitude on a regional basis.

- An “a priori” introduction of sectoral or typological boundaries to the contexts studied can limit severely opportunities for potential synergistic interactions among the entities involved, including the neighbouring ones. In addition, contexts change over time and the adoption of a too rigid approach would limit the possibilities of incorporating solutions and synergies that emerge during its evolution (A. Simboli, Taddeo, and Raggi 2019).
- The model partly considers losses in quantity through the use of substitution factors, however there might be other efficiency coefficients and quality losses that the model does not consider.
- The macro-analysis potentially evaluates the replacement of virgin RM with waste. However, for many cited reasons (technological, quality related, organisational etc.) the availability of potential substitutes on the market does not guarantee substitution.

4 Micro analysis: empirical research on C&D supply chain and related stakeholders

This chapter discussed the methodology for data collection and analysis in the micro case. The micro analysis has been carried out in **qualitative terms** starting from data of companies operating in the C&D sector in Lombardy. The phase of companies' selection has been included in section 4.0 and answers to RQ 7.1 *"What are the actors taken into account? What are the criteria?".* The reason behind the choice of going for a qualitative analysis lies in the trade-off between detail and depth of analysis: while a quantitative approach at the micro level would consider a lower amount of material flows with a higher detail, a qualitative approach allows the exploration of more flows with a lower level of detail. As an analogy, monitoring every single action of a soccer player during a game allows us to get a huge amount of data about him but would give a limited vision of the team overall performance, while monitoring less parameters of all of the players on the field allows us to get a better idea of how the team has played. In the same way, quantitatively monitoring some material flows in detail would give us a worse perspective of the overall performances of the company.

As UIS is still a relatively unexplored field, and the aim of the Thesis is to set the basis for further research and to explore the whole supply chain, this is believed to be the best approach. Results have been used to answer two research questions; in particular, an input output analysis of materials and waste flows has been used to analyse the current situation of some selected actors and by suggesting an optimal UIS configuration (based on flows from LR) answer to RQ 7.2 *"What are the main flows? How could UIS impact them*?", while a detailed analysis of influencing factors has been proposed to evaluate the perspective of actors regarding UIS systems and answer to RQ 8.1 "*According to the actors located in Lombardy, what are the most influencing factors?".*

Hence, this chapter has been structured as follows: after the explanation of companies' selection process (section 4.0), the methodologies for data collection (section 4.1) and for data analysis (section 4.2) have been described. Subsequently, findings have been outlined (section 4.3) and then discussed (section 4.4). Finally, the main limitations of the micro-analysis have been pointed out (section 4.5).

4.0 Selection of Companies

Before talking about the instruments that have been used for data collection, a brief discussion concerning the process of companies' selection is proposed. There is a **huge trade-of**f embedded in this choice as more companies should in theory provide a higher amount of information but a lower level of detail, while a smaller pool entails a higher level of detail but may not be big enough to provide a full representation of the issue. As this study aims to set the initial ground for research and to provide a general view of actors operating throughout the supply chain, the hope and objective was to have at least one actor from each stage of the supply chain described in section 2.2.3.

As a low response rate was expected, due to the difficulties for companies to find time in a challenging period like the pandemic one, a large pool of candidates for potential inclusion was created. Moreover, as the properties and usability of a pool of companies are determined by the items that make it up, it did not only include C&D actors but also those industries that could be related in some useful ways to our research. This phase has been critical to highlight further potential links to the ones considered in literature, especially considering a sector that is as broad and intertwined as C&D. An **initial pool** of one-hundred and eighty-nine companies was therefore created. A full list of all of the companies that were initial contacted has been reported in Appendix 6 (“List of contacted companies for micro-analysis”).

The contact format initially chosen was emails from the contact section on companies’ websites. It is firmly believed that this was the best option to try to arise interest in this project from as many actors as possible. Realistically, by looking at the results of previous projects, the hope was to have around a 10% response rate (that formally meant 15 to 20 companies to work with). Unfortunately, only five companies answered and only 1 agreed to do an interview. That was obviously not enough to carry out an analysis, but by leveraging upon some **personal contacts** four more companies were approached and three of these agreed to answer our questions in an interview. This was also a reason why a qualitative approach was chosen as the number of companies involved was not high enough to proceed with a quantitative analysis.

Towards the end of the project, three additional interviews have been scheduled, one with Rete Sand, one with Regione Lombardia and one with Holcim.

In order to contribute to the reader's knowledge on the built framework, a **table of the positively reached companies/institutions** either through a questionnaire, an interview or their publicly available reports is hereby reported.

Table 4. 1 List of companies involved in the Micro-Analysis.

			Interview				
Company	**Sector**	**Size**	**Date**	**Duration**	**Position of interviewees**	**SR and documents**	**Questionnaire**
ARUP	Consultancy firm working across every aspect of the built environment	LARGE	05/02/2021	60 min	Engineer from the Sustainability & MEP Team, Urban Planner	"First steps towards Circular built Environment", Arup and Ellen MacArthur Foundation, 2016	Filled and discussed in the interview
Acciaieria Arvedi	Steel	LARGE	20/01/2021	40 min	Head of quality management, Environmental consultant	"The first Sustainability report of Acciaieria Arvedi", 2018	Filled and discussed in the interview
Colacem	Cement	LARGE	12/02/2021	50 min	2 controllers from the Accounting finance and control department	"Rapporto di sostenibilità 2019", 2019	Filled and discussed in the interview
Feralpi Siderurgica	Steel	LARGE	/	/	/	"Bilancio di Sostenibilità 2018", 2018	Filled
Lagalla Costruzioni	C&D	MEDIUM	22/01/2021	53 min	CEO, Site manager	Non-Available	Discussed in the interview
Lafarge Holcim	Cement	LARGE	/	/	Communication coordinator, Head of Marketing and Sales @ Geocycle, Sustainable Product Development Manager	"Sustainability performance Report", 2019	Filled and discussed in the interview
Regione Lombardia	Public Institution	-	24/03/2021	60 min	Project Manager, Senior Executive, Environmental officer	Not-Available	Filled and discussed in the interview
Rete Sand	IS Network	SMALL	18/03/2021	60 min	Lawyer and Co-Founder, Communication Coordinator	Not-Available	Discussed in the interview
Special Rubber	Rubber	SMALL	/	/	/	Non-Available	Filled

In particular, for some of these actors, chosen as **sector representatives**, where a full view of companies' activities emerged, a deeper analysis concerning materials and waste flows has been developed in section 4.3. In order to provide clarity, a description of companies' activities is hereby reported. Also, despite the fact that Rete Sand has not been included in the analysis of flows, and due to the fact that they may be unknown to many, a brief description of their activities has been reported too.

ACCIAIERIA ARVEDI is one of the most important steel producers in Europe, located in Italy, where two plants are operated; the first one is in Trieste, while the second one, the largest and most important for our research is in Cremona. Overall, the group counts 3800 workers and is responsible for the production of almost 4 million tons of steel products with an annual revenue of 3 billion of Euros (Gruppo Arvedi). Our focus has been the Cremona plant that produces steel coils that are then transformed and used by many industries in a wide variety of applications, including C&D. A simplified representation of the production process is hereby reported:

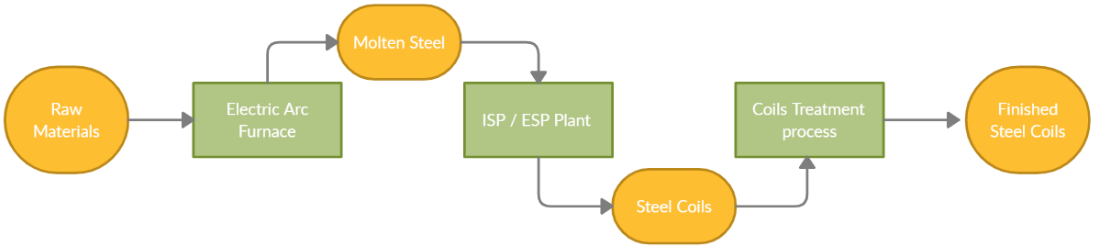


Figure 4. 1 Steel coils production process.

COLACEM is an international cement producer that operates on a large scale in many countries. The group can count on 8 full cycle plants and 7 other plants (including terminals, warehouses, and non-full-cycle plants). In 2019 it reported a revenue of 275 million of euros and it currently employees 900 workers in Italy. In this Thesis the focus is on the Caravate plant, the only full cycle plant located in Lombardy and the one that, as later explored in the following paragraphs, best aligns with the needs of this analysis in terms of symbiotic linkages. A chart that simplifies the procurement and production process is hereby reported:

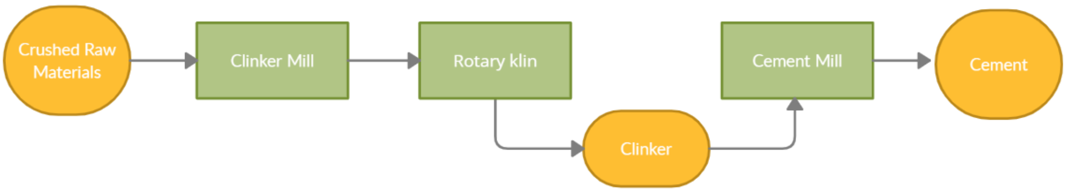


Figure 4. 2 Cement production process.

LAFARGE HOLCIM similarly to Colacem is an international cement producer that operates on a large scale in many countries born from the fusion between Lafarge and Holcim. Our analysis has focused on Holcim Italia that can count on 1 full cycle plant (in

Ternate (Va)), one grinding station (in Merone (Co)) and various other assets such as terminals, quarries, and warehouses.

LAGALLA COSTRUZIONI is a construction, renovation, and interior design firm active in the Italian territory and located in Milan. It currently employees 106 people and works on an average of 50 projects per year in the city of Milan. As this data shows, differently from the other firms that have been included in our research, it is not a huge company, but rather a small medium enterprise. Generally, **SME** are overlooked in most existing studies as their impact as a single entity is not great. However, by considering the overall effect the is situation changes. As a matter of fact, according to ISTAT (Imprese e addetti) almost every C&D company based in Lombardy employees less than 10 people (95,6%) and can therefore be considered a SME. In particular, out of the 4077 companies operating in Lombardy, only 24 have more than 250 employees. This effectively shows how important the perspective of SME is and how failing to consider their impact can result in a **huge loss** of an opportunity under both the economic and environmental perspective.

RETE SAND is a newly established network of companies working to promote CE and IS practises in the C&D supply chain. It operates in the Milan area and currently includes six companies (three mining quarries, one bitumen producing company, one ferrous scraps recovery company and one company operating in the road works field) that actively exchange materials and waste in an IS system.

4.1 Data Collection

Data collection is surely something that should be developed in the most precise manner in order to ensure that correct data can later be elaborated in an easy way. Particularly, to ensure compatibility between what was needed and what could be obtained, the development of a good data collection mechanism has been carried out together with the definition of the pool of companies. This process has been based on three important and fundamental principles oftentimes mentioned during our university experience: **efficiency, completeness, and timeliness**. Efficiency refers to the fact that useful data had to be collected with the lowest interactions possible (especially from interviewees that did not have a lot of time available). This is mostly referred to the first approach with companies, where there was the need to put in place an effective but easy to fill questionnaire. Completeness is connected to the fact that, especially for interviews, every interaction with the company had to be the most complete in a sense that it provided the highest amount of usable data. Timeliness deals with the temporal dimension of interactions: questionnaires had to be fast to be filled in order to reduce the effort needed and consequently increase the probability of getting an answer while for interviews, as they were often set with a maximum duration, getting the right answer in a limited time was fundamental to increase the obtainable information. In order to collect data, three main sources reported in the following sections have been used: **Sustainability reports, Interviews, and a Questionnaire**. The choice of relying on these sources came from the fact that they could each provide a different piece of information to the "final puzzle". The objective was to gain a complete picture of some companies' activities as well as their perspective on this topic. Table 4.2 highlights the different types of data provided by each source.

Table 4. 2 Data sources and data types used in the micro-analysis.

Data Source	Data Type
SR	Information about companies' activities, processes, material, and waste flows. General perspective about Circular Economy
Questionnaire	Information about D&B influencing companies' processes.
Interview	Precise information about companies' activities, clarification about material and waste flows. Specific perspective concerning UIS and D&B affecting the company/sector. Past and Future projects. R&D in terms of UIS.

4.1.1 Analysis of sustainability reports

Analysing sustainability reports is useful get an idea of the **companies' activities** and consequently of the different raw materials, by-products and wastes involved in the process. It also allowed us to be more prepared to actively discuss topics during interviews. Many of the information that have been included in the following flow charts originally came from sustainability reports and have later been further discussed in the interviews. The most recent versions of sustainability reports have been chosen meaning that they are all referring to data from 2019. This is better as, in most of the cases, 2020 data has been strongly affected by the COVID 19 situation and would not represent a fair view of companies' activities.

4.1.2 Questionnaire

Differently from the analysis of sustainability reports, questionnaires have been the methodology used to collect **initial data and information about influencing factors and about the company and its processes** from which the discussion of the interview has started. Surveys have been sent both to a broad list of selected companies operating in Lombardy and to each of the interviewed ones where answers have been discussed in order to clarify results. The advantages of using this methodology are substantially two: the first one is related with the possibility of reaching a high number of companies, while the second one is related with the ease of analysis of the results. Questions that have been included in the survey have been developed to be as fast to be answered and as standardised as possible. In this way, on one side, the survey would not have been much of a time loss for the companies while on the other side, it allowed us to easily analyse answers. Moreover, being the questions the same for everyone, the comparability of questionnaires from different companies is surely high. Factors included have been developed on the basis of those mentioned in the Literature and they are displayed in Table 2.7.

The platform that has been chosen for this purpose is Google Form mainly due to its ease of use and the fact that is widespread and know to companies. As for the structure of the questionnaire, it has been divided into 3 sections:

- Section 1 includes general information about the company, such as Name, operating sectors, number of employees and geographical location in order to better classify the companies.
- Section 2 examines D&B influencing the reuse of secondary raw materials in production processes. This section aims to explore what are the factors currently impacting the reusability of raw materials. Companies are required to assign a "rate of importance" (that goes from 1 to 5, where 1 means very little influence), that describes how much a specific factor influences its activities in relation with the reuse of secondary raw materials.
- Section 3 is quite similar in its structure to section 2 but concerns the "output" part of the process: waste management. The objective of the section is to explore what are the factors currently impacting waste management practises. To do so, similarly

to section 2, companies are required to assign a “rate of importance” to each factor from the list.

Results of the survey have been reported in section 4.3. For those companies that agreed to proceed with an interview, results have been used as a talking point to better discuss drivers and barriers.

4.1.3 Interview Protocol

Differently from the questionnaire, that was built following a very structured approach, interview protocols had to be differentiated to cope with the dissimilarities between interviewees. However, to maintain the advantages provided by standardisation, a **semi-standardised approach** was adopted: a list of general and common questions has been developed for each category of actors and, in addition, a tailored set of questions have also been included in each interview protocol in order to differentiate actors and analyse their specific activities.

Particularly, four categories of actors have been considered: C&D actors, companies related to C&D, Consultancy companies and Public institutions. Common questions, excluding general ones such as number of employees or geographical location, mainly concerned knowledge about UIS, previous involvements in some projects concerning these systems, common by-products or waste reusing options of the C&D sector and a deeper discussion on drivers and barriers. Deeper and more precise questions concerning the nature of the flows and their usage for both raw materials and wastes have also been included in the protocols for manufactures (including both C&D and related actors). Obviously, each protocol has also been adapted on the basis on information gained on Sustainability reports and in many cases, it allowed us to investigate some “best practises” from companies. These questions were the first attempt to clarify numerical and complete information about the flows involved in the sector upon which our calculations were based.

Moreover, to increase the quality of information and efficiently use the time of the interview, according to the principles of completeness and timeliness cited in section 4.1, questions were always sent in advance in order to allow interviewees to better prepare themselves.

Also, to double check our understanding on data and information **every company has been further contacted and a recap of every statement** from interviews that have been included has been sent before the finalization of the project.

4.2 Data Analysis

To explore material flows of selected actors a basic **Input Output analysis methodology** (IOA) has been adopted. The former traces process flows related to a region, a network of companies or a specific company. Differently from the traditional IOA, that has an economic origin, this part of the thesis overlooks quantitative economic advantages in favour of a qualitative analysis. In line with the IOA perspective, every actor is represented as a **"Black box"** meaning that processes that resources go through in order to become finished products are overlooked and attention is only posed on the flows of materials that enter the company and exit as either finished products or waste. However due to the fact that, especially for steel and cement, production processes are quite complicated, an oversimplified version of them has been reported in figure 4.3.

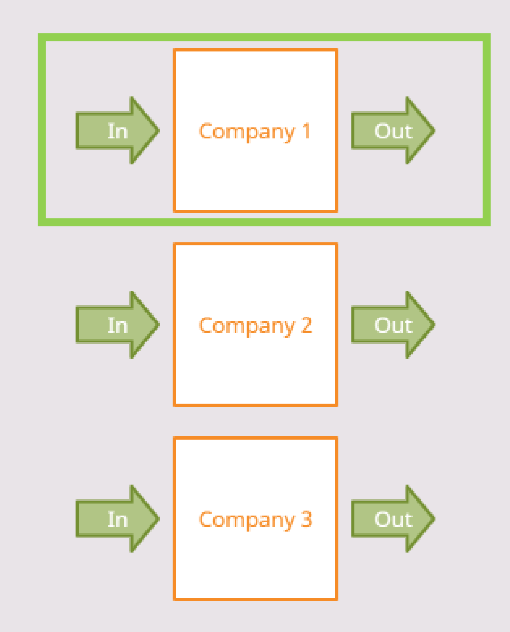


Figure 4. 3 Input-output analysis scheme.

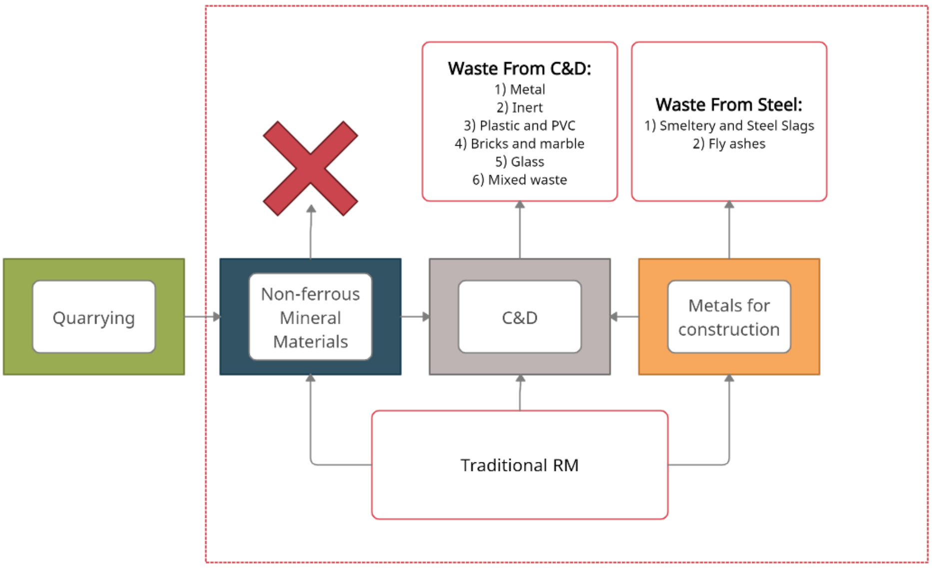
Flows have been built mainly based on information from sustainability reports and have been further explored during the interviews. As for the width of analysis, initially, companies have been considered as "stand-alone entities" and therefore a single flow chart for each of them (section 4.3.1) was created (**intra-company level**). Starting from these, the aggregated flow chart, built by combining different information from companies, was developed (**inter-company level**, Figure 4.4). The difference between the two is that while the latter gives an idea of current inter-company exchanges and the overall situation, the former focuses on single entities and therefore provides a higher degree of precision of inputs/outputs, meaning that it includes every material that goes in and out of the system.

After this initial phase, based on both previous virtuous examples from literature and the results of the Macro Analysis, a new inter-company chart was developed by including new flows of materials from the introduction of a potential UIS system (section 4.4.2). Every flow has been later analysed by looking at its nature and feasibility (or ease of implementation).

Based on the results of the questionnaire, **influencing factors** have been analysed with a two-step process: at first, some of them (in particular the ones that companies evaluated as critical were the ones important to be further explored) have been discussed with the interviewees in order to further investigate their perspective and then, based on previous literature findings and this new data, an assessment of the reasons behind the choice of companies was produced. By doing so, the perspective of actors has been empirically outlined and then justified from an academic standpoint.

4.3 Findings

Similarly to the macro analysis, starting from figure 2.10, and building upon various new information that were gained through the sources that have been mentioned, a restricted analysis of some common flows is hereby proposed. Due to the unavailability of interviews and data, some cuts to the supply chain of Figure 2.10 had to be made. Particularly, quarrying activities have been excluded from the analysis while actors on which a clear



and precise analysis of flows could be built have been chosen as representatives for each step of the supply chain.

Figure 4.4 shows the starting situation with no symbiotic links in place. However, nowadays companies already engage in some exchanges between them that have been addressed in the following sections. In particular, the companies that have been interviewed for our project are **already good examples** of this. Still, this does not mean that all of the companies operating in the field, also in view of what has been previously said concerning SME are as good as the analysed actors. A deeper and more complete analysis on each company's flow chart is proposed in the following section.

4.3.1 Flow charts: No UIS

This section presents the flow charts that were developed for each manufacturer that represents each step of the supply chain. Due to the nature of processes, RM used, and waste produced are assumed to be very similar. To confirm our assumption, in the case of Cement producers (the only one in which we were able to interview more than one actor), flows and materials used were very similar for both Colacem and Holcim and therefore only one flow chart has been included.

Both **materials/waste and energy** have been included in flow charts and expressed quantitatively. However, this has been done to give an order of magnitude of different flows but, differently from an MFA analysis, where greater attention on the conservation of mass between inputs and outputs has to be considered, they are not used to evaluate a company ability to optimize inputs/outputs in quantitative terms.

In the **first flow chart** (Steelmakers), based on the information gained during the interview, there has been a further distinction for quantities: first the total production amounts and then its subset destinated to the C&D sector have been indicated. As for *waste production*, there are two main type of waste produced: slags and fly ashes. In particular, slags are produced both in the electric furnace (black slag), in the ladle furnace (white slag) and from decapping and lamination activities, while fly ashes come from combustion activities. There are also other types of waste such as sludge from the cooling circuit or hydrochloric acid that have not been included in the graph as they will not be analysed. Current recovery options have been further discussed in section 4.4.2.

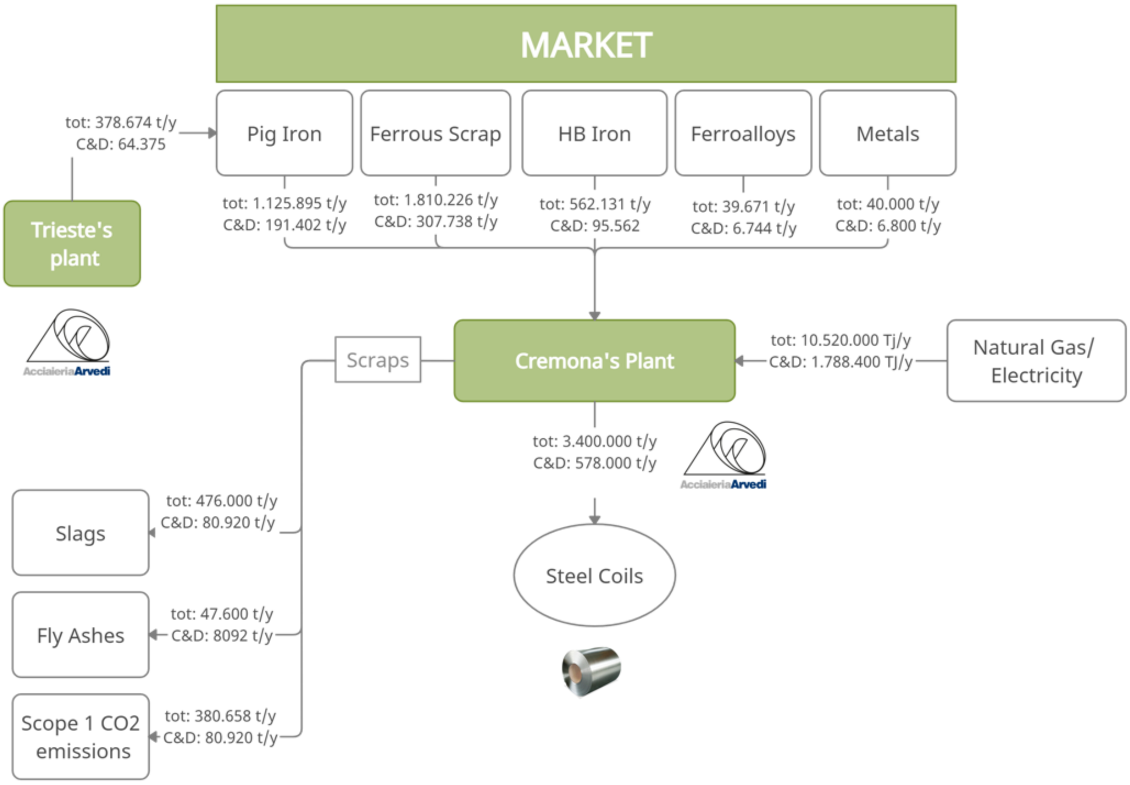


Figure 4. 5 Arvedi's flow chart.

As figure 4.5 shows, the highest source *of raw material* that is currently used in the process is Ferrous scraps. The steelmaking industry has always been a virtuous example of reuse and overtime the quantity of secondary raw materials that could be added to the processes without compromising the quality of the finished product has increased. Nowadays, Arvedi can use up to 80% of ferrous scrap and 20% of virgin raw materials to produce one ton of steel. Obviously, this is only a maximum level as "recipes" may significantly vary according to the characteristics that are needed for each client.

The **second flow chart** (Cement producers) is a little bit more complicated due to the higher number of raw materials and finished products. Starting from energy, the first big difference compared with Arvedi emerges as, due to the different production processes, the former needs pet-coke (coke derived from crude oil) and other raw materials to fuel the cement Kiln.

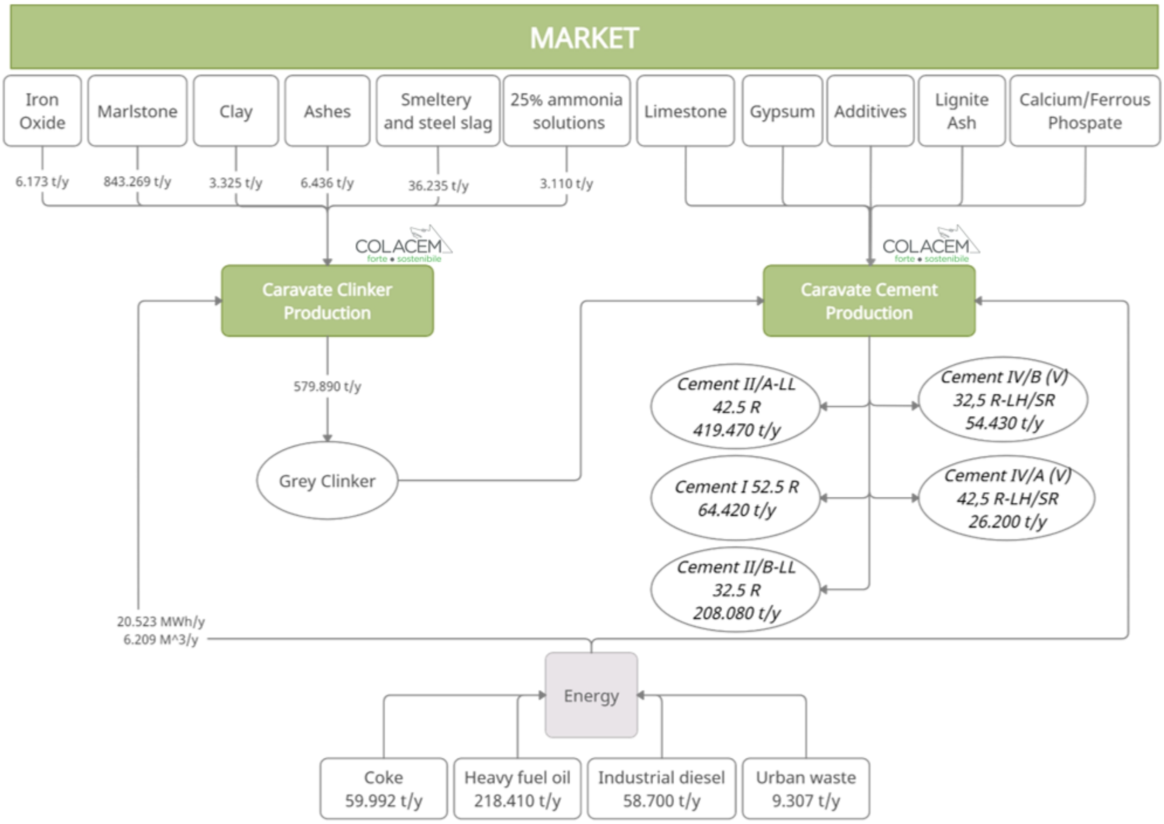


Figure 4. 6 Colacem's flow chart.

As for *raw materials*, both Colacem and Holcim produce grey clinker that is later internally used in the production of various types of cement. Quantities that have been included in the graph refers to Colacem. Cement raw materials quantities have not been included as they are strongly dependent on the type of cement that needs to be produced. Specific recipes include different percentages of the mentioned raw materials as this will determine different properties of the finished product.

A very interesting aspect about this process is that there is no *waste* created. Every ash or slag that is produced in a step of the production process is then reintroduced in the system resulting in a net production of waste equal to 0. Overall, these reuse practices account for about 4,5% of the total quantity of raw materials that are used (Colacem Rapporto di Sostenibilità 2019). The only waste that is produced is not related to the production process but rather concern the maintenance of the machines (such as lubricant oil) or packaging activities.

The **last flow chart** (C&D) that has been created is the one of Lagalla Costruzioni. As figure 4.7 highlights, quantities have been omitted because there is not precise data available about materials that are annually purchased and scraps that are produced in the process.

Energy has been omitted too as in the actual construction process the quantity of used energy is negligible when compared with the one of Arvedi or Colacem.

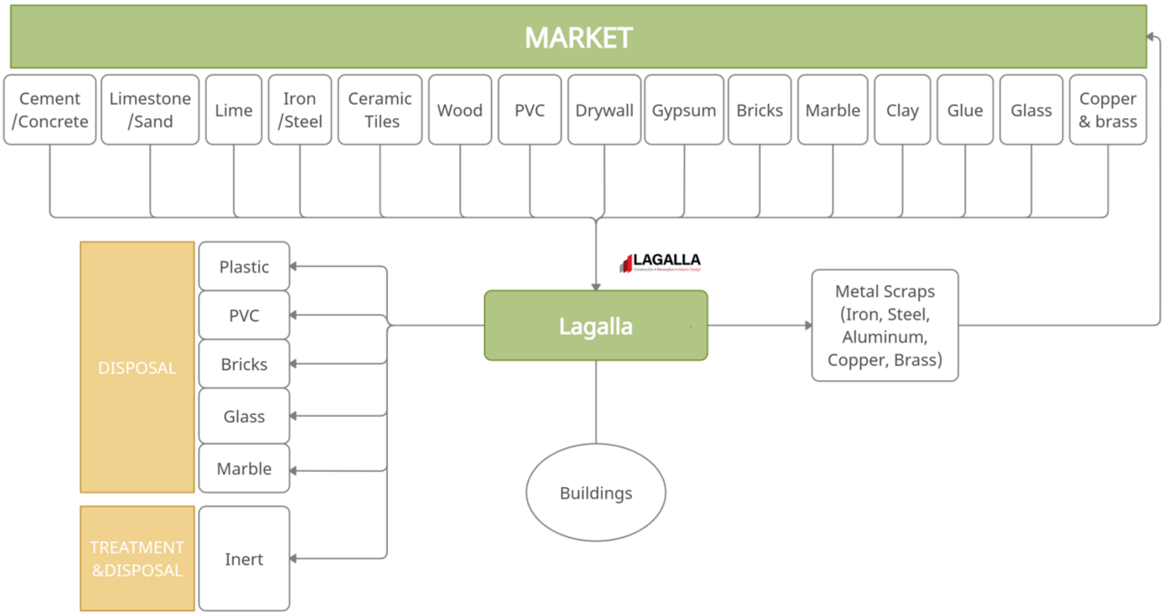


Figure 4. 7 Lagalla's flow chart.

As for -, the company does not specifically look for any secondary raw materials but rather buy them from traditional suppliers.

There are *many scraps* connected with the construction process. Generally, scraps follow three different paths. Metal scarps, such as iron, steel, aluminium, copper, lead, and brass are sold on the market; inert are disposed through specialised companies after being correctly treated while other scraps such as plastic, bricks, marble or glass are disposed through traditional methods. Lagalla also carries out demolition activities where the main objective of the company is to recover materials (especially copper, brass, iron, and aluminium) to later sell it on the market. However, demolition activities do not have the objective of recovering materials to reuse them in the construction process. More on this topic has been discussed in section 4.4.2.

4.3.2 D&B

This section presents results of research in terms of influencing factors and their impact on companies' activities. As it has already been said, questionnaires were the main source that has been used to find data. At the end, eight actors provided usable responses: Arup, Acciaieria Arvedi, Colacem, Holcim, Lagalla, Special Rubber, Feralpi Siderurgica and Regione Lombardia (even if they did not provide an answer for every factor). Companies (therefore excluding Regione Lombardia) can be classified according to:

1. **Size**: three of them (Arup, Arvedi and Colacem) employ over 500 workers and can therefore be considered large enterprises; Lagalla and Feralpi employ between 100 and 500 workers and can be classified as medium enterprises while Special rubber can only count on less than 10 workers and is therefore a small enterprise.
2. **Core business**: One consultancy company, two steelmakers, one company from the rubber industry, two cement producers, and one company from the C&D sector.
3. **Geographical location** of Lombardy's plants: Colacem, Holcim and Special rubber are all based in Varese, Arvedi in Cremona, Feralpi in Brescia and Lagalla in Milan. Arup has its offices in Milan.

An additional actor filled the questionnaire by assigning a value of 5 to each factor without leaving any comment and, so, it has been excluded as the questionnaire was believed not to be filled consciously and it could not provide additional value to the thesis.

Results of the survey have been reported in the following table. Factors have been distinguished in those that are related the reuse of secondary materials (input) in the production process (section 2 of the questionnaire) and those that are related to waste management (output) (section 3 of the questionnaire). The table has been filled with a NA if the company classified a certain factor as "Non-Applicable" to their specific processes. Discussion of the answers and their implications on companies' activities is provided in the following section.

Table 4. 3 Results of D&B questionnaires.

Process	#	Factor	Acciaieria Arvedi	Colacem	Lagalla costruzioni	Special Rubber	Feralpi Siderurgica	ARUP	Reg Lom	Holcim
SRM**	1	Composition of waste from other actors	5	5	NA*	1	5	5	5	5
SRM**	2	Availability of technology	4	5	NA*	3	NA*	4	4	4
SRM**	3	Standardization of technology	4	3	NA*	4	NA*	4	3	4
SRM**	4	Awareness about the potential of waste reuse	4	5	NA*	1	5	5	3	5
SRM**	5	Development of a digital platform to exchange waste	1	4	NA*	1	4	3	2	3
SRM**	6	Cost of raw materials, energy and labor	5	5	NA*	5	5	4	2	5
SRM**	7	CAPEX needed for new technologies	5	4	NA*	1	NA*	3	3	5
SRM**	8	Quality of finished products if secondary raw materials are used	5	5	NA*	1	5	4	3	5
SRM**	9	Transaction costs	4	4	NA*	1	4	2	1	3
SRM**	10	Long Term impact	4	3	NA*	1	5	3		5
SRM**	11	Logistical aspects (geographical proximity)	3	4	NA*	3	5	2	1	5
SRM**	12	Volatility of supply	4	5	NA*	2	5	2	4	5
SRM**	13	Cooperation and coordination with different actors	4	4	NA*	1	5	2	2	3
SRM**	14	Specificity of industrial sites	4	4	NA*	1	5	3		5
SRM**	15	Norms forbidding the use of hazardous materials	4	5	NA*	5	5	5	2	5
SRM**	16	Cost reduction/Revenue increase	4	5	NA*	3	5	4		4
SRM**	17	Investment opportunity	4	4	NA*	1	5	3		5
SRM**	18	Creation of new jobs	1	5	NA*	1	5	2	1	5
SRM**	19	Development of nearby area	2	4	NA*	1	5	4	1	4
SRM**	20	Green legislations	4	5	NA*	4	5	5	3	5
SRM**	21	Incentives on materials reuse or taxes on virgin raw materials	4	4	NA*	1	5	5	3	5
SRM**	22	Community involvement	3	4	NA*	1	5	2	3	4
SRM**	23	Reduction of disposed waste and preservation of natural resources	4	4	NA*	1	5	2	1	5
SRM**	24	Air quality and community health concerns	5	5	NA*	1	5	2	2	5
WMGT ***	25	Composition of waste generated by the company	5	2	5	3	5	4	5	4
WMGT ***	26	Availability of technology	4	NA*	1	3	5	4	4	4
WMGT ***	27	Standardization of technology	4	2	1	2	5	3	3	3
WMGT ***	28	Development of a digital platform to exchange waste	1	3	1	1	5	3	2	4
WMGT ***	29	Disposal cost	5	4	5	5	5	4	3	5
WMGT ***	30	Awareness about environmental damages resulting from incorrect disposal	4	5	5	4	5	2	2	5
WMGT ***	31	Green legislation	4	5	5	4	5	5	3	5
WMGT ***	32	Authority support and control	5	4	4	5	5	5		5
WMGT ***	33	Long term impact	4	3	5	5	5	4		5
WMGT ***	34	Logistical aspects (geographical proximity)	4	3	5	5	2	3	3	5
WMGT ***	35	Cooperation and coordination with different actors	3	3	5	4	5	3	2	4
WMGT ***	36	Company's green image	4	5	5	5	5	2	2	5
WMGT ***	37	Norms forbidding the use of hazardous materials	4	3	1	5	5	4	2	5
WMGT ***	38	Investment opportunity	4	4	3	1	5	3		4
WMGT ***	39	Community involvement	4	4	NA*	5	5	3		4
WMGT ***	40	Fines and sanctions	5	4	5	1	5	4	3	5
WMGT ***	41	Reduction of disposed waste and preservation of natural resources	4	5	5	4	5	3		5

*NA: Non applicable to the company's process ** SRM: Secondary RM reuse ***WMGT: Waste Management
Regione Lombardia did not provide an answer for all of the factors

It can generally be said that the **results of factor selection were positive** as, by computing a simple frequency analysis (figure 4.8), it is clear how most of the factors have been classified as high impact ones by the companies. In particular, 72% of them were evaluated with a value higher than three and there has been an overall low percentage of factors that have been evaluated as "non applicable" (2% without considering Lagalla).

About this manner, there has been a further distinction as **Lagalla** has not evaluated any of the factors of the first process since they do not deal with secondary RM but rather only purchase virgin ones (Section 4.3.1).

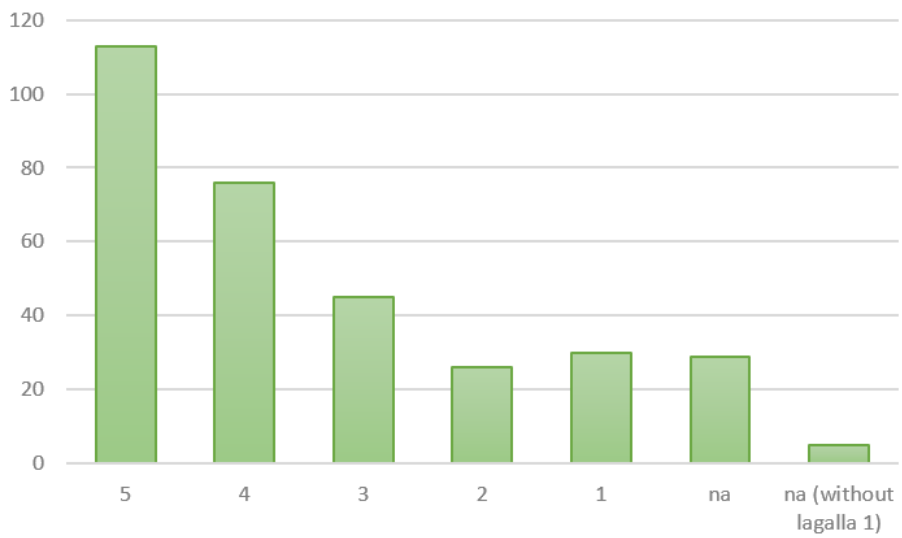


Figure 4. 8 Frequency Analysis of answers from the survey

The following graphs (figures 4.9 and 4.10) rank factors of the two processes according to their evaluation. In general, factors that have an immediate impact on company's activities, that mostly concern **economic or normative aspects** have been evaluated as the most impactful in both processes while those that entail advantages that are less obvious or visible, were generally ranked as less important. This tendency has also been discussed with ARUP since, as a consultancy company, it deals with many clients with different preferences. In general, most of their clients, only tend to focus on cost or time drivers and seem to not tend to consider others that may result to be beneficial in a less obvious way.

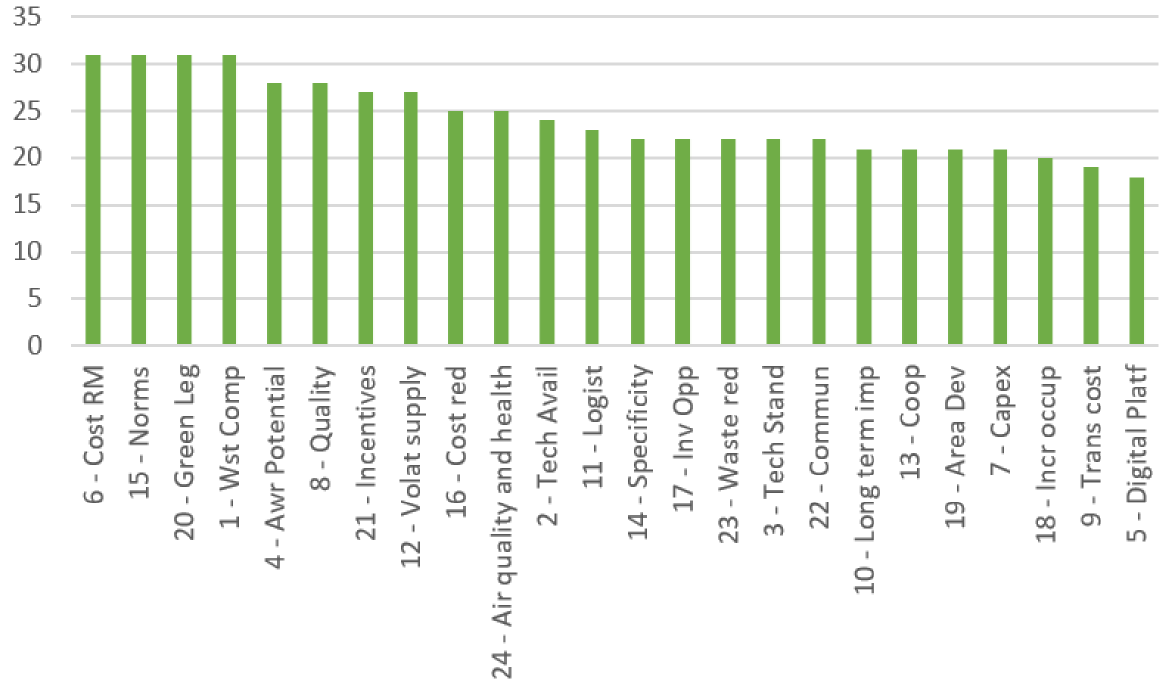


Figure 4. 9 Most impactful factors for the secondary RM reutilization process.

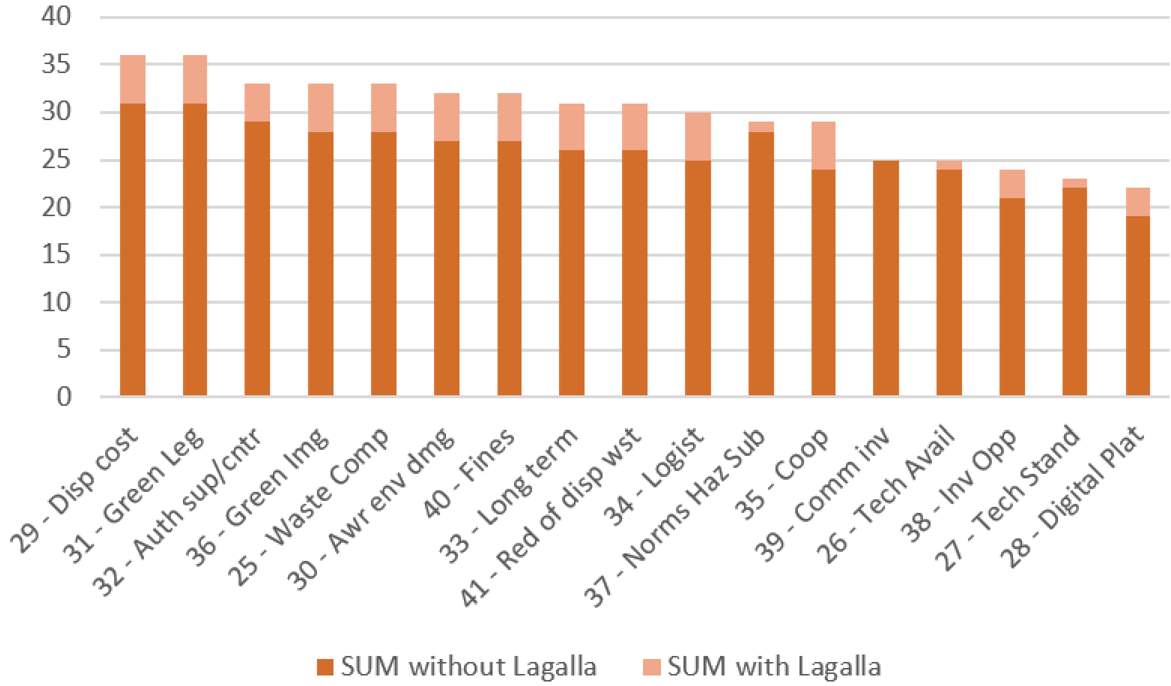


Figure 4. 10 Most impactful factors for the Waste management process.

To analyse which of the two processes was believed to be more impactful, a comparison between Secondary RM reuse (input side) and waste management (output side) is hereby proposed. To provide a fair situation and improve comparability, two adjustments had to be made:

1. Only those factors that have been included in both processes have been considered.
2. As Lagalla only provided answers for waste reuse, they have been excluded from this comparison.

In general, data shows that the **process that is believed to be more impactful** on companies' activities is waste management. This is related with the tendency, supported by institutions, and verified by Literature, to give a greater importance to what comes out of the company rather than what goes in. This means that a greater attention may be placed on waste production and trying to reduce waste rather than raw materials reuse. Various reasons, both internal such as the lack of a long-term vision, and external such as the need of appearing "green", support this behaviour and have been further explored in section 4.4.1.

Table 4. 4 Comparison between Secondary RM substitution and Waste reutilization processes.

Factor	Process 1: Secondary RM reuse	Process 2: Waste Management
Composition of waste from other actors /the company	31	28
Availability of technology	24	24
Standardization of technology	22	22
Development of a digital platform to exchange waste	18	19
Cost of raw materials, energy and labor / Disposal cost	31	31
Long Term impact	21	26
Logistical aspects (geographical proximity)	23	25
Cooperation and coordination with different actors	21	24
Norms forbidding the use of hazardous materials	31	28
Investment opportunity	22	21
Green legislations	31	31
Incentives on materials reuse / Taxes on disposal	27	27
Community involvement	22	25
Reduction of disposed waste and preservation of natural resources	22	26
SUM	**346**	**357**

After these general considerations, an initial idea of companies' perspective can be built. The topic is further explored in the next section where individual factors are discussed.

4.4 Discussion of findings

4.4.1 Influencing factors

This section examines **the perspective of actors** with respect to some of the previously factors mentioned that have been discussed with companies. The objective here is to clearly understand what the current situation on UIS is and, by building upon literature findings, determining a starting point upon which institution and researchers can further work. It would have been good to have more responses to work with but due to the reasons that have been explained in section 4.0, the amount of available data was limited. To try to solve this issue, given that 7 responses do not make a large enough statistical pool, a joint publication by **ARUP and the Ellen MacArthur** foundation, based on more than 100 stakeholders has been used to add some data (ARUP 2018)**.** Moreover, many useful insights that were obtained through one-to-one interview have been included and largely contribute to the result.

Waste composition (from other actors or from the company). As already mentioned, the composition of waste strongly influences its recovery process. In this sense, a tradeoff can be found as waste that enters a company should be as homogeneous as possible in order to simplify recovery operations while on the other side it should be more heterogeneous in order to allow more variety of use. On the input side (waste that is reused as secondary RM), the field search, has highlighted that companies tend to prefer to have a lower number of types of waste in order to ease operations. This is understandable as, especially in the initial phase of UIS, efficient internal protocols still need to be developed in order to properly deal with secondary materials without damaging the quality of final products. In this sense, Acciaieria Arvedi can be considered as a starting point. As a matter of fact, over the years they have been able to develop a system that categorizes waste into different families. In order to be classified into one of these families, each metal scrap has to have specific requirements. This level of organization and standardization is fundamental to preserve the quality of the finished product as each of these families requires different quantities of virgin raw materials to be added in the system. If the quality of the finished product is high, it

means that waste can effectively substitute virgin RM. This factor has been further considered in the discussion of “Quality of finished products”.
As for the Output side, the composition of waste generated by the company has received an equal level of attention. In this case too, companies have identified this factor as one of the most influencing ones for their activities. This is mostly not a matter of increasing recyclability and the possibility of reuse but rather related with the “normative” sphere that has been explored later in this section.

Green image: Green image has been evaluated as one of the strongest barriers for waste management. As the environmental attention of consumers has increased, especially in the last years, companies are trying their best to be, or at least appear to be as “green” as possible. This, together with the complexity of some industrial processes and their high perceived environmental impact, may result in low acceptance rates of companies, especially those dealing with waste. This is referred as the “not in my backyard” effect (NIMBY) where people oppose to an activity carried out by an actor only because it happens close to them while they would not care if it were in another place. We discussed this issue during the interview with Holcim and from their perspective, acceptability, especially connected to the use of SRT is the main issue for the development of UIS systems. The topic has been further debated in section 4.4.2.

Availability and standardization of technology: Both factors have surprisingly been classified as low impact ones by the respondents both for Secondary raw material and Waste reuse. This is probably due to the fact that, at least for the actors that have been included in our work, extensive know how on processes, technologies and machineries is already widely available and consolidated. Moreover, raw materials that are used in these industries are easily substitutable and the use of these secondary materials does not require different machineries than normal.
If availability of technologies is a factor that is understandably considered as a low impact one, standardization might still be wrongly overlooked. As a matter of fact, the more there is the tendency to pursue standardization inside of the boundaries of the company to fasten processes and increase quality, the less this good practice tend to be enlarged to the network of partner companies. However, the more actors produce, collect, and dispose in a

standardized way, the easier the recover activities become and the easier it is to implement UIS. This push for standardization has to be mostly carried out by large enterprises as they are the only ones that can set the rules to which other companies have to agree.

Digital platform to exchange waste: The creation of a digital platform to exchange waste can foster the maximization of value of wastes produced by companies and increase demand for secondary RM, one of the problems that has been later discussed in the Supply/Demand volatility section. Positive examples of such systems have already been experimented around the world, discussed by Angela Neves (et al. 2019), and in Italy both in the Marche region (Marconi et al. 2018) (Section 2.5.1) and in Sicily (Luciano et al. 2016). Some experiments are also being carried out in Lombardy with MarketInerti (in which Rete Sand has been involved in the testing phase), Edilgo (still in its testing phase) and Ecomateria platforms. We have had the opportunity of discussing MarketInerti, that among the three is the closest one to launch (forecasted in the next weeks) in the interview with Regione Lombardia. This platform allows actors to signal their availability of materials and specify their features and by doing so, potential buyers can verify their needs and purchase materials (the contractual part is however carried out outside of the platform). The theoretical premises are good, but an initial trial period is necessary to evaluate actor's involvement and the potential of practical applications.

An additional successful example that has particularly been discussed in one of the interviews (Rete Sand) is the Excess Material exchange, a fully digital platform developed in the Netherlands that, through an internal marketplace effectively finds high reuse options for materials and wastes. The main limitation of all these systems is that, due to the fact that they are still a novelty and still in an embryonal phase, they fail to account for urban flows and benefits that may stem from their inclusion. In this study, this factor has divided respondents between those that believe that it may have a great impact (Colacem and Feralpi) and those that do not (Arvedi and Special Rubber). In the interview with Arvedi the topic has been further explored and their belief is that, despite their success in Europe, with the current Italian regulatory framework and bureaucracy, such systems would not work properly, and their potential would not be fully exploited. Moreover, there is an issue concerning quality too. In order to be sold on such platforms, materials need to have specific requirements that need to be certified meaning that the complexity of the whole system

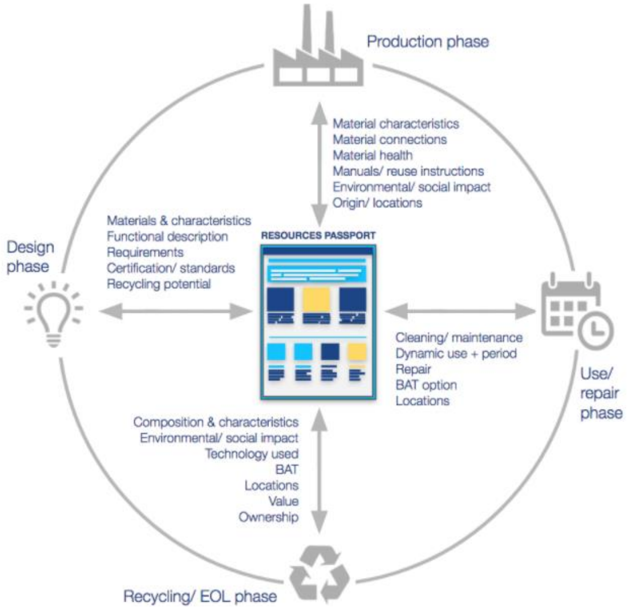


Figure 4. 11 Resources passport (taken from Resources Passport).

sharply increases. This would also require every producer to track each material and record its characteristics. Standardization may help to solve this issue by providing specific "categories" of materials that may ease the exchange flow of materials. An instrument that could be used to simplify the process of data collection is the resource passport. Resource passports are instruments that allow the tracking of materials and their residual value along the whole supply chain. A resource passport gives an identity to waste. Information about the material is stored in each step of its life cycle. In this way, when the material is ready to re-enter the "loop" and be reused, complete and precise information about it is already available. This solves the problem of standardization (at least for quality) and, together with the digital platform may strongly facilitate the process of waste reuse. Figure 4.11, taken from the official resource passport website (Resources Passport) shows how the system works.

Cost of raw materials / Energy / Labour and disposal cost: These two factors have been discussed together as they both represent the major source of economic savings connected to the two processes that have been analyzed. Coherently with what was expected, these processes have been voted as the most impactful ones by respondents with an almost perfect "score". This is important because it further highlights how companies are used to evaluate a new proposal or system mainly based on the economic advantage that it provides, and consequently how important it is to develop a system that is both environmentally and economically beneficial. Moreover, calculations in the Macro Case (section 3.3.2) show that as the price of substituted RM tends to be quite low for these sectors, while the cost of waste disposal is non negligible the advantage is even higher. Also, the considered sectors are all classified as Energy intensive sectors and consequently, overhead costs savings (such as the cost of energy) play a great role too. Quantitatively calculating exact savings is almost impossible but for example, considering that the energy needed to produce clinker is 99% of the total energy used (Italcementi SR) and that the former is equal to more than fifteen TJ per year, substituting clinker (even in a small percentage) with a product that is ready to be used should entail huge benefits. Labor cost may have a decent weight too if all the activities not needed to transform virgin RM would be accounted. However, considering the high level of automation that usually characterizes these sectors, labor cost is deemed to have a lower impact overall. Although, an improvement may be made under the time perspective as the cycle time (defined as the time needed to transform a RM into a finished product) may be shortened.

Quality related to production: intended as the lower quality that might arise from the re-utilization of by-products/waste in production to replace fresh new RM. Quality is always a difficult parameter to estimate as it is strongly based on the perception of who uses the product and consequently very few studies effectively tackle this issue. Quality of the finished product may be the most important driver to obtain a competitive advantage for some actors and is also what customer use to evaluate companies. Consequently, most manufacturers are not willing to give a higher level of quality up in exchange for better environmental performances. This means that, as it has been verified with Rete Sand, companies may be reluctant to use certain secondary RM from waste without an assurance of the quality of finished products obtainable.

When the questionnaire was initially created, this was feared to be a strong barrier to the development of UIS systems. On one side, the impact of this factor has been confirmed by the results of the questionnaire as almost every one of the answers was a 5. However, on the other side, approached companies said that despite its high impact on companies' activities, quality is not a huge concern in a sense that over time, through extensive R&D, a precise limit to the amount of secondary RM that can be added to the recipe of the finished product without affecting its features has been developed. As an example, steel can be produced a maximum of 80% secondary RM and 20% virgin ones (Arvedi Interview). Colacem and Holcim can even fully substitute some virgin materials with secondary ones without affecting the quality of the finished product. With these considerations it is clear to see how, if quality may have been a barrier in the past, nowadays, at least for the C&D sector, this situation is not a concern anymore. Moreover, these percentages, and in general the quantity of secondary materials that can be added to the final product have been growing year by year, and thanks to new technologies and materials that are being developed, will continue to grow in the future. Obviously, a structural limit will be reached somedays, but still the advantages that will have been reached at that point will be huge.

Quality may be an issue for the reuse of construction materials if proper techniques are not adopted. These include a series of good practices to be deployed throughout the whole supply lifecycle, from the design to the demolition phase. As an example, *Design for disassembly* that has been later discussed connected with the long-term vision of actors, and proper *selective demolition* techniques that have been discussed in section 4.4.2 need to be put in place in order to ensure that high quality materials can be recovered from buildings and therefore effectively used.

Long Term impact: This factor has been evaluated very differently in the two processes. It has received one of the lowest values for the process of secondary materials reuse while it has been classified as one of the most important ones in waste management. This testifies even more how companies tend to be more focused on the impact that their waste has on the environment without considering that the input side and resource depletion matters just as much. This is especially valid for C&D companies and from the interview with ARUP this behavior was confirmed. As a matter of fact, on one side there is the increasing trend of trying to adopt practices to reduce the overall waste produced, while on the other side clients may be reluctant to change something to allow ease of reuse in the future. Also, new technologies and materials may prove to be detrimental in this sense by amplifying this behavior. As an example, the extensive use of *glue* both reduces the amount of waste that is produced (for example by avoiding the usage of nails) while on the other side it increases the complexity of the disassembly operations and reduces the amount of wood that can later be recovered and reused as secondary RM. The same concept is valid for steel: making a client understand that using bolts instead of welds will generate a benefit overtime is quite difficult as companies tend to have a short-term perspective. The ease of disassembly, needed to "create" reusable secondary RM, is not a criterion that can foster the long-term vision of a client, or at least it cannot do it by itself (ARUP interview). Institutions are needed to put this vision in place. As a matter of fact, they are responsible of this "non consideration" of resource depletion as much as companies are. Overtime many requirements and

certifications have been introduced to foster the use of secondary raw materials (such as the CAM for public procurement or the LEED certification) while there are no specific requirements on the reusability of resources after demolition operations (interview with Regione Lombardia). Through this behavior, on one side companies are required to reuse materials while on the other side nothing is done to guarantee the availability of quality materials. It is clear that, if companies are left with the choice of whether to consider disassembly operations or not, only based on their own vision without setting some specific authority objectives or requirements, it is less likely to happen.
The habit of companies of not considering the long-term impact of their operations is also connected to the fact that oftentimes waste disposal costs are not paid by the actor that finances the project and therefore it may not be considered as its own problem. This topic will be further discussed in the Taxes and incentives section.

Supply Volatility and existence of a market: intended as the rate at which material and waste flows are stable or unstable over time. This is obviously only related to the process of secondary raw materials' reuse. In general companies have ranked this flow as a medium impact one in the questionnaires and only Special Rubber has evaluated it as low impact. The volatility of supply is indeed considered as a very strong barrier for UIS in Literature. However, being Lombardy a heavily industrialized region, the presence of many industries, most of which manufacturers, may result in a larger production of waste that in turn could determine a higher supply for companies and a lower risk of shortages. During the interview with both Rete Sand and Regione Lombardia the topic has been extensively discussed and according to them, the problem lies in the unavailability of demand rather than supply. This is related to the fact that, especially for C&D, secondary materials' prices (excluding metals) are actually close to virgin ones, meaning that economic advantages from their substitution are very limited or even absent (as it has been demonstrated in the macro analysis) and consequently their demand is depressed. This issue has also been confirmed by Holcim that has also highlighted how permits to deal with waste concur to inhibit demand. On this topic, Rete Sand said that, adding to what has been said in the paragraph concerning the Regulatory framework, existing legislation only allows three paths for recovered waste: environment recovery, backfilling activities, and secondary RM for Construction. However, the requirements on the former (the one that is most interesting from our perspective) are too strict and rarely recovery plants are able to meet them. Also, requirements are unique and undifferentiated according to the final destination of the secondary C&D RM (ex: the same requirements are asked to use secondary RM in a project for a landfill or a school). This results in an oversupply of many materials that are effectively recovered but cannot be used due to a shortage of demand. As a matter of fact, by looking at national and regional waste recovery percentages (71.5% for C&D - ISPRA 2020) the availability of supply is confirmed while its actual usage is still low.

Geographic location: It is one of the most highlighted, important, and discussed factors in literature. Geographic remoteness may act as a barrier by negatively impacting the benefits of UIS and even canceling them. The topic has been discussed in the interview with ARUP and what has been found is that, even if the differences in terms of performances between a virgin product (such as Portland cement) and a secondary one (such as cement made by substituting limestone with flying ashes) are very low or even absent, a client may decide to go for the virgin one because overall, savings from substitution are compensated by the increased transportation cost.

However, in Lombardy, distances between most companies are lower than 250km and as observed from the calculations of the Macro Analysis this has an extremely reduced impact on the overall result (less than 4% on the overall impact for most symbiosis). Also, the same considerations about the degree of industrialization of the region that have been made above can be applied in this case too. In addition, Lombardy can boast a strongly connected and well-designed transportation network (roads, railways and waterways) that can surely contrast the negative effects of geographical distances. Consequently, especially in the advanced phase of UIS, where many companies are involved, transportation distances should not be a problem for actors. All these considerations are reflected by the low/medium impact rating that has been given to this factor by most of the companies.

Also, as mentioned before, short distance (such as the ones that separate these companies) are more likely to facilitate relationships between actors and to build trust among them. The creation of these relationships may evolve into UIS systems with time as explained in section 2.4.

This is also related with another factor that has been included in this research: **Cooperation and coordination between actors**. Overall, companies seem to understand the importance of cooperation and trust between actors of the supply chain to build a UIS system. All the companies but Special Rubber have evaluated this factor as a high impact one. However, from the interview with Rete Sand it was verified that oftentimes the importance of collaboration is advocated with words rather than actions. As a network of companies working together to create value for everyone, collaboration is one of the bigger pillars at the basis of the Rete Sand project. However convincing firms to work together rather than as single entities and share information is oftentimes very hard and rather unfeasible.

On the other hand, once the process of collaboration starts, positive results are gained for all of the involved actors. Holcim works as an example, as through the years it has established a strong partnership with many suppliers that now means that those suppliers can be trusted more, and this entails strong benefits for both actors (Holcim interview).

The observation that can be made in this sense is that large actors in virtue of their consolidated power and strong influence, may be keener to establish relationships with other companies as they would better be able to influence their decisions. However, this influence could even be beneficial for both actors, as imposing certain standards to suppliers that have to be met, pushes them towards efficiency and may be useful especially for SME that otherwise may be left behind.

Also, many stakeholders from ARUP's report (ARUP & Ellen MacArthur 2018) said that the fact that CE is not diffused in the built environment is partly due to the fragmented and uncoordinated nature of the industry that separates decision makers from the consequences of their actions. An example of this is disposal cost, that has been later explored in the "Taxes / incentives and Fines" paragraph.

An innovative company culture based on cooperation and coordination may result to be a driver to change rather than an obstacle. Having a whole supply chain that works together as one single entity rather than as a series of companies fighting for market share may contribute to the creation of an effective green image for customers and institutions that may increase competitive advantage for the members of the supply chain.

Awareness about the potential of waste reuse: As ARUP's report (ARUP & Ellen MacArthur 2018) suggests, stakeholders throughout the supply chain remain insufficiently familiar with how CE principles could be applied to the build environment. In this research most of the companies showed to be aware of the potential of reuse but one. The same consideration that has just been made for cooperation still stands here. As a matter of fact, stating that a company is aware of the potential of waste reuse is extremely different that actually being aware.

The interesting thing is that the only company that did not showed awareness is the only small company that has been involved in the study. This is perfectly in line with what is found in literature, where most large companies tend to be in line and to recognize the impact of awareness on UIS systems while SME tend to fall behind. As a matter of fact, SMEs often perceive environmental protection as a burden instead of something that provides ‘‘added value,’’ or a way to affirm public image, or a means to gain a larger share of consumers who are partial to the environmental quality of the products (Ardente et al. 2010). This low level of awareness also translates into a reduced know how on environmentally friendly building practices and an inability of satisfying requests on the matter.

Solving this issue and increasing awareness and the knowledge of this category of actors is crucial in order to reach the critical mass (intended as the number of users needed for significant network effects), especially in a region like Lombardy where most companies' employees less than 10 people (ISTAT).

Regulatory Framework: This paragraph discusses all those factors that concern the regulatory framework and the existing norms regarding waste and reuse practices. Discussing this matter is extremely important as companies have classified the factors included in this category amidst the most impactful ones. As a matter of fact, green legislation and authority control are among the top 5 most impactful factors for waste reuse while norms concerning the use of Hazardous materials and Green Legislation are among the top 3 for secondary RM. There are three levels of the regulatory framework that can be discussed: European, National and Regional. A detailed description of them goes beyond the scope of this work. However, a brief discussion of is necessary in order to understand the perspective of the involved actors and therefore a summary of some of the norms that have been adopted overtime is reported in the following table. The first column concerns EU directives while the second one is the translation of such directives in the Italian framework.

Table 4. 5 Waste Regulatory Framework Overview

EU	IT
CE 75/442 CE 78/319	DPR 915 10/09/1982
91/156 CEE 91/689 CEE	DLGS 22 05/02/1997
/	DLGS 152/2006 Part 4
Waste Framework Directive (2008/98/EC)	DLGS 116/2020
CE Package (2018)	/
Green New Deal (2020)	/

The first norm adopted about waste management at the national level was in 1982 as a translation of the CE 75/442 concerning hazardous waste and the CE 78/319 concerning waste in general. The focus of these norms was the promotion of techniques to destroy waste without effectively trying to capture its value. It was only 15 years later, in 1997, with the 91/156 and 91/689 that recovery and recycling operations started to be treated as more important than disposal. In 2006, with the approval of the DLGS 152/2006 waste management has been grouped together with other environmental norms in what is commonly referred as *"Testo unico ambientale"* (environment code), without radically changing the perspective of the previous law. Overtime, in EU there have been some norms that concerned this issue: Prevention rather than action has become a fundamental part of the European strategy with directive 2008/98, later substituted by directive 2018/851 and translated at the national level in 2020 while both the CE package and the new Green Deal partially tackled the problem of waste without having a normative value. However, at least at the national level, what this brief history of waste management norms in Italy demonstrates is that waste is still mainly managed through norms that are almost 25 years old. This is not the only problem as companies, in accordance with what has been found by Iacondini (et al. 2015) also highlighted that the regulatory framework seems to be more severe and complex in Italy than in the rest of Europe. Also, the absence of precise selective demolition norms and standardized practices is a strong barrier to the process.

This topic has been further discussed in all the interviews and the answer of respondents has always been the same: the regulatory framework is old, complicated (and in some cases contradictory too) and is the strongest barrier to UIS development. In general, the DLGS 116, has been a good attempt to try to renew an outdated system that clearly does not reflect the needs of current industrial actors by better clarifying the priorities and the value of recovery activities. However, there is still a long way to go before being able to fully exploit UIS systems and their possibilities and that cannot be done without a complete redesign of the regulatory framework on the subject. Another issue that was highlighted by interviewees and also mentioned in ARUP's report (ARUP 2018) concerns waste management permits and the definition of" end of waste". As it should be clear by now, UIS systems are based on the exchange of waste and to do so, a clear definition of when a product becomes a waste is needed to allow actors to safely deal with materials. The topic has been addressed with Regione Lombardia and the delay of norms and their complexity at the national level has been confirmed as well as their need to start UIS.

Also, according to the Dlgs 152/2006, companies cannot directly manage scraps and waste unless authorized. Although, according to companies, the authorization process, granted at the regional level upon verification of the ministry of the environment is long and complicated and oftentimes does not lead to a success. As a matter of fact, processes, and materials for which an authorization can be released are included in article 28 of the DLGS 22/1997. It is easy to understand that this may not allow the authorization of innovative waste management activities.

A clear paradox is therefore present as on one side, the EU pushes to introduce new strategies to pursue circularity of industrial systems while on the other side, national and regional policies fail to drive this change but rather act as a barrier. In conclusion the perspective of actors is clear: without a revised and updated regulatory framework UIS systems cannot be feasible for companies and therefore cannot exist.

Taxes / incentives and Fines: Even if these factors could be considered as part of the normative sphere and thus included in the previous paragraph, they have been discussed separately to highlight their importance. As it was expected, they were evaluated as high impact factor by almost all the interviewees. This is connected to the fact that, as already mentioned, there is the tendency to give higher importance to those factors that have an economic impact on companies' activities. Incentives may be used to promote the usage of secondary raw materials and even balancing the price differences between them and virgin ones in those cases in which the former turns out to be less expensive than the latter. As it was confirmed in the interview with Rete Sand, incentives are not available for recovery of specific materials but are only granted through occasional tenders related to innovative CE projects. Conversely, taxes are an effective instrument to transfer the disposal cost between actors. As a matter of fact, in Construction contracts, the cost of disposal is generally a responsibility of the general contractor rather than the client. This means that the client is less likely to take this aspect into consideration during the project.

This is not only valid for construction companies. A fine system that “limits” the disposal of waste may make the companies more “imaginative” with their flow and may result in higher materials recovery through UIS practices. Obviously, trying to confront companies about this is hard as they would like to be given the choice of whether to dispose or recover waste according to their necessities. It is also probable that eventually, with time, every company would increase the percentage of waste that is recovered through technology advancements, but incentives, taxes and ultimately fines, are the most effective way to speed up the process.

4.4.2 Flow chart: UIS Network

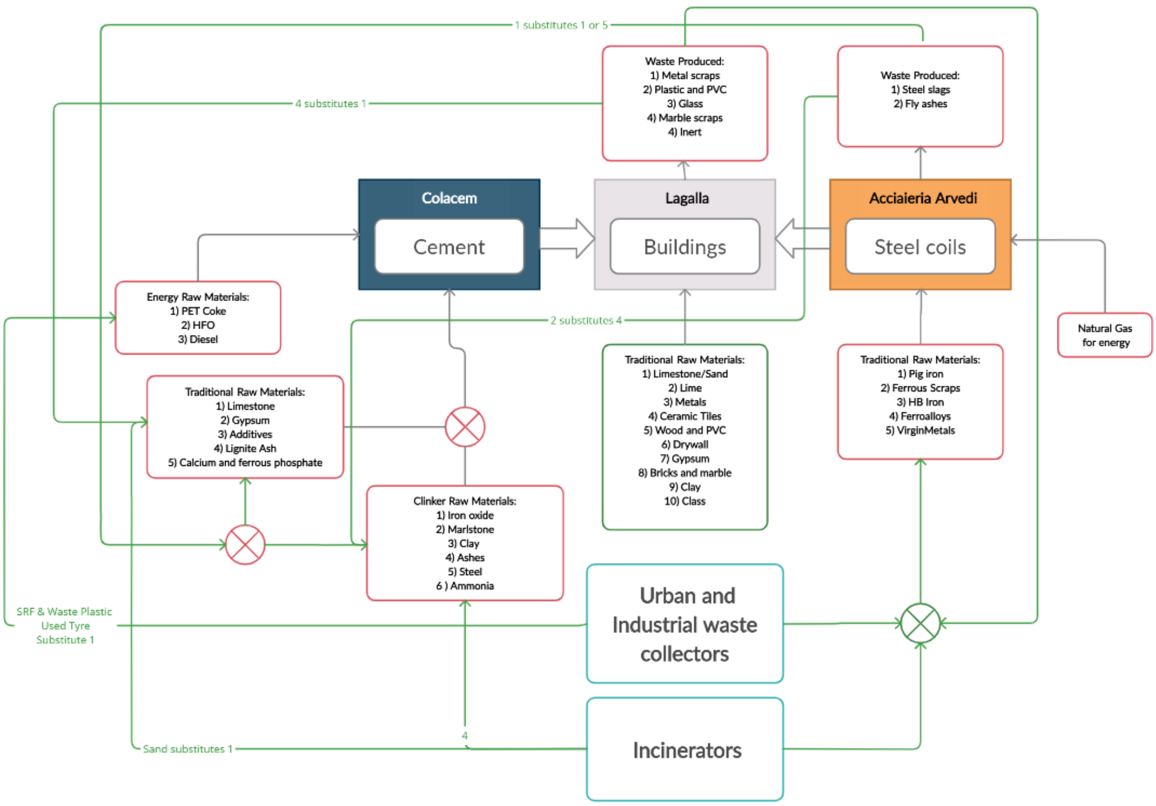


Figure 4. 12 To-be flow chart of material and waste.

The objective of this section is to discuss the nature and the feasibility of UIS links applied to the micro case scenario. The nature has been explored on the basis of data from Literature on previous successful examples, while the feasibility of flows is related to the analysis of D&B included in the previous section.

For ease of discussion purposes, this section has been divided into three parts, one for each company/sector, where raw materials and finished products flows are reviewed, and changes are discussed.

Cement: Starting from finished products, cement production is already a virtuous example in terms of materials recovery through the so-called co-processing as the inert portion of waste (ashes and slags) generated during their combustion, is fully recovered as raw materials becoming part of the final product. This is also true for energy RMs as every fuel turns out to be composed by two parts: one that supplies the thermal energy needed and the other one (inert) that, through mineralization reactions, is incorporated into the clinker (Holcim interview).

In terms of raw materials reuse, existing symbiosis with other companies are already extensive and include the reuse of steel slags from metal industries and the reuse of fly ashes (mainly from power plants). Examples of these substitutions, carried out by Colacem are (Colacem Rapporto di Sostenibilità 2019):

1. Steel slag coming from steelmakers to substitute iron oxide content in clay.
2. Ashes coming from nearby power plants that can be used to substitute natural pozzolana.
3. Heavy ashes from biomass or waste incineration to substitute aluminium or iron content in clay.

The secret to this ability of reusing materials and producing no waste is connected with the necessity and availability of a **cement Kiln**. Through this instrument that brings materials to almost 1500°, and that is able to "destroy" the chemical composition of materials and then "recreate" the minerals needed in the clinker (Holcim Interview), a portion of waste that cannot be directly reused in many processes can be used (such as white slag). As a matter of fact, rather than using materials for their chemical composition (intended as elements combined together), and properties, such as a substitution of limestone with ashes where the latter are simply mixed in the content, in the kiln, materials are employed for their chemical elements that are then recombined in a new composition.

However, the cement kiln is a **double-edged sword** as on one side it allows vast reutilization of materials while on the other side it needs huge amount of energy to function.
Discussing raw materials that are used for **energy** and possible ways to get them through UIS links is fundamental. The cement industry is an “energy intensive” sector and is responsible for a huge amount of energy consumed each year. For Colacem, this mostly comes from Heavy fuel oil, industrial diesel, and Coke, while a limited amount of it is generated from urban waste while Holcim uses fewer virgin materials and has a thermal substitution rate (defined as energy from waste over total energy) between 70% and 80% (Holcim interview).

To partially solve this issue, new forms of energy that come from the recycling process of materials need to be found. Two symbiotic links, that are already partially adopted for Colacem and extensively used in Holcim have been proposed in this work: SRF and Tyres.

Solid Recovered Fuels (SRF) are highly heterogeneous mixtures generated from high calorific fractions of non-hazardous waste materials intended to be fired in existing coal power plants and industrial furnaces (Dunnu et al. 2009). The usage of these fuels has increased in the last decade and their environmental benefits have been largely proven in literature. The 2020 IEA Bioenergy report on “Trends on use of solid recovered fuels” shows how Energy intensive industries have increased their demand of SRF over time and the same report forecasts an increase in the consumption of such fuels in the next years. As for feasibility of the flow, this has been extensively discussed with Colacem during the interview and, despite the strong benefits of SRF under the environmental perspective, some drawbacks have been highlighted:

1. The first problem concerns **quality and the composition of waste**: different types of SRF are not equal and the properties of the final product strongly depends on its composition. In general, to have a high calorific power, the highest the amount of plastic is needed. On the other hand, a low quality, other than a reduction of the heat generation performance may even damage the cement Kiln. As cement Kilns are among the most expensive components of the process, a damage to them would mean a huge economic setback and a loss of trust in the energy source. The problem with quality is that there is no way to exactly verify it before consuming SRF and consequently companies simply must trust their suppliers**.** The choice of trustworthy

suppliers allows the company to obtain high levels quality constantly, a necessary condition for a safe utilization of any fuel in the cement Kiln.

2. **Laws, Norms and Community Approval**: Even though SRF are correctly treated following existing regulations and they pose no harm to the environment but rather generate positive externalities, they are not positively seen by the community. Both existing Literature and the European C&D waste management protocol (ARES Protocol 2016) refer to this as the “Not in my backyard effect”, where a community opposes to a certain development or practise in an area only because it is close to them while they would tolerate it if it were not close. The topic has been discussed with Holcim too that uses these fuels in high percentages and has therefore developed advanced techniques to minimize negative externalities Still, communicating with communities and stakeholders and making them understand the potential environmental advantages connected with the use of SRF is difficult as traditionally combustion of waste is instinctively connected with filth and environmental damages.

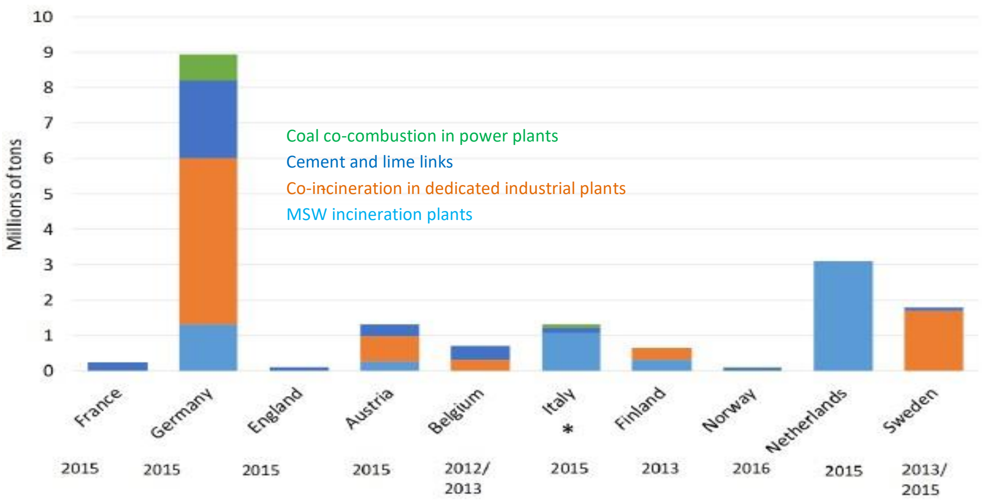


Figure 4. 13 Yearly consumption of SRF/RDF in the domestic EfW systems of some European countries (taken from 2020 IEA Bioenergy report)

This effect is evidently stronger in Italy than other countries. As a matter of fact, as figure 4.13, taken from the 2020 IEA Bioenergy report on “Trends on use of solid recovered fuels” (Matignon 2020) shows, while the use of SRF in industries in Italy is encountering high barriers, Germany, Belgium, and Austria promote the extensive use of this fuels in industrial contexts. In Italy, most of the available SRF enters the fuel mix for MSW incinerators while a very low percentage is used by companies.

This is due to the fact that the authorization necessary for companies to deal with these wastes only allows the consumption of a very limited amount. Also, the authorization is quite stringent as it grants the usage of a certain quantity of materials per hour rather than setting a daily limit. This means that if on a certain time of the day actors are not able to use the allowed limit of SRF (for example due to technical difficulties or shipment delays), they miss the opportunity to increase their usage the next day. In conclusion, this mimics the same "behaviour" that has been verified before where on one side, EU pushes for the consumption of recovered materials, while on the other, local communities and national laws act as a barrier.

3. **Supply volatility and Technology**: Differently from coal, which is always available on the market, the availability of SRF may vary strongly according to many variables such as availability of closer suppliers, delay of deliveries or unavailability high quality fuels. This is also because current technologies cannot support the extensive use of SRF over coal but rather only work when a certain percentage of the two materials is mixed. The problem of supply availability may be overcome in the future, with an increase in the number of waste treating plants that are currently a limit (170 in Italy (Matignon 2020)). The same applies to technological limits that may be overcome with the development of new and more advanced waste treatment plants.

The other source of secondary RM that may be used for energy production is **Tyres.** Using tyres for energy production is the cleanest way to recover their value. As a matter of fact, Tyres have a very high calorific power, even higher than the traditional pet-coke (EPA 2018) and their recovery as energy is a fundamental component to close the loop of these materials that would be difficult to recycle. Each ton of tyres used to substitute a ton of coke can both save one ton of Co2eq emitted in the atmosphere and avoid the consumption of 210kg of virgin raw materials (Holcim Italy). Differently from SRT, this is a process that is more mature and feasible now. As a matter of fact, it does not suffer from quality issues or technological limits and it is also less subjected to supply volatility resulting to be a win-win scenario for everyone. The availability of used tires as well as waste from production activities is high. Holcim makes extensive use of tyres as alternative fuels through a company called Geocycle, that is responsible of looking for alternative fuels to be used in the process. The unusable portion of shredded waste tyres is collected through various platforms managed by EcoPneus an Italian consortium managing tyres EOL and delivered to the Ternate plant that uses them to produce energy (Holcim interview). By recovering materials first and then energy with the unusable portion, the value from tyres is truly maximized.

Lagalla: Companies like Lagalla are those that may benefit more from the introduction of UIS systems. As a matter of fact, material reuse is currently non-existent as most resources are purchased from the market and sent for disposal. In line with what has been said until now concerning SME, only those materials that have a visible and know market value are sent for recovery (such as metals) while others, for which recovery is less obvious or economically beneficial are disposed. As an example, sewing marble scraps could be used to replace limestone in the production of cement instead of being used for backfilling activities, while waste plastic could be used in replacement of coke, as explained in the previous paragraph.

But what could determine a bigger change and impact on company's activities is the reuse of construction materials. As of now, all the materials that are obtained from demolition activities are disposed as they are classified as non-useful for construction. Pomponi (2017) perfectly embodied this concept in the phrase "people do not want to buy steel for their brand-new shiny building from the scrapman". The fact that the market for demolition materials is pretty much non-existent, entails disposal costs for the company that are non-negligible and high waste production. However, many of the materials from demolition activities are still usable as they still meet structural requirements. The correct application of selective demolition techniques could preserve most of the value of materials and allow their reutilization in other projects. Nowadays, according to Rete Sand, these activities are still too expensive, and they are not recognized in public procurement projects. Regione Lombardia highlighted a simple but very important issue connected with selective demolition related with the available space to stock materials on site. In those cases where space is limited, selective demolition has to be restricted to a few types of materials (mostly metals that guarantee an economic advantage) and is therefore limited.

Still, the fact that demolition materials are not reused turns out to be scarcely of a technical matter but rather of a cultural one. Regione Lombardia has characterized the cultural factor as the strongest barrier to UIS as everything that comes from the world of waste is perceived as unusable only because it comes from demolition activities.

As an example to address technical capabilities of materials, the Colosseum was built in 80 AD and still stands, while materials from fifty years' old houses are considered as unusable or too outdated. This is an exaggerated example but is useful to highlight the tendency of always wanting new things rather than reusing old ones that both directly generates unnecessary waste that is then disposed and indirectly contributes to resource depletion. In conclusion, feasibility of these reuse practises is not a matter of being able to reuse materials but rather to wanting to reuse them. Obviously both demolition practises developed to preserve materials' value and a proper regulatory framework that defines which materials can be reused are needed but mostly a cultural change is fundamental to solve this issue.

Acciaieria Arvedi: As the steel sector is already a good example of raw materials reuse, UIS is not going to radically change input composition for steelmakers. As a matter of fact, ferrous scarps are a necessary component of steel and their usage is already widely diffused.

On the other hand, the production of waste is one of the problems that mostly affect this sector. Arvedi luckily represents a good example on this matter, as intensive recovery options are already in place. In this sense a distinction must be made between hazardous and non-hazardous waste. The former, basically entirely represented by Hydrochloric acid has a 97% recovery rate (Arvedi SR) due to the presence of two big internal recovery cycles that allow the company to basically sustain itself with a very small additional injection of "virgin RM". The latter, as mentioned in section 4.3.1 is represented by 3 sources:

- Black steel slags and decapping waste, entirely sent to the cement industry to be fully reused.
- White steel slags originated from the ladle furnace, that unfortunately cannot be currently effectively reused in C&D nor other sectors due to their high unstable lime content (used to prevent finished product's impurities) and are therefore sent to pre-disposal treatment plants.
- Fly ashes that are currently collected from bag filters and sent to recover for a part of zinc oxide (20%) even if the remaining waste is still used for backfilling activities.

The overall disposal rate of these materials is 66% and in turn recovery accounts for 34% (Arvedi SR). Recovery could be increased by changing the destination of fly ashes to cement producers as clinker substitution. However, as fly ashes account for a small percentage of overall waste production (9%) their impact would not be massive.

The strongest impact could be given by white slags recovery. Unfortunately, as discussed in the interview with them, this value cannot be currently increased due technical issues rather than a company choice. As a matter of fact, due to their basicity and instability, today's technologies are not able to effectively turn white slags into usable materials. The only possible way to reuse white slags is by adding them in the cement Kiln for the production of clinker (Holcim interview). However, due to the high amount of energy that is needed, the environmental benefits may be partially offset and therefore a clear outcome of the process is difficult to be established.

In conclusion, the impact that a potential UIS network could have on Acciaieria Arvedi as a single entity is not huge. However, two considerations must be made:

- The first one is that Arvedi is "an exception and not a rule" meaning that as a steelmaking company, it is very sensitive to the environmental perspective and it tries to adopt most of the recovery operations that are feasible today. However, many other companies do not do that and if the impact on Arvedi is small because they are already ahead of times, the impact of UIS on other less advanced companies may be way bigger.
- The second one is that the advantages of UIS should be calculated in overall terms rather than on a single entity. As a matter of fact, being UIS a complex and intertwined system, benefits should be evaluated on the whole network rather than on the single entity.

4.5 Limitations of the micro-analysis

As the macro analysis, the micro analysis suffers from some limitations too. In particular

- The strongest limitation of this part is the **amount of data analysed**. 7 companies surely do not make a large enough pool to determine unchallengeable results but rather only provides a perspective of some of the actors of the supply chain. The inclusion of more companies in the future may prove robustness of results or challenge them. Also, characteristics of the involved companies are a big limitation. As a matter of fact, most of the companies but one were large enterprises. We have already stated the importance of including the perspective of SME throughout our whole work and interviewing at least one of them would have surely been a great addition to the final result.

- Quarrying activities: As remarked in section 4.3, quarrying activities have been excluded from the analysis due to unavailability of data. However, this **cut** may have limited opportunities for potential synergistic interaction among entities.
- **Qualitatively assessing** materials flows is surely effective to initially define their impact with a broad scope. However, further and deeper analysis of them that can truly highlight value for entities requires the adoption of quantitative calculations.
- The way in which the **survey has been created** entails some limitations too. As a matter of fact, to increase comparability, as well as for other reasons mentioned in section 4.1.2, companies have been required to rank factors on a scale of one to five. This was done in view of the fact that a higher number of answers was initially expected. However, this restricts the amount of information that can be extracted by the answer. A different methodology, that allowed companies to include a written explanation of concepts may have been more beneficial under this perspective.
- In the creation of a possible UIS system, even if properly discussed in the influencing factors section, **technical, contractual, or logistical limits** that may prevent flows from realizing have been excluded. However, due to the huge amount of data involved in UIS systems, taking all of these and other factors into account is almost impossible and would require an amount of time, work and knowledge that is far higher than the scope of this thesis.

5. Conclusions

5.1 Final Remarks

Both the macro and micro analysis, performed on very different levels have come together to the goal of shedding light on UIS in Italy. In the past, Italian cases had the tendency to neglect joint benefits arising from urban-industrial contexts and only focused on the former. Therefore, the first goal of this Thesis was to reverse this tendency and encourage future researchers to enlarge the scope and adopt a broader perspective.

Contributions given by the macro-analysis are related to the **estimation of the potential** that UIS practices might have in highly industrialized regions such as Lombardy. However, in order to allow the full realization of such savings, an extensive diffusion of UIS is needed. Currently, as seen from the micro case, some companies already have synergies and waste reutilization mechanisms in place but to wholly fulfil the achievement of eco-areas and sustainable environments, and to fully capture the advantages of UIS, these should be **standard practices** adopted by each company rather than some occasional good examples. This process is not as easy as one may think due to the colourful and multi-sided nature of UIS, that parallelly is its main strength and its main liability, as merging together different perspectives, different cultural and technological factors, different transportation and reutilization modalities, and different know-hows is extremely complex, requires commitment of many players and, above all, requires time and long-term vision.

To increase the adoption rate of such techniques, considering the high commitment from every actor that is needed, relying on companies' willingness to be part of an environmental change is simply not enough. Some **facilitating factors** such as an improved system of taxes/incentives have emerged from the interactions with involved actors as tangible economic benefits have been identified as the most important current driver for companies. Other than this, severe application of requirements concerning both the usage of secondary raw materials (such as the Italian CAM), that are oftentimes included in the initial phases of the project but later ignored in the actual construction phase (Interview with Regione Lombardia), and the inclusion of proper **selective demolition obligations** to ensure that materials can be properly reused is mandatory to allow the extensive diffusion of UIS. Moreover, a proper cultural evolution that can radically change both the concept of "waste" from non-valuable resource to valuable one, and as a consequence, the view of actors on secondary raw materials, has been identified as one of the necessary factors on which future UIS development paths should be based. Also, an easier, simpler, and leaner bureaucracy and regulatory framework is a necessary condition to foster UIS deployment. As a matter of fact, normative issues have been highlighted as the strongest **barrier to UIS** introduction and the responsibility of easing the burden on companies by introducing better rules, laws and bureaucracy falls on national and regional public institutions. Their role in this system should be to facilitate exchanges rather than obstructing them, yet companies find themselves in between very demanding EU requirements and unclear and unsupportive national laws. In combination with that, another "silent" factor hindering the engendering of symbioses is stakeholders' awareness, whose weight can be considered higher than technical constraints. As a matter of fact, many companies may think that their knowledge and awareness about UIS practises is high while in reality are scarcely able to precisely identify proper opportunities. A complete education of the whole supply chain is needed to allow the full realization of benefits especially considering SME that have shown to be less aware and more likely to be left behind. However, considering the high percentage and consequently high potential influence of SME in the Lombardy industrial network, designing an inclusive system to support these companies is a requirement of UIS development.

Obviously, simply considering these facilitating factors is not enough to properly define a program for the application of UIS as there is not a unique and unquestionable path leading to the former. However, some **triggering synergies**, defined as those that are easier to put in place and at the same time entail higher benefits exist, and have been explored in the macro analysis together with the most valuable sectors: results highlight how the C&D sector is among the best candidates due to the high environmental liabilities and economic burden in terms of RM supply, and properly readdressing its waste would be highly beneficial.

By relying on the aforementioned considerations, the **intent of this Thesis** has been to lay the ground for future researchers and circular economy experts by providing the spark to enlighten the vast and unexplored UIS field, especially in Italy. However, it must not be forgotten that this work is only centred around the C&D supply chain and therefore only covers a small fraction of the whole UIS sphere; in this sense, many other sectors and actors need to be properly explored in order to fully establish where to start with changes.

5.2 Suggestions for the future

Some daring suggestions, based on the little experience gained during this year of research, have been hereby proposed:

- ✓ The first suggestion concerns the already cited **regulatory framework** and it is quite mandatory, as all the interviewed actors have complained about the old regulations in place. As a matter of fact, all of the countries in which IS or UIS represent a positive example, that may be considered as a challenging benchmark, enjoy a clear, simple, solid, and well defined normative on waste The DLGS 116/2020, has been a good attempt to try to renew an outdated system that clearly does not reflect the needs of current industrial actors by better clarifying the priorities and the value of recovery activities. However, the former decree must not be the end of the road but rather the start of a complete redesign of the system. This redesign process should include regional authorities and waste authorizations too, a necessary instrument to allow actors to deal with waste more efficiently, one of the unavoidable conditions in a UIS system. Also on this matter, a clear and improved "end of waste" normative is strictly necessary to properly define when a product ceases to be classified as usable and becomes a waste.

  However, as in most of times where politics is involved, these changes are not easy to put forward. Interests of many parties, many actors, sector representatives and consumers too have to be considered and accounted for. Consequently, finding a solution that pleases everyone is difficult and almost impossible. A radical change would be lethal for both companies that may be unprepared, and institutions that may lose their consent. Due to this fact, the **"regulatory revolution"** that both actors and institutions are waiting but still hinder has to come in steps to reduce the negative impact on actors.

  In a long-term perspective, the swift translation at the national level of the European Green new Deal could be an extraordinary opportunity for development of CE and UIS in Italy. The budget law for 2020 already contains some first measures, with the establishment of a public investment fund (4.24 billion euros for the years from 2020 to 2023), intended to support highly innovative investment projects and programs concerning environmental sustainability (Circular Economy Network and ENEA 2020) but much more has to be done in the future.

- ✓ Creation of a **market**: contrarily with what has been found in literature, where shortages of materials were considered as a limiting factor, in Lombardy the problem of the exchange of treated waste and secondary raw materials does not seem to lie in the volatility of supply but rather in the absence of a proper market. As a matter of fact, the region has a very high supply of treated waste whose reuse is however hindered by many factors. Other than the normative issue that has already been cited and the quality one that has been discussed in the next paragraph, other factors concur to this misalignment between supply and demand. As an example, **geographical distance or logistic** difficulties strongly mine the creation of a proper market as transportation cost may be high enough to offset the advantages from reuse. This, at least in the first phase of development of UIS where the lack of distributed suppliers is likely to happen (intended as those companies that actively participate in the network) is a limiting factor. However, as verified in the macro analysis, in the maturity stage of the network, where a considerable number of actors engages in UIS exchanges the impact of transportation on overall savings is limited (4%). An instrument that may be applied to solve the issue of close supply availability and consequently market creation is the development of digital platforms to exchange waste. Examples of these are already widely available both in Asia and Europe and have proven to be effective. Lombardy is starting to move in this direction too with MarketInerti, a platform that is going to be launched in the immediate future and that could theoretically improve the market of C&D waste.

  Other than solving the problem related to the availability of close suppliers, a digital platform may also tackle issues related to **matching product characteristics.** As a matter of fact, having a high availability of supply does not always translate into having products that are suitable to work with, as many sectors and many companies require materials that have certified features in order to be used. However, oftentimes there is still not a proper characterization and classification of materials' that make them unusable. A digital platform may solve this issue by showing a clear detailed description of a material without having to deal with a long and complex process to verify compatibility with a company's process.

- ✓ Throughout the micro analysis, it has been verified that, at least for some specific processes and especially in those cases where materials' reuse is still a novelty for the sector, some actors are still reluctant to reuse materials due to their lower perceived **quality**. It has already been mentioned that in most of the cases, this perception comes from a cultural factor rather than a technical one, as potential secondary materials oftentimes still meet technical requirements.

Therefore, solving this issue is not a matter of regulations but rather of a radical cultural change. A process of "waste branding" carried out with a strategic perspective, that aims to increase the perception of companies concerning secondary raw materials could be a solution. As a preamble to this, a semantic matter has to be addressed, as referring to EOL products as waste, rather than secondary raw materials, strongly mines their credibility for substitution and fuels the perception of low quality. Then, by emulating what is usually done in the marketing world, were products are labelled through specific tags to certify and distinguish them from competitors, the same logic may be applied to waste reuse by introducing some specific standards and labels to classify waste according to its potential and assure companies about its quality. This process would obviously be difficult as the establishment of requirements would be quite long but, in the end, it may benefit both suppliers, that could sell their products at a higher price (and still lower than virgin ones) and buyers that had an insurance on products' quality.

- ✓ **Economic viability** and profitability of synergies: in the micro analysis, actors have highlighted how economic benefits are still the strongest driver for UIS. Literature has shown how, these are crucial especially in the first stages of the network where a clear and tangible economic advantage may not be present. However, some problems concerning economic viability of some symbiosis exists. These mainly come from the fact that due to treatment activities, transportation or the cheapness of virgin RM, the price for secondary ones is in some cases similar or even higher that the former. Due to these reasons, some synergies that have been analysed in the macro analysis, have proven to be unprofitable under the economic perspective but with important savings under the environmental one. A proper system of taxes and incentives may be used to even out the differences and turn the tables in favour of UIS. The feasibility of such systems to determine in which scenario the former is better the latter and vice versa has to be properly discussed to avoid unfairness along the supply chain. This is especially valid for those companies that may take more time to adapt to change such as SME.

In conclusion, Lombardy and the C&D sector offer huge possibilities for the implementation of UIS systems. All of the premises for their realization are there, but still some non-negligible barriers exist and mine their feasibility and future realization. Overcoming these barriers is not easy and needs a lot of work from both institutions and actors that may take some time.

However, considering the fact that UIS and CE in general are regarded as a necessary choice for the future, quickly adapting to change is an unavoidable condition to develop good performances of such systems.

After having fixed these practical issues, Lombardy and Italy as a whole will eventually get UIS to work, the questions that remain concern when and how (ARUP Interview).

5.3 Implications of the Thesis

As a final section of the conclusions, the implications that the Thesis might have on the stakeholders are pointed out:

- ✓ **Implications for C&D business actors**: develop a clearer understanding of what the circular paths for waste are, a better overview on what the achievable *economic and environmental benefits* are, and which factors could be the most influential. On the basis of this information, better management practices can be identified to best valorise waste (sustainable waste management within the entire supply chain) and improve the overall efficiency.

- ✓ **Implications for actors of associated industries** be aware of the significant *economic and environmental benefits*, which may increase competitivity and ease the process of waste disposal.

- ✓ **Implications for Consultancy companies/Sector associations**: propose *new alternatives* for their customers/affiliates operating in the C&D sector.

- ✓ **Implications for Academic Researchers**: this Thesis could be the *basis of further UIS research* in Lombardy and in Italy.

- ✓ **Implications for Public Institutions**: *support regional and national resource efficiency policies* by identifying potential actions, based on UIS and sustainable waste management to achieve environmental and economic benefits. Also, adopted practices may favor compliance to European regulations and objectives.

6. Personal Remarks

In this last chapter we briefly intend to disclose personal feelings that this experience enclosed. We must admit that the **Thesis writing process has not been easy at all**, as especially in a challenging period like the one we are living right now, finding good, reliable, and usable data has been rather arduous. Moreover, in a field that is as vast and as full of facets as Urban-Industrial Symbiosis, the risk of focusing on unnecessary or redundant elements while not giving enough importance to needed ones is high. Also, the rate of response of the contacted companies has been very low and probably in non-pandemic times we would have received more attention by external stakeholders for the empirical search. Surely, having a higher number of interviewees would have had a more positive impact on the Thesis in covering the perspective of a larger portions of actors belonging to the C&D supply chain. Although, the **overall experience has been fruitful and extremely helpful** to understand how to develop an empirical analysis and especially how to collaborate with companies, what to look for, how to conduct interviews and most importantly, the importance of data and databases.

Conclusively, **we would like to thank our supervisor**, Professor Yulia Lapko, for the patience, availability and support given throughout this intense year of research, as well as all the companies that supported us with their time. A special thanks also to Professor Paolo Trucco that committed himself to arrange some of the interviews and to all friends and families that morally supported us alongside this journey.

References

Acharya, Devni, Richard Boyd, and Olivia Finch. 2018. "From Principles to Practices: First Steps towards a Circular Built Environment." : 14.

Albino, Vito, Luca Fraccascia, and Tommaso Savino. 2015. "Industrial Symbiosis for a Sustainable City: Technical, Economical and Organizational Issues." *Procedia Engineering* 118: 950–57.

Ardente, F., M. Cellura, V.L. Brano, and M. Mistretta. 2010. "Life Cycle Assessment-Driven Selection of Industrial Ecology Strategies." *Integrated Environmental Assessment and Management* 6(1): 52–60.

Van Berkel, R., T. Fujita, S. Hashimoto, and Y. Geng. 2009. "Industrial and Urban Symbiosis in Japan: Analysis of the Eco-Town Program 1997-2006." *Journal of Environmental Management* 90(3): 1544–56.

Van Berkel, Rene, Tsuyoshi Fujita, Shizuka Hashimoto, and Minoru Fujii. 2009. "Quantitative Assessment of Urban and Industrial Symbiosis in Kawasaki, Japan." *Environmental Science and Technology* 43(5): 1271–81.

Butturi, M.A. et al. 2019. "Renewable Energy in Eco-Industrial Parks and Urban-Industrial Symbiosis: A Literature Review and a Conceptual Synthesis." *Applied Energy* 255.

Cao, Xin et al. 2018. "Transforming the Cement Industry into a Key Environmental Infrastructure for Urban Ecosystem: A Case Study of an Industrial City in China." *Journal of Industrial Ecology* 22(4): 881–93.

Chen, X. et al. 2012. "The Impact of Scale, Recycling Boundary, and Type of Waste on Symbiosis and Recycling: An Empirical Study of Japanese Eco-Towns." *Journal of Industrial Ecology* 16(1): 129–41.

Chertow, M.R. 2000. "Industrial Symbiosis: Literature and Taxonomy." *Annual Review of Energy and the Environment* 25: 313–37.

Chertow, Marian, and John Ehrenfeld. 2012. "Organizing Self-Organizing Systems: Toward a Theory of Industrial Symbiosis." *Journal of Industrial Ecology* 16(1): 13–27.

Circular Economy Network, and ENEA. 2020. "Rapporto Sull'economia Circolare in Italia." www.fondazionesvilupposostenibile.org.

Commission, European. 2016. "EU Construction & Demolition Waste Management Protocol." *Official Journal of the European Union* (September).

Copper.org. 2015. "Brass Recyclability: Environmental & Economic Advantages." *Copper Development Association Inc.*: 7034. https://www.copper.org/publications/pub_list/pdf/a7034-Brass-Recyclability.pdf.

D'Amico, Flaviano, Marian Mihai Buleandra, Maria Velardi, and Ion Tanase. 2007. "Industrial Ecology as 'Best Available Technique': A Case Study of the Italian Industrial District of Murano." *Progress in Industrial Ecology* 4(3–4): 268–87.

Dahlbo, Helena et al. 2015. “Construction and Demolition Waste Management - A Holistic Evaluation of Environmental Performance.” *Journal of Cleaner Production* 107: 333–41.

“Dati e Indicatori — Italiano.” https://www.isprambiente.gov.it/it/banche-dati (March 12, 2021).

Dei, Caratterizzazione, and Rifiuti Urbani. “Capitolo IV Caratterizzazione Dei Rifiuti Urbani.” : 27–30.

Di, Rapporto. 2019. “Sostenibilità 2019.”

Dong, H. et al. 2014. “Achieving Carbon Emission Reduction through Industrial & Urban Symbiosis: A Case of Kawasaki.” *Energy* 64: 277–86.

Dong, L. et al. 2013. “Environmental and Economic Gains of Industrial Symbiosis for Chinese Iron/Steel Industry: Kawasaki’s Experience and Practice in Liuzhou and Jinan.” *Journal of Cleaner Production* 59: 226–38.

Dong, Liang et al. 2013. “Promoting Low-Carbon City through Industrial Symbiosis: A Case in China by Applying HPIMO Model.” *Energy Policy* 61: 864–73. http://dx.doi.org/10.1016/j.enpol.2013.06.084.

Dong, Liang et al.. 2014. “Uncovering Opportunity of Low-Carbon City Promotion with Industrial System Innovation: Case Study on Industrial Symbiosis Projects in China.” *Energy Policy* 65: 388–97. http://dx.doi.org/10.1016/j.enpol.2013.10.019.

Dong, Liang et al.. 2016. “Towards Preventative Eco-Industrial Development: An Industrial and Urban Symbiosis Case in One Typical Industrial City in China.” *Journal of Cleaner Production* 114: 387–400. http://dx.doi.org/10.1016/j.jclepro.2015.05.015.

Dong, Liang et al.. 2017. “Highlighting Regional Eco-Industrial Development: Life Cycle Benefits of an Urban Industrial Symbiosis and Implications in China.” *Ecological Modelling* 361: 164–76. http://dx.doi.org/10.1016/j.ecolmodel.2017.07.032.

ENIT. 2020. *Piano Annuale 2020*. http://www.enit.it/images/amministrazionetrasparenteepe/disposizionigenerali/PIANO ANNUALE 2020.pdf.

EPA. 2018. “Emission Factors for Greenhouse Gas Inventories : U.S Environmental Protection Agency.” 2017(March): 1–5. https://www.epa.gov/sites/production/files/2018-03/documents/emission-factors_mar_2018_0.pdf.

Fang, Kai et al. 2017. “Carbon Footprints of Urban Transition: Tracking Circular Economy Promotions in Guiyang, China.” *Ecological Modelling* 365: 30–44. http://dx.doi.org/10.1016/j.ecolmodel.2017.09.024.

Federacciaio. 2017. “Produzione Italia Acciaiao.” : 7–9.

Fernandez-Mena, H., T. Nesme, and S. Pellerin. 2016. “Towards an Agro-Industrial Ecology: A Review of Nutrient Flow Modelling and Assessment Tools in Agro-Food Systems at the Local Scale.” *Science of the Total Environment* 543: 467–79.

Fraccascia, L. 2018. “Industrial Symbiosis and Urban Areas: A Systematic Literature Review and Future Research Directions.” *Procedia Environmental Science, Engineering and Management* 5(2): 73–83.

Fujii, Minoru et al. 2016. “Possibility of Developing Low-Carbon Industries through Urban Symbiosis in Asian Cities.” *Journal of Cleaner Production* 114: 376–86. http://dx.doi.org/10.1016/j.jclepro.2015.04.027.

G. Dunnu, J. Maier, and A. Gerhardt. 2009. Thermal Utilization of Solid Recovered Fuels in Pulverized Coal Power Plants and Industrial Furnaces as Part of an Integrated Waste Management Concept

Geng, Y., F. Tsuyoshi, and X. Chen. 2010. “Evaluation of Innovative Municipal Solid Waste Management through Urban Symbiosis: A Case Study of Kawasaki.” *Journal of Cleaner Production* 18(10–11): 993–1000.

“Gruppo Arvedi.” https://www.arvedi.it/ (March 13, 2021).

Gruppo, Sandrin, and Minerali Maffei. 2008. “I Residui Dell ’ Attività Estrattiva : Scarti Da Deposito o Neominiere Da Valorizzare ?” : 1–16.

Guo, B. et al. 2016. “Evaluation of Promoting Industrial Symbiosis in a Chemical Industrial Park: A Case of Midong.” *Journal of Cleaner Production* 135: 995–1008.

Hashimoto, Shizuka, Tsuyoshi Fujita, Yong Geng, and Emiri Nagasawa. 2010. “Realizing CO2 Emission Reduction through Industrial Symbiosis: A Cement Production Case Study for Kawasaki.” *Resources, Conservation and Recycling* 54(10): 704–10. http://dx.doi.org/10.1016/j.resconrec.2009.11.013.

Huang, Wei et al. 2016. “Effect of Urban Symbiosis Development in China on GHG Emissions Reduction.” *Advances in Climate Change Research* 7(4): 247–52. http://dx.doi.org/10.1016/j.accre.2016.12.003.

“I METALLI PER L’EDILIZIA | FALP.” https://www.falpsrl.it/i-metalli-per-ledilizia/ (December 3, 2020).

Iacondini, Antonella et al. 2015. “Feasibility of Industrial Symbiosis in Italy as an Opportunity for Economic Development: Critical Success Factor Analysis, Impact and Constrains of the Specific Italian Regulations.” *Waste and Biomass Valorization* 6(5): 865–74.

“Il Recupero Dei Pneumatici Fuori Uso Attraverso Il Co-Processing: La Miglior Scelta Strategica per La Sostenibilità Ambientale Ed Economica. | Holcim Italy - Forza. Azione. Passione.” https://www.holcim.it/il-recupero-dei-pneumatici-fuori-uso-attraverso-il-co-processing-la-miglior-scelta-strategica-la-0 (March 15, 2021).

“Imprese e Addetti.” http://dati.istat.it/Index.aspx?DataSetCode=DICA_ASIAUE1P# (March 13, 2021).

“Inquinamento e Cambiamenti Climatici: L’impatto Degli Inceneritori - Dossier Inceneritore - LaPressa.It.” https://www.lapressa.it/rubriche/dossier-inceneritore/inquinamento-e-cambiamenti-climatici-limpatto-degli-inceneritori (March 14, 2021).

ISPRA. 2014. *Rapporto Sul Recupero Energetico Da Rifiuti Urbani in Italia*.

"Istat.It." https://www.istat.it/ (March 12, 2021).

Italcementi, 2019, Report di Sostenibilità

Kerdlap, P. et al. 2019. "Collaboration Platform for Enabling Industrial Symbiosis: Application of the Industrial-Symbiosis Life Cycle Analysis Engine." In *Procedia CIRP*, , 655–60.

Kim, Hyeong Woo et al. 2018. "Co-Benefit Potential of Industrial and Urban Symbiosis Using Waste Heat from Industrial Park in Ulsan, Korea." *Resources, Conservation and Recycling* 135(August 2017): 225–34. https://doi.org/10.1016/j.resconrec.2017.09.027.

Lenhart, J., B. Van Vliet, and A.P.J. Mol. 2015. "New Roles for Local Authorities in a Time of Climate Change: The Rotterdam Energy Approach and Planning as a Case of Urban Symbiosis." *Journal of Cleaner Production* 107: 593–601.

Li, Hong, Liang Dong, and Jingzheng Ren. 2015. "Industrial Symbiosis as a Countermeasure for Resource Dependent City: A Case Study of Guiyang, China." *Journal of Cleaner Production* 107: 252–66. http://dx.doi.org/10.1016/j.jclepro.2015.04.089.

Liu, G.-F., and F.-D. Chen. 2013. 427–429 Applied Mechanics and Materials *NISP-Based Research on the System Structure of Urban Symbiosis Network in China*.

Liu, Z. et al. 2018. "Co-Benefits Accounting for the Implementation of Eco-Industrial Development Strategies in the Scale of Industrial Park Based on Emergy Analysis." *Renewable and Sustainable Energy Reviews* 81: 1522–29.

Lombardi, D. Rachel, and Peter Laybourn. 2012. "Redefining Industrial Symbiosis: Crossing Academic-Practitioner Boundaries." *Journal of Industrial Ecology* 16(1): 28–37.

Lu, C. et al. 2020. "Uncovering the Benefits of Integrating Industrial Symbiosis and Urban Symbiosis Targeting a Resource-Dependent City: A Case Study of Yongcheng, China." *Journal of Cleaner Production* 255.

Luciano, A. et al. 2016. "Potential Improvement of the Methodology for Industrial Symbiosis Implementation at Regional Scale." *Waste and Biomass Valorization* 7(4): 1007–15.

Luciano, A. et al.. 2020. "Resources Optimization and Sustainable Waste Management in Construction Chain in Italy: Toward a Resource Efficiency Plan." *Waste and Biomass Valorization* 11(10): 5405–17. http://dx.doi.org/10.1007/s12649-018-0533-1.

MacLean, Malcolm. 2013. 30 International Journal of the History of Sport *Cracks in the (Self-Constructed?) Ghetto Walls? Comments on Paul Ward's Last Man Picked*.

Marchi, Beatrice, Simone Zanoni, and Lucio E. Zavanella. 2017. "Symbiosis between Industrial Systems, Utilities and Public Service Facilities for Boosting Energy and Resource Efficiency." *Energy Procedia* 128: 544–50. https://doi.org/10.1016/j.egypro.2017.09.006.

Marconi, Marco et al. 2018. “An Approach to Favor Industrial Symbiosis: The Case of Waste Electrical and Electronic Equipment.” *Procedia Manufacturing* 21: 502–9. https://doi.org/10.1016/j.promfg.2018.02.150.

Martin, M., S. Poulikidou, and E. Molin. 2019. “Exploring the Environmental Performance of Urban Symbiosis for Vertical Hydroponic Farming.” *Sustainability (Switzerland)* 11(23).

Matignon, Giovanna Pinuccia. 2020. “Trends in the Use of Solid Recovered Fuels.” *IAE Bioenergy* (May 2020).

McCulligh, C., and G.V. Fregoso. 2019. “Defiance from Down River: Deflection and Dispute in the Urban-Industrial Metabolism of Pollution in Guadalajara.” *Sustainability (Switzerland)* 11(22).

Neves, A., R. Godina, S.G. Azevedo, and J.C.O. Matias. 2020. “A Comprehensive Review of Industrial Symbiosis.” *Journal of Cleaner Production* 247.

Neves, Angela et al. 2019. “The Potential of Industrial Symbiosis: Case Analysis and Main Drivers and Barriers to Its Implementation.” *Sustainability (Switzerland)* 11(24): 1–68.

Neves, Angela, Radu Godina, Susana G. Azevedo, and João C.O. Matias. 2020. “Carbon Dioxide Recovery through Industrial and Urban Symbiosis.” *ICITM 2020 - 2020 9th International Conference on Industrial Technology and Management*: 171–75.

Notarnicola, Bruno, Giuseppe Tassielli, and Pietro Alexander Renzulli. 2016. “Industrial Symbiosis in the Taranto Industrial District: Current Level, Constraints and Potential New Synergies.” *Journal of Cleaner Production* 122: 133–43. http://dx.doi.org/10.1016/j.jclepro.2016.02.056.

Ohnishi, S. et al. 2017. “A Comprehensive Evaluation on Industrial & Urban Symbiosis by Combining MFA, Carbon Footprint and Emergy Methods—Case of Kawasaki, Japan.” *Ecological Indicators* 73: 315–24.

Ohnishi, Satoshi et al. 2018. “Efficient Energy Recovery through a Combination of Waste-to-Energy Systems for a Low-Carbon City.” *Resources, Conservation and Recycling* 128: 394–405. http://dx.doi.org/10.1016/j.resconrec.2016.11.018.

Ong, D, X Ie, and Y T F Ang. 2016. “LOW-CARBON BENEFIT OF INDUSTRIAL SYMBIOSIS FROM A SCOPE-3 PERSPECTIVE : A CASE STUDY IN CHINA.” 15(3): 135–53.

Park, Hung Suck, Eldon R. Rene, Soo Mi Choi, and Anthony S.F. Chiu. 2008. “Strategies for Sustainable Development of Industrial Park in Ulsan, South Korea-From Spontaneous Evolution to Systematic Expansion of Industrial Symbiosis.” *Journal of Environmental Management* 87(1): 1–13.

Pomponi, Francesco, and Alice Moncaster. 2017. “Circular Economy for the Built Environment: A Research Framework.” *Journal of Cleaner Production* 143: 710–18. http://dx.doi.org/10.1016/j.jclepro.2016.12.055.

“Resources Passport – Resources Passport.” https://www.resourcespassport.com/ (March 13, 2021).

Sacirovic, Selim, Sonja Ketin, and Nada Vignjevic. 2019. “Eco-Industrial Zones in the Context of Sustainability Development of Urban Areas.” *Environmental Science and Pollution Research* 26(24): 24346–56.

Saunders, M., Lewis, P. and Thornhill, A. (2012) Research Methods for Business Students. Pearson Education Ltd., Harlow.

Simboli, A., R. Taddeo, and A. Raggi. 2019. “The Multiple Dimensions of Urban Contexts in an Industrial Ecology Perspective: An Integrative Framework.” *International Journal of Life Cycle Assessment* 24(7): 1285–96.

Simboli, Alberto, Raffaella Taddeo, and Anna Morgante. 2014. “Analysing the Development of Industrial Symbiosis in a Motorcycle Local Industrial Network: The Role of Contextual Factors.” *Journal of Cleaner Production* 66: 372–83. http://dx.doi.org/10.1016/j.jclepro.2013.11.045.

Simboli, Alberto, Raffaella Taddeo, and Anna Morgante. 2015. “The Potential of Industrial Ecology in Agri-Food Clusters (AFCs): A Case Study Based on Valorisation of Auxiliary Materials.” *Ecological Economics* 111: 65–75. http://dx.doi.org/10.1016/j.ecolecon.2015.01.005.

Sminkey, Patrice V., and Jeannie Le Doux. 2016. 21 Professional Case Management *Case Management Ethics: High Professional Standards for Health Care’s Interconnected Worlds*.

Sun, Lu et al. 2017. “Eco-Benefits Assessment on Urban Industrial Symbiosis Based on Material Flows Analysis and Emergy Evaluation Approach: A Case of Liuzhou City, China.” *Resources, Conservation and Recycling* 119: 78–88. http://dx.doi.org/10.1016/j.resconrec.2016.06.007.

Susur, Ebru, Daniela Martin-Carrillo, Davide Chiaroni, and Antonio Hidalgo. 2019. “Unfolding Eco-Industrial Parks through Niche Experimentation: Insights from Three Italian Cases.” *Journal of Cleaner Production* 239: 118069. https://doi.org/10.1016/j.jclepro.2019.118069.

“Top 7 Most Polluting Industries | The Eco Experts.” https://www.theecoexperts.co.uk/blog/top-7-most-polluting-industries#link-construction-work (March 10, 2021).

Xia, Bing, Tao Ding, and Jianzhuang Xiao. 2020. “Life Cycle Assessment of Concrete Structures with Reuse and Recycling Strategies: A Novel Framework and Case Study.” *Waste Management* 105: 268–78. https://doi.org/10.1016/j.wasman.2020.02.015.

Yedla, Sudhakar, and Hung Suck Park. 2017. “Eco-Industrial Networking for Sustainable Development: Review of Issues and Development Strategies.” *Clean Technologies and Environmental Policy* 19(2): 391–402.

Appendix

“LR flows Description”

Row 1 – Plastic reuse in form-boards (substitution of plywood)

Symbiosis description: The global forest harvest is about 3.5 billion cubic metres per year, or about 0.7 cubic metres per person per year, which approximately equals our food intake on a green weight basis [link]. To reduce wood consumption, it can be possible to use plastic from-board to substitute plywood forms.

Row 2 – Plastics Gasification

Symbiosis description: A way to convert waste to energy is through gasification, a process that melts plastics at very high temperatures in the near-absence of oxygen (which means toxins like dioxins and furans are not formed). The process generates a synthetic gas that is used to fire turbines. But with natural gas so cheap, gasification plants are not competitive. A more attractive technology right now is pyrolysis, in which plastics are shredded and melted at lower temperatures than gasification and in the presence of even less oxygen. The heat breaks plastic polymers down into smaller hydrocarbons, which can be refined to diesel fuel and even into other petrochemical products—including new plastics. (The Alliance to End Plastic Waste includes pyrolysis companies [link].

Row 3 and 4- Plastic Waste in Iron & Steel or in Cement

Symbiosis description: Waste plastic can be used to replace coke by iron & steel industry (Under the process, waste plastics are fed into electric steel-making furnaces as an alternative source of carbon and heated to super-hot temperatures of 1600°C.) or replace coal by cement industry in kiln. Such a substitution can reduce both direct energy consumption emissions and the emissions embodied in the upstream production of coke and coal.

Row 5- Organic Waste

Symbiosis description: Organic waste can be used, as well as plastic waste, as a fuel replacing coal in cement production.

Row 6- Soot and Burnt Residues

Symbiosis description: Soot is a mass of impure carbon particles resulting from the incomplete combustion of hydrocarbons. In this case, instead of landfilling the soot it can be used as a fuel substitute of coal for cement production.

Row 7 – Construction and Demolition waste

Symbiosis description: described in the Thesis.

Rows 8 and 9 - BF slag and steelmaking slag

Symbiosis description:

Row 8) BF slag is recovered by melting separation from blast furnaces that produce molten iron pig. It consists of non-ferrous components contained in the iron ore together with limestone as an auxiliary material, and ash from coke. Depending on the cooling method used, it is classified wither as air-cooled slag or granulated slag. Regarding air-cooled slag, the molten slag flows into a cooling yard, where it is cooled slowly by natural cooling and by spraying with water; this results in a crystalline, rock-like air cooled slag [link]. However, the greatest economic benefit is gained using granulated blast furnace slag (GBFS) in the cement industry to produce Portland blast furnace cements and other Portland blended cements. How is GBFS generated? When the blast furnace refines iron ore into iron, molten slag is produced. The iron is used to produce steel, and the molten slag is converted to a cement-like material by rapidly cooling it with water. This rapid cooling, called quenching, creates glassy granules, which are then ground into the fine powder known as slag cement.

Row 9) The steelmaking slag is a by-product from steelmaking processes in which the components of pig iron and steel-scrap are modified in order to produce steel that is so highly valued for excellent toughness and workability. Steelmaking slag consists of converter slag that is generated by converter and electric arc furnace slag that is generated during the electric arc furnace steelmaking process that uses steel-scrap as the raw material [link]. In conclusion, BF slag and Steelmaking slag could substitute part of the clinker resulting in Portland BF cements production.

Row 10 – Fly ashes

Symbiosis description: As seen before for rows 8 & 9 replacing a portion of clinker with other cementitious materials has the potential to significantly reduce emission, without adversely impacting on the cement performance. Fly ashes, arising from coal fired power generation, have cementitious properties and can be used to supplement clinker in cement.

Row 11 and 12– Phosphorus slag and Aluminium slag

Symbiosis description: Refining of the molten steel can occur simultaneously with melting, especially in EAF (Electric Arc Furnace) operations where oxygen is introduced throughout the batch. During the refining process, substances that are incompatible with iron and steel are separated out by forming a layer of slag on top of the molten metal. Chemically, the slag layer consists primarily of oxides of calcium, iron, silicon, phosphorus, sulfur, aluminum, magnesium, and manganese in complexes of calcium silicates, aluminosilicates and aluminoferrite. The slag is typically removed by tipping the furnace backwards and pouring the molten slag out through a slag door, at which point the slag is further processed (i.e., cooled, cured, and sized) into a product [link]. This kind of slag can be used to replace a portion of cement RM.

Row 13 – Clay Substitution by using paper sludge

Symbiosis Description: Paper mill sludge is a major economic and environmental problem for the paper and board industry. The material is a by-product of the de-inking and re-pulping of paper. The main recycling and disposal routes for paper sludge are land-spreading as agricultural fertiliser, incineration in CHP plants at the paper mill, producing paper sludge ash, or disposal to landfill. In functional terms, paper sludge consists of cellulose fibres, fillers such as calcium carbonate and china clay and residual chemicals bound up with water. [link]:

After incinerating paper sludge at approximately 800°C, the resultant fly ash may contain reactive silica and alumina (in the form of metakaolin) as well as lime (CaO) which contribute chemically to the Portland cement ingredients. Paper sludge ash is therefore potentially suitable as an ingredient in:

- the cement kiln feed, contributing calcium, silica and alumina
- the manufacture of blended cements

Row 14 – Carbide slag to replace Limestone

Symbiosis Description: Calcium carbide slag can be a substitute for the natural limestone to produce cement clinker and also with a high portion of CaO as an excellent calcium raw material. Thus, it not only reduces the pollution that the calcium carbide slag brings to the environment, but also reduces the exploitation of non-renewable resource-limestone. The main chemical composition of carbide slag and limestone were basically the same, which mainly oxides were CaO, SiO_2, Al_2O_3 and Fe_2O_3. Meantime, a few harmful components, such as K_2O, Na_2O, SO_3 and Cl, are also contained in carbide slag. According to the chemical composition, the content of CaO in carbide slag with a range of 60%-67% was much higher than that in limestone; therefore, it can be used as top quality calcareous materials [link].

Row 15 – Copper ash used in concrete production

Symbiosis Description: Copper slag has a high Fe content and has been used as an iron adjustment material during the cement clinker production. The use of copper slag also results in lower required calcination temperature and improved grindability of the clinker although the raw materials cost may or may not be reduced depending on the local availability of copper slag [link].

Row 16 – Gypsum used to replace RM in cement production

Symbiosis Description: Gypsum is calcium sulfate dihydrate ($CaSO_4 2H_2O$), a white or gray naturally occurring mineral. Raw gypsum ore is processed into a variety of products such as a portland cement additive, soil conditioner, industrial and building plasters, and gypsum wallboard. Comprising gypsum and additives such as blast furnace slag, fly ash, and natural pozzolana in cement mix, would cause reductions in the clinker/cement ratio and consequently reduce energy use and process CO2e emissions.

Row 17 and 18 – Iron mine tailings to replace RM in cement production

Symbiosis Description: The abundance of mining activities continuously increases mine wastes/tailings that require storage/disposal. It is well understood that the accumulation of tailings around mines, and consequently, their spreading in the environment could cause serious ecological hazards. Reuse and recycling of mine tailing materials, in construction and earthwork applications (such as non-structural building elements, roads), offset possible environmental pollutions and safeguard natural resources [link]. With the benefit of high content of silica and iron, IOT (iron ore tailings) can be utilized as silicate or iron corrective material during the Portland cement clinker production, but the consumption of IOT is rather low. In addition, the effect of using IOT as raw material on the properties of raw meal and hydration characteristic of Portland cement has also been seldom discussed. Comparing with being used as corrective material, utilizing IOT as alumina-silicate raw material for Portland cement clinker production can consume more IOT and decrease the mining of clay; IOT can completely (SF=1) replace clay as an alternative alumina-silicate raw material for the production of Portland cement clinker. The availability and low cost of IOT make it attractive to replace clay as alumina-silicate raw material for the production of Portland cement clinker [link].

Row 19- Production of Fertilizers from desulfurization

Symbiosis Description: Flue-gas desulfurization (FGD) is a set of technologies used to remove sulfur dioxide (SO_2) from exhaust flue gases of fossil-fuel power plants, and from the emissions of other sulfur oxide emitting processes such as waste incineration.

Row 20 – Chromium slag

Symbiosis Description: Aluminium–chromium slag is produced by the aluminothermic metallurgical refinement of chromium ore into metal. As a long-term metallurgical industrial solid waste, slag not only occupies land, but also deteriorates and pollutes the soil [link].

Row 21 and 22 – Steel slag replacing ceramics

Symbiosis Description: Ceramics include the production of bricks and roof tiles, vitrified clay pipes, refractory products, expanded clay products, wall and floor tiles, table and ornamental ware (household ceramics), sanitary ware, technical ceramics, and inorganic bonded abrasives. Process-related emissions from ceramics result from the calcination of carbonates in the clay, as well as the addition of additives. Similar to the cement and lime production processes, carbonates are heated to high temperatures in a kiln, producing oxides and CO2e. Most ceramic products are made from one or more different types of clay (e.g., shales, fire clay and ball clay). The raw materials are collected and finely crushed in successive grinding operations. The ground particles are then fired in a kiln to produce a powder (which may be liquefied). Additives are subsequently added and the ceramic is formed or moulded and 'machined' to smooth rough edges and achieve the desired characteristics of the ceramic. In the case of traditional ceramics, the ceramics are then dried and glazed prior to firing in the kiln. After firing, some ceramics may undergo additional treatment to achieve the final desired quality [link]. By using the slag to replace those ceramics RM, it is possible to obtain environmental and economic benefits.

Row 23 – Waste steel recycling

Symbiosis description: produce new steel by replacing iron ore with waste steel.

Row 24 – Red mud

Symbiosis Description: Bauxite residue (red mud) is a hazardous waste generated from alumina refining industries. Unless managed properly, red mud poses significant risks to the local environment due to its extreme alkalinity and its potential impacts on surface and ground water quality. Given the scarcity of iron supply globally, the iron content of red mud has attracted increasing research interest. The red mud contain up to 58 % of iron and are a potential raw material for ferrous metallurgy [link].

Row 25- Waste tyre replacing rubber

Symbiosis Description: Today tires consist of about 19 % natural rubber and 24 % synthetic rubber, which is a plastic polymer. The rest is made up of metal and other compounds. Producing tires still has monumental environmental impacts, ranging from continued deforestation to the climate-harming fossil fuels used to make synthetic rubbers to the assembly process. Modern car tires require about 7 gallons of oil (7*3.785 litres) for production, while truck tires take 22 gallons. Recycling and reusing tires is therefore a crucial activity to decrease the environmental impact of the supply chain. According to the Japan Automobile tire manufacturers association, the amount of ELT tires generated by both replacement or scrap vehicles is 1.026.000 tons of which 966.000 was recycled for different means. Recycling and reusing tires is therefore a crucial activity to decrease the environmental impact of the supply chain. According to the Japan Automobile tire manufacturers association, the amount of ELT tires generated by both replacement or scrap vehicles is 1.026.000 tons of which 966.000 was recycled for different means.

Row 26, 27, 28 – Waste tires, Agroforestry and straw replacing coal (incineration)

Row 29 – MSW replacing coal in electricity generation

Row 30- Plastic Waste replacing coke in electricity generation

Symbiosis Description: Incineration of waste to produce electricity.

Row 31 - Coal gangue for power supply

Symbiosis Description: The disposal of such large quantities of coal gangue solid waste not only occupies a great deal of land but also is harmful due to initiating geologic hazards and land degradation. In addition, landfilling faces another serious problem concerning the leaching of heavy metals such as Pb^{2+}, Zn^{2+}, Cu^{2+}, and Cd^{2+} which can contaminate the groundwater by advection and diffusion processes, leading to secondary pollution. Coal gangue is likely to cause large-scale fire and blast disasters, and produce a significant amount of toxic emissions such as SO_2, CO, H_2S, Hg, Pb and benzopyrene into the atmosphere [link]. The mineral composition of gangue is mainly affected by clay mineral content, which usually contains about 10%-70% of clay, 20%-30% of quartz and 10–20% of other mineral and carbonaceous matter. Despite its possible uses, here it will be considered the use of coal gangue in replacement of coal for electricity generation.

Row 32 – Cogeneration by using kiln exhaust gas

Symbiosis description: The generation of Power from the cement kiln Waste Heat gases is an energy saving opportunity and it entails the recovery of the heat energy contained in the waste gases that are emitted into the atmosphere from the cement kiln. The generation of Power from kiln Waste Heat Recovery is about conversion of the waste heat from the clinkering process into useful electrical energy. Cogeneration of power is achieved by utilizing this waste heat streams from the preheater and the cooler, passing the waste gases through boilers, which in turn generate steam which is used to turn/run turbines to generate electricity. The amount of heat energy recovered depends on several factors: namely the temperature of the waste heat gases, amount/volume of gases and thermal capacity of the waste gas, kiln system design and production capacity and the moisture content of the raw materials. Most cement industries have not been able to generate power from waste heat recovery due to the high initial investment cost involved, the high energy requirement for drying the raw materials, in adequate technical competencies and fairly stable power cost. However, power generations from kiln waste heat has become a very important venture in cement industry mainly due to fluctuating power costs, improvements in the economy of plant operations and the need to reduce power consumptions and finally strict environmental guidelines regarding reduction of CO2e emissions. The Cost of installation is considered as the main obstacle in the installation of a waste heat recovery power plant. The High the cost of a project, the less it is feasible for investors to invest [link].

Row 33- BFG for power supply

Symbiosis Description: A typical blast furnace produces 1200 – 2000 N cum of BF gas per ton of hot metal. The energy content of this gas may equal to an energy export of around 1.2 M cal/ton (5GJ/ton or 1.38888 Gwh/kton) of hot metal, or approximately 30 % of the gross energy consumption in the blast furnace. This energy content can be utilized by recovering, cleaning, and storing the BF gas and using it as a fuel gas in the steel plant or in the boilers for the production of steam for the electricity generation. The calorific value of the BF gas varies but is usually low (between 650 kcal/N cum to 900 kcal/N cum and depends on the CO concentration). Therefore, BF gas is often enriched by coke oven gas or natural gas prior to use [link].

Row 34 – Replace coal for hydrogen production COG

Symbiosis Description: There are four main sources for the commercial production of hydrogen: natural gas, oil, coal, and electrolysis; which account for 48%, 30%, 18% and 4% of the world's hydrogen production respectively. Fossil fuels are the dominant source of industrial hydrogen. The coke oven gas includes hydrogen (about 55-58% vol.), as well as methane (about 25% col.) and other gases. The hydrogen can be separated from the coke oven gas in the process of pressure swing adsorption (PSA) or membrane separation to obtain a product with a purity of 99.999% [link1]. However, here it is considered as symbiosis the replacement of coal in hydrogen production with COG.

<u>Row 35 and 36 – Low and High pressure steam</u>

Symbiosis Description: to date, large quantities of low-grade waste heat (between 30 and 100 °C) are discharged into the environment without being exploited. To quickly explain how the h**eat flows work**: Figure a) (Kim et al. 2018) shows how the low-grade waste heat from the industrial sector is supplied towards a heat management center and this is carried over as a district heat supply in the urban sector. At the urban sector, the combustible municipal waste is sent through the incinerator plant and its waste thermal high/medium-grade heat are sent back in the industrial sector, meanwhile generating electricity. In addition, combustible waste and by-product gas in the industrial sector are utilized to generate electricity (orange arrow).

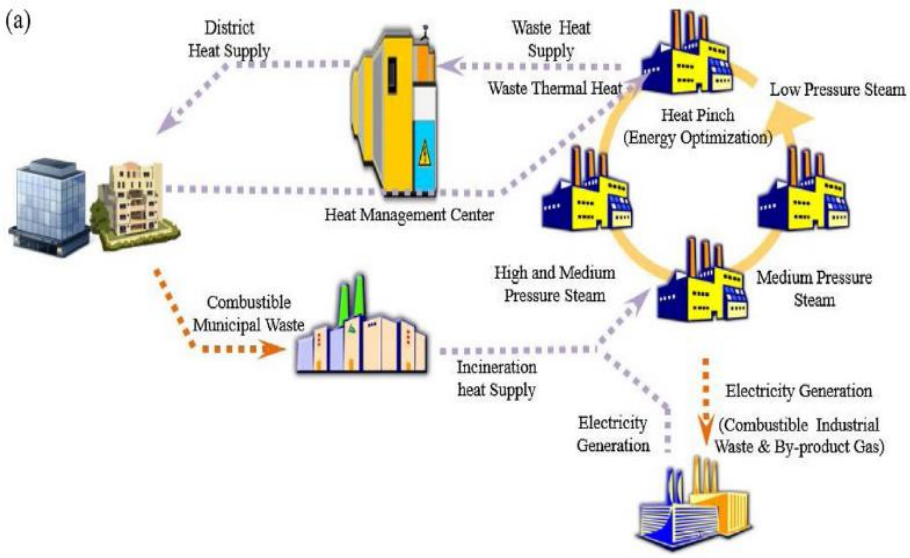


Fig. 3b (Kim et al. 2018) illustrates the technical concept of the I-US using low grade waste heat in an industrial park. The industrial waste heat is processed at the 1st heat exchanger at 120 °C and goes to a 2nd heat exchanger in the heat management center at 95–115 °C. After this, heat around 95 °C is going to through pressure pump (5–7 kg/m2) in a supply header. The waste heat would go to a heat exchanger of the urban area and be pumped at 65 ± 5 °C to the public, office buildings and apartment. The waste heat at 50 ± 5 °C from the urban area will go through a heat exchanger to a return header in the pressurization facility at 3–4 kg/m2 straight to a recycle pump. The waste heat

is returned to the 1st exchanger at 62 ± 3 °C and comes out at 93 °C as processed waste heat. In conclusion, the UIS networks using high and low-grade waste heat are an effective measure to reduce the energy consumption and greenhouse gas (GHG) emissions.

Row 37 and 40 – organic waste

Symbiosis Description: Organic waste can be used as a substitute of fertilizers.

Row 41 – Paper recycling

Row 42 – Carton board/Strawboard Production

Symbiosis Description: Carton board is made from cellulose fibres that are produced either from wood or from recovered paper and board. A combination of the two can be used and there are various types of fibre that produce different characteristics. The fibres can also be treated with various chemicals to improve a variety of properties such as moisture and grease barriers. Additionally, they can be coated with a range of coatings to produce carton board that can be used in ovens and microwaves and other specialist packaging [ELCD].

Row 43 and 44- WEE

Symbioses Description: Row 43 is related to fluorescent lights recycling for glass and aluminum Recycling and recovery of mercury. Row 44 is about home appliances dismantling for non-ferrous metals recovery from separated parts and shredder residue. Sadly, there are no quantitative data available about these two flows.

Row 45 and 46 – Wastewater for reclaimed water in Still Mill and Power Plants

Symbioses Description: Wastewater is liquid waste that is discharged by domestic residences, commercial properties, industry, agriculture, it most often contains contaminant when mixing wastewater from different origins. When wastewater has been treated and cleaned of all contaminants, it can be reused as drinking water.

Row 47 – Wastewater incineration

Symbiosis Description: Where a suitable site for land disposal is not available, as in urban areas, sludge may be incinerated. Incineration completely evaporates the moisture and converts the organic solids into inert ash. The ash must be disposed of, but the reduced volume makes disposal more economical. Air pollution control is a very important consideration when sewage sludge is incinerated. Appropriate air-cleaning devices such as scrubbers and filters must be used.

Tables and charts included

The following QR code opens up a folder with all the charts and tables mentioned as "contained in the appendix":

1) Literature Table

Authors	Title	Year	Cited b	Link	Index Keywords	Focal topic	Urban-related	Description	AN.TYPE	Type of paper	Analysis/Content	Social. dimenSociali	Category	Country	City	Actors	Elements
Kim H.-W.,	Co-benefit potentia	2018	22	https://w	District heating; Eco-i	IS/UrS	Yes	this study systematically develops an industrial-urban symbiosis (I-US) analysis for 4 scenarios, through technological assessment of energy balance between waste heat source in industrial park and urban area	Quantitative	Case study	Carbon footprint	Env Eco	Emissions	Korea	Ulsan	Industries and households	.
McCulligh	Defiance from Dow	2019		https://w	atmospheric pollution	UrS	Yes	In this paper, we explore two interconnected nodes in the metabolism of the Guadalajara Metropolitan Area inWestern Mexico.	Qualitative	Case study	Social context and pollution	Env Social	Emissions	Mexico	Guadalajara	Communities	Water, air
Van Berke	Quantitative assess	2009	117	https://w	Co-located firms; Com	UrS	Yes	Estimation of benefit and competitive advantage from exchanging physical resources	Quantitative	Case study	MFA	Env Eco	Material	Japan	Kawasaki	Industries and Recycling facilities	cement, chemical, and
Chen X., F	The Impact of Scale,	2012	46	https://w	Circular economy; Ind	UrS	Yes	this article focuses on the factors of project scale, recycling boundary, and types of waste in relationship to environmental benefits and operational performance.	Quantitative	Case study	Factors	Env Eco	Material	Japan	.	Waste treatment plants	virgin materials
Dong L., Z	Environmental and	2013	88	https://w	China; Circular econor	IS	Yes	this paper evaluates and compares the number, scale and the related environmental/economic gains of IS activities in iron/steel-centered industrial areas in Liuzhou and Jinan in China, and Kawasaki in Japan	Quantitative	Case study	MFA/Factors	Env Eco	Material	China/Japan	uzhou and Jinjan/Kawasa	iron&steel plant	
Dong H., O	Achieving carbon er	2014	62	https://w	Blast furnaces; Carbor	IS/UrS	Yes	the purpose of this paper is to make a quantitative analysis on Kawasaki Eco-town, Japan. A hybrid LCA model was employed to evaluate to the lifecycle carbon footprint	Quantitative	Case study	Carbon footprint	Env	Material&Emissions	Japan	Kawasaki	iron & steel industry, cement industry and "paper making" industry	iron, steel, paper,
Lenhart J.,	New roles for local	2015	18	https://w	Industrial research; N	IS/UrS	Yes	this paper aims to identify how urban actors, notably local authorities, can facilitate improved urban resource management to mitigate climate change.	Qualitative	Case study	Factors	Env	Energy	Netherlands	Rotterdam	local authorities, urban actors	.
Guo B., Ge	Evaluation of promo	2016	17	https://w	Calcium carbide; Cem	IS	No	this study is aiming to shed light on the current IS activities in a typical chemical industrial park in western China, so as to quantitatively evaluate the environmental benefits and economic benefits of IS	Quantitative	Case study	MFA	Env Eco	Material	China	Midong	Companies in MCIP	, coal gangue, fly ashes
Lu C., Wan	Uncovering the ben	2020		https://w	Carbon dioxide; Emiss	IS/UrS	Yes	approach to facilitate the sustainable development of resource-dependent cities, and could be expanded to other similar cities.	Quantitative	Case study	MFA/Emergy Analysis	Env	aterial&Emissions&Ener	China	Yongcheng	Industries	)2, emergy, fly ash, ste
Liu Z., Ada	Co-benefits account	2018	10	https://w	Climate change; Cons	IS	Yes	this study aims to evaluate the co-benefits resulting from eco-industrial development and demonstrate how an emergy accounting-based approach can be applied	Quantitative	Case study	Emergy Analysis	Env Eco	Energy	China	(DETDZ)		Air and Water
Wu Y., Que	Efficiency estimatio	2018	10	https://w	Ecology; Ecosystems;	UM	Yes	In this paper, there are the combination Emergy synthesis, Principal Component Analysis (PCA) and Date Envelopment Analysis (DEA) of time-series approach to comprehensive assessment urban metabolism for the first time.	Quantitative	Case study	Emergy Analysis	Env Eco Social	Energy	China	Changsha		
Ohnishi S.,	A comprehensive e	2017	30	https://w	Blast furnaces; Byproc	IS/UrS	Yes	this study aimed to establish a comprehensive framework to evaluate I/UrS by combining the material flow analysis (MFA), carbon footprint (CF) and emergy methods	Quantitative	Case study	MFA/Emergy Analysis/Carbon footprint	Env	aterial&Emissions&Ener	Japan	Kawasaki	.	CO2
Kwon G.-R	Industrial ecology-b	2015	5	https://w	Amphibious vehicles;	IS/UrS	Yes	this study presents and assesses CO_2 reduction strategies to mitigate the drawbacks of magnesium metal, based on the concepts of industrial ecology	Quantitative	Case study	Carbon footprint	Env	Material&Emissions	.	.	cement plant	C02, magnesium
Kerdlap P.	Collaboration platfo	2019		https://w	Carbon dioxide; Econ	IS	Yes	This paper aims to address the analytical gap by introducing the Industrial Symbiosis-Life Cycle Analysis (IS-LCA) Engine designed to assess the environmental performance of IS	Quantitative	Case study	LCA	Env Eco	Emissions	Singapore	.	Cooking oil factory, Electricity generation plant, Fertilizer factory, Animal feed factory, Diesel refinery	CO2
Geng Y., Ts	Evaluation of innova	2010	109	https://w	Additional costs; Curr	UrS	Yes	this paper simulates and evaluates an innovative waste management initiative in Kawasaki by an scenario simulation model based on the LCA approach	Quantitative	Case study	LCA	Env Eco	Material	Japan	Kawasaki	Industries	municipal solid waste
Kennedy C	Industrial ecology a	2015	5	https://www.scopus.com/inwa		IE/UrS	Yes	In this review of work on IE and cities, a Scopus search of ISI-rated publications finds over 200 papers on the topic	Qualitative	Literature	General	Env	none in particular	.	.	.	.
Fernandez	Towards an Agro-Ind	2016	18	https://w	Agriculture; Autonom	Agro-Industrial Ecology	No	Review the literature on nutrient cycling in complex social-ecological systems that can provide a basis for Agro-Industrial Ecology. Approaches: Environmental Assessment tools, Stock and Flow Analysis methods and Agent-based models	Qualitative	Literature	Tools for IE	Env Social	Material	.	.	.	Food
Neves A.,	A comprehensive re	2020		https://w	Industrial research; Pu	IS	No	this work aims to trace the trend of industrial symbiosis research and to map the existing case studies around the world, with a critical analysis of its impact.	Qualitative	Literature	General	Env Eco Social	none in particular			Communities; Industries	.
Ness D.A.,	Toward a Resource-	2017	24	https://w	Asset management; E	CE/IE	Yes	It reviews literature on the CE and industrial ecology, their application to industrial and urban contexts, and the gaps pertaining to the building sector.	Qualitative	Theoretical	General	Env Eco	Material&Emissions	.	.	.	.
Tseng M.-L	Circular economy m	2018	69	https://w	Big data; Digital storag	IS	Yes	Can big data drive IS?	Qualitative	Literature	Big Data	Env Eco	Information	.	.		.
Van Berke	Industrial and urban	2009	155	https://w	environmental econo	IS/UrS	Yes	Japan's Eco-Town Program: use of previously discarded commercial, municipal and industrial waste materials in industrial applications	Quantitative	Theoretical	General	Env Eco	Material	Japan	.	Private sector, local government, civil society	.
Raabe B., L	Collaboration Platfo	2017	14	https://w	Byproducts; Compute	IS	Yes	This paper introduces the system architecture of a collaboration platform for enabling industrial symbiosis	Qualitative	Theoretical	Factors	Env Eco	Information	Singapore			.
Low J.S.C.,	A Collaboration Plat	2018	11	https://w	Byproducts; Database	IS	No	In this paper, we describe how we enhance the platform with a database engine for waste-to-resource matching.	Qualitative	Theoretical	Factors	Env Eco	Information				.
Simboli A.	The multiple dimen	2019	2	https://w	analytic method; Artic	UrS	Yes	This article analyses, in an industrial ecology (IE) perspective, urban contexts with specific features, such as a reduced space scale, a hybrid nature, which includes a residential, industrial and rural dimension	Qualitative	Theoretical	Factors	Env	aterial&Emissions&Ener	Italy	Pescara	Residential; Industrial; Rural	.
Dong L., W	Recent progress on	2018	12	https://w	Environmental manag	UrS	Yes	Analyze the sustainability of infrastructure system towards sustainable urban development and resource management, based upon comprehensive reviews, regenerative urban infrastructures development and urban industrial symbiosis, novel and integrated planning and evaluation tools/methods, and the innovative policies.	Qualitative	Theoretical	General	Env	none in particular	.	.	.	.
Butturi M.	Renewable energy	2019	3	https://w	Carbon emissions red	EIP/UrS	Yes	This study thus provides an overview of the scientific literature on energy synergies within eco-industrial parks, which facilitate the uptake of renewable energy sources at the industrial level, potentially creating urban-industrial energy symbiosis.	Qualitative	Literature	RES	Env	Energy	.	.	.	.
Chertow M	Industrial symbiosis	2000	807	https://w	.	IS	No	Literature analysis	Qualitative	Literature	General	Env	Material		.		
Liu G.-F., C	NISP-based researc	2013	2	https://w	Eco-industrial park; Fo	UIS	Yes	.			NISP	Env		China			

	Title	Reference	Match			Focal topic	Urban-related	Description	AN.TYPE	Type of paper	Analysis/Content	Social. dimenSocialion	Category	Country	City	Actors	Elements
2	trial symbiosis cons	atsu et al	No	D		IS	No	In this study, rural energy system was designed with industrial symbiosis c	Quantitative	Case study	LCA	Env Eco	Material&Emissions	Japan	Tanegashima	gar industry, Wood Industry, D	ugar Pulp, wood, heat
4	: Tracking circular ec	g et al., 2	No	D		IS/UIS	Yes		Quantitative	Case study	Carbon Footprint	Env	Material&Emissions	China	Guiyang		
6	material flows analy	n et al., 2	No	D		IS/UIS	Yes		Quantitative	Case study	MFA/Emergy Analysis	Env		China	Liuzhou		
7	e development: revi	and Deutz	No	D		IS/EIP	Yes		Qualitative	Theoretical	Factors for development	Env	-	Korea	Ulsan		
8	ntext of sustainabilit	vic et al.,	No	D		EIP	Yes		Qualitative	Theoretical	Factors for development	Env	-				
9	velopment in China	ng et al., 2	No	D		UrS	Yes		Quantitative	Case study	IPCC	Env		China		iron and steel scraps, waste paper, and	
10	nbination of waste-t	shi et al.,	No	D		UrS	Yes		Quantitative	Case study	New model	Env Eco	Energy			Municipalities, recycling faciliyie	MSW, heat
13	e cycle benefits of a	ng et al., 2	No	D		UIS	Yes		Quantitative	e study/Theoretical Framewo	LCA/IOA	Env	Emissions	China	Liuzhou	, scrap tire recycling, coal flying ash recycling, biomas	
15	e for resource deper	et al., 20	No	D		IS	Yes		Quantitative	Case study	MFA	Env	Materia&Emissions	China	Guiyang	coal, electricity, aluminum, phosphor chemical, ir	
16	le city: technical, ec	no et al., 2	No	D		UIS	Yes		Qualitative	Conceptual Framework		Env					
17	g using waste heat u	et al., 20	No	M		Is/Uis	Yes	this study aims to create a model framework based on the combination of	Quantitative	Theoretical / Case study	General	Env Eco	Emissions	Japan	Shinchi	Industries and power plants	
18	biosis from a scope	et al., 20	No	M		Is	Yes	Calculating the Scope 3 (upstream emissions embedded in products	Quantitative	Case study	MFA	Env	Emissions	China	Linzhou	Iron/steel	
19	oon industries throu	ii et al., 2	No	M		Us	Yes	This study examines the feasibility of hybrid industries (based on recycled	Quantitative	Case Study	Emissions	Env Eco	Emissions	Asia	awasaki, Ulsan, Shenyan	Industries	
20	ustrial symbiosis: A	g et al., 2	No	M		IS/UIS	Yes	his research shed light on how industrial symbiosis contributes to city's lov	Quantitative	Case Study	HPIMO	Env	Emissions	China	Linzhou	Iron/steel	
22	dustrial symbiosis: A	moto et al	No	M		Is/Uis	Yes	This article is one effort to examine the present and potential performance	Qauntitative	Theoretical / Case study	LCA	Env/Eco/Soc	Emissions	Japan	Kawasaki	Cement	
23	outh Korea-From sp	k et al., 2	No	M		Is/Uis	Yes	This paper describes the Korean national policies and the developmental a	Qualitative	Theoretical / Case study		Env	Emissions	Korea	Ulsan	Industries	
24	industrial and urba	ng et al., 2	No	M		IS/UIS	Yes	In order to investigate the eco-benefits of eco-industrial development in C	Quantitative	Theoretical/Case Study	HPIMO	Env	Emissions	China	Guiyang	Indistries	
25	o a Key Environmen	p et al., 2	No	M		Is/Uis	Yes	this article introduced an urban ecosystem in which the cement industry w	Quantitative	Theoretical/Case Study	MFA	Env/Eco/Soc	Emissions	China	Wuhan	Cement	
26	ith industrial system	ng et al.,	No	M		Is/Uis	Yes	this study conduces a quantitative evaluation of CO2 reduction potential th	Quantitative	Case study	MFA	Env	Emissions	China	Linzhou/Jinan	Iron/steel	

2) LR Synergies References

#	Symbiosis	Resource Tranferred	Resoruce Substituted	From	To	UIS/IS	Type of flows	(Rene Van Berkel et al. 2009)	(L. Dong et al. 2013)	(Hashimoto et al. 2010)	(Cao et al. 2018)	(Guo et al. 2016)	(Liang Dong et al. 2014)	(Fang et al. 2017)	(Li, Dong, and Ren 2015)	(Liang Dong et al. 2016)	(Lu et al. 2020)	(Sun et al. 2017)	(Ong, Ie, and Ang 2016)	(Liang Dong et al. 2013)
1	Plastic reuse in form-boards	Mixed plastic waste (containers and wrapping)	Plywood forms	Municipal Waste Collectors	Chemical companies	UIS	M	x												
2	Synthesis gas for ammonia production (equivalent of coal substituted)	Mixed plastic waste (containers and wrapping)	Coal	Municipal waste collectors	Chemical companies	UIS	M	x		x										
3	Replace coke for BF supply	Plastic waste	Coke	Industrial /commercial waste collectors	Iron and Steel mills	UIS	M	x	x	x			x							
4	Replace coal for cement kiln supply	Waste plastic	Coal	Industrial/commercial waste collectors	Cement Producers	UIS	M	x		x										
5	Replace coal for cement kiln supply	Organic Waste	Coal	Industrial/commercial waste collectors	Cement Producers	UIS	M	x		x										
6	Replace coal for cement kiln supply	Soot and Burnt Residue	Coal	Industrial/commercial waste collectors	Cement Producers	UIS	M	x		x										
7	Alternative RM for Concrete	C & D Scraps	Concrete	Construction and demolition (C&D) sites	Cement Producers	UIS	M	x		x										
8	Slag replacing a fraction of clinker in cement production	BF slag	Clinker	Iron and steel mill	Cement producers	IS	M	x	x	x	x		x	x	x	x	x	x		
9	Slag replacing a fraction of clinker in cement production	Steelmaking slag	Clinker	Iron and steel mill	Cement Producers	IS	M						x				x			
10	Use fly ashes to replace clinker	Coal Fly Ashes	Clinker	Power Plants	Cement Producers	IS	M				x	x		x	x	x	x	x	x	
11	Substitute cement RM	Phosporus Slag	Clinker	Iron and steel mill	Cement producers	IS	M							x	x	x				
12	Substitute cement RM	Aluminum Slag	Clinker	Iron and steel mill	Cement producers	IS	M							x	x	x				
13	Substitute cement RM	Paper sludge	Clay	Paper producers	Cement Producers	IS	M	x												
14	Replace limestone	Carbide Slag	Limestone	Chemical companies	Cement Producers	IS	M					x								
15	For Copper cement production	Copper ash	Clinker	Urban context	Cement Producers	UIS	M					x								
16	Gypsum from desulfurizationd as hardener in concrete production	Gypsum	Clinker	Power Plant	Cement Producers	IS	M				x	x	x							
17	Alternative cement RM from Mines	Iron mines tailings	Clay	Mines	Cement Producers	UIS	M				x									
18	Alternative cement RM from Mines	Iron mines tailings	Bricks	Mines	Bricks producers	UIS	M				x									
19	Production of Fertilizers from desulfurization	Desulfurization by-products	Fertilizers	Iron and Steel mill	Chemical companies	IS	M											x		
20	Recycling of Chromium Slag as sinter ore	Chromium Slag	Sinter ore	Chemical companies	Iron and Steel mills	IS	M						x							
21	Glass Ceramics production from steel slag	Molten Steel Slag	Ceramics RM	Steel mill	Ceramic producers	IS	M				x									
22	Wear-resistant Ceramics production from steel slag	Cooled Steel Slag	Ceramics RM	Steel mill	Ceramic producers	IS	M				x									
23	Waste Steel recycling	Urban steel waste	Iron ore	Industrial/commercial waste collectors	Iron and Steel mill	UIS	M		x	x		x	x	x	x	x	x	x		
24	Red mud reuse to refine ferrous elements	Red mud	Iron ore	Aluminum mill	Iron and steel mill	IS	M						x							
25	Waste tyre replacing rubber	Waste tires	Rubber	Urban context	Rubber Producers	UIS	M					x		x				x	x	
26	Incineration of waste tyres	Waste tires	Coal for electricity	Municipal waste collectors	Power Plants	UIS	M/E										x			
27	Agroforestry Waste replacing coal for power generation	Agroforestry waste	Coal for electricity	Municipal Waste Collectors	Power plants	UIS	M/E										x			
28	Incineration of Straw	Straw	Coal for electricity	Farmers	Power Plants	UIS	M/E												x	x
29	Electricity production from MSW incineration	MSW	Coal for electricity	Municipal waste collectors	Power plant	UIS	M/E										x			
30	Plastics wastes for substituting coke	Plastic Waste	Coke for electricity	Industrial/commercial waste collectors	Power Plants	UIS	M/E							x	x	x				
31	Coal Gangue used to produce energy	Coal Gangue	Coal for electricity	Coal mines	Power Plants	IS	M/E				x	x		x	x	x				
32	Cogeneration by using waste heat from Kiln exhaust gas	Waste heat/ Kiln exhaust gas	Coal for electricity	Cement Producers	Power plants	IS	E				x									
33	BFG for power supply (replace coal)	BFG gas	Coal for electricity	Steel & Iron mill	Industries/power production	IS	E		x				x				x			
34	Alternative Coal for Hydrogen Production	Coke Oven Gas	Coal for hydrogen production	Iron and steel mill	Chemical companies	IS	M						x					x		
35	Steam reuse as heat source	Low Pressure Steam	Coal for electricity	Power plant/industrial actors	Urban context	UIS	E						x				x			
36	Steam reuse as heat source	High Pressure Steam	Coal for electricity	Power Plant/Industrial Actors	Industrial districts	IS	E										x			
37	Livestock manure reutilization for Fertilizer Production	Livestock Manure	Fertilizers	Farmers	Chemical companies	UIS	M										x			
38	Straw reutilization for Fertilizer Production	Straw	Fertilizers	Farmers	Chemical companies	UIS	M										x			
39	Plant ash reutilization for Fertilizer Production	Plant ash	Fertilizers	Farmers	Chemical companies	UIS	M										x			
40	Distiller's grains reutilization for Fertilizer Production	Distiller's grains	Fertilizers	Breweries	Chemical companies	UIS	M										x			
41	Paper recycling	Paper waste	Virgin Fiber Pulp	Industrial/commercial waste collectors	Paper Producers	UIS	M	x		x										
42	Strawboard Production	Paper waste (waste yellow straw boards)	Strawboards	Municipal Waste Collectors	Paper Producers	UIS	M					x								
43	Fluorescent lights recycling	Flurescent lights	Glass, Aluminum, Mercury	Industrial/Commercial Waste collectors	Recycling plants	UIS	M			x										
44	Home appliances dismantling	Home appliances	Non-ferrous metals recovery from separated parts and shredder residue	Municipal waste collectors	Iron and steel producers & non ferrous materials users	UIS	M			x										
45	Treated municipal water reuse	Wastewater	Water	Waste Water Treatment Plant	Iron and steel	UIS	W						x							
46	Treated municipal water reuse	Wastewater	Water	Waste Water Treatment Plant	Thermal Power Plant	UIS	W					x								
47	Treated municipal water reuse	Wastewater	Limestone	Waste Water Treatment Plant [WWTP]	Cement Producers	UIS	W	x												

3) D&B References

References

[1]	[4]	[18]	[21]	[22]	[24]	[28]	[30]	[32]	[33]	[34]	[35]	[37]	[38]	[43]	[45]	[46]	[47]	[48]
(Chertow 2000)	(A. Neves et al. 2020)	(Chen et al. 2012)	(Lenhart, Van Vliet, and Mol 2015)	(Guo et al. 2016)	(Z. Liu et al. 2018)	(Geng, Tsuyoshi, and Chen 2010)	(G.-F. Liu and Chen 2013)	(Fang et al. 2017)	(Sun et al. 2017)	(Yedla and Park 2017)	(Sacirovic, Ketin, and Vignjevic 2019)	(Satoshi Ohnishi et al. 2018)	(Liang Dong et al. 2017)	(Fujii et al. 2016)	(Hashimoto et al. 2010)	(Park et al. 2008)	(Liang Dong et al. 2016)	(Cao et al. 2018)

*each yellow cell represents a relationship

*by definition means that according to the definition given to each factor they are related

MATRIX OF RELATIONSHIPS BETWEEN FACTORS		Waste composition	Technology availability	Standardization Level	Information sharing through IT	Communication	Awareness	Volume	Supply Volatility	Infrastructure (energy, utility and transport)	Price of VRM, energy and labor cost	Revenues generation	Investment opportunity	Employment opportunity	Property value and area development	CAPEX	Transaction costs	Quality related to production	Long term impact	Geographical location	Cooperation and coordination	Firm commitment	Multiparty involvement	Sites specificity	Green regulations	Incentive schemes	Hazardous materials	Community approval	Waste reduction	Resources Conservation	Landfilling	Health and air quality	# of relationships
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
Waste composition	1	X	[37]	[32],[34]								[37]								[18]													4
Technology availability	2	[37]	X	[32],[34]	By definition											[22],[47]		[32]															5
Standardization Level	3	[32],[34]	[32],[34]	X		[32]																											3
Information sharing through IT	4		By definition		X	By definition															By definition												3
Communication	5			[32]	By definition	X											[34]		[30],[21]				[34]										5
Awareness	6						X												[34]	[21]						[34,45,46]							3
Volume	7							X	[18],[48]																								1
Supply Volatility	8							[18],[48]	X										[34]	[34]		[34]											4
Infrastructure (energy, utility and transport)	9									X		[34]	[34]		[35]	[34]	By definition						[34]										6
Price of VRM, energy and labor cost	10										X	[22],[37]	By definition											[22],[33]	[22],[33]	[22],[33]				[22]			6
Revenues generation	11	[37]								[34]	[22],[37]	X								[18]						[47]							5
Investment opportunity	12									[34]	By definition		X		[34],[35]																		3
Employment opportunity	13													X	[35]				[35]									[35]					3
Property value and area development	14									[35]			[34],[35]	[35]	X																		3
CAPEX	15		[22],[47]							[34]						X										[48]							3
Transaction costs	16					[34]				By definition							X			[30]		[30]				[48]							5
Quality related to production	17		[32]															X									[34]						2
Long term impact	18					[30],[21]	[34]		[34]					[35]					X														4
Geographical location	19	[18]					[21]		[34]			[18]					[30]			X													5
Cooperation and coordination	20				By definition																X	[34]											2
Firm commitment	21							[34]									[30]				[34]	X	[34]										4
Multiparty involvement	22					[34]				[34]											[34]	[34]	x										4
Sites specificity	23										[22],[33]													X									1
Green regulations	24										[22],[33]														X		[34]		[34]	[34]	[34]	By Definition	6
Incentive schemes	25						[34,45,46]				[22],[33]	[47]				[48]	[48]									X							5
Hazardous materials	26																	[34]							[34]		X					[34],[24]	3
Community approval	27													[35]														X			[28]		2
Waste reduction	28																								[34]				X				1
Resources Conservation	29										[22]														[34]					X			2
Landfilling	30																								[34]			[28]			X		2
Health and air quality	31																								By Definition		[34],[24]					X	2
																																	107

4) EF and Prices with references for Macro-Analysis

Prices

		Prices [€/t]		Source			
Fresh RM	Limestone	€	6.33	(Guo et al. 2016)			
	Concrete	€	75.00	Percassi			
	Iron	€	130.00	link			
	Aluminum	€	1,550.00	link			
	Brass	€	5,000.00	brass & copper			
	Copper	€	6,000.00	brass & copper			
	Coal	€	32.95	(Guo et al.			
	Clinker	€	16.35	clinker			
	Nat.Gas	€	0.26	gas			
Waste	Magnetic Fraction	€	33.33	HP	red	disposal cost	
	White and colored marble sawing	€	-	(Guo et al. 2016)	black	waste selling price	
	White marble sawing	€	-	(Guo et al. 2016)			
	Granite and soliceous sawmill	€	-	(Guo et al. 2016)			
	Mixed (granite+marble) sawmilland siulicatic	€	-	(Guo et al. 2016)			
	Concrete and mineral waste	€	33.33	Lagalla+HP			
	Wood	€	33.88	wood			
	Miscellaneous Waste	€	33.88	wood			
	Unsorted Mixed Fraction	€	33.33	Lagalla+HP			
	Waste plastic	€	110.00	plastics			
	Organic Waste	€	100.00	link			
	Coal Fly Ashes	€	2.28	(Guo et al.			
	Sand	€	33.33	HP			
	GBS	€	0.13	(Guo et al.			
	ABS	€	0.13	(Guo et al.			
	Basic Oxigen Slag (BOS)	€	0.13	(Guo et al. 2016)			
	EAF-S	€	0.13	(Guo et al.			
	Iron	€	130.00	Lagalla			
	Aluminum	€	600.00	Lagalla			
	Brass	€	1,500.00	Lagalla			
	Copper	€	3,000.00	Lagalla			

Cost €/t

Waste	pre-treatment	Treatment	Avoided Production	Net "Good" Impact	Source
Metal	0.57	0.11	40	39.32	(Dahlbo et al. 2015)
Concrete&Mineral	2.9	0.14	2.6	-0.44	(Dahlbo et al. 2015)
Wood	0.82	0	13	12.18	(Dahlbo et al. 2015)
Miscellaneous	1.3	2.6	40	36.1	(Dahlbo et al. 2015)

Emissions Factors

List of Emission Factors	Combustion Emissions Value	Meaure Unit
Wood and wood residuals	1.83	tCO2e/ton
Coal Coke	3.13	t CO2e/ton coke
Petroleum Coke	3.45	t CO2e/ton coke
EFBiomass	0.11	tCO2e/ton
EFNatural Gas	2.88	tCO2e/ton

List of Emission Factors	Lifecycle Emissions Value	Meaure Unit
EF BF slag cement	0.51	tCO2e/t BF slag
EF Portland Cement (energy+RM+Upstream)	0.89	tCO2e/t cement
EF Steelmaking (production of steel)	1.80	tCO2e/t steel
EF waste Steel	0.42	t CO2e/ton
EF iron ore	0.27	t CO2e/ton
EF aluminum	1.60	t CO2e/ton
EF Limestone	0.44	t CO2e/ton
Concrete Production (RM extraction+processing)	1.02	t CO2e/ton
Clinker EF (RM+Energy)	0.79	tCO2e/t clinker

List of Emission Factors	∆Emissions Value	Meaure Unit
∆EF when using BF slag for replacing clinker	0.47	tCO2e/t BF slag
∆EF when using steelmaking slag for replacing clinker	0.34	tCO2e/t steelmaking slag
∆EF (just RM) for each t of fly ash/copper ash replacing 30% of cement RM	0.45	KtCO2 / kt of fly ashes
∆Direct reduced Iron Production	0.70	t CO2e/ton

Emissions ktCO2e/kt waste

Waste	Production	Recycled	Landfilled	Combusted/ Incinerated	Composted	Unit	Source	
Mixed Organics	NA	NA	0.55	0.05	0.09	tCO2e/t	EPA	
Grains	NA	NA	0.68	0.05	0.07	tCO2e/t	EPA	
MIxed paper	NA	0.07	NA	0.05	NA	tCO2e/t	EPA	
Waste Plastics	NA	0.22	0.02	2.34	NA	tCO2e/t	EPA	
C&D waste	NA	0.01	0.02	NA	NA	t CO2e/ton	EPA	
Fly ashes	NA	0.01	0.02	NA	NA	t CO2e/ton	EPA	
Copper	2.77	0.18	0.02	0.01	NA	t CO2e/ton	EPA	
Aluminum	NA	0.06	0.02	NA	NA	t CO2e/ton	EPA	link copper prod
Steel	NA	0.32	0.02	NA	NA	t CO2e/ton	EPA	
MSW	NA	NA	0.63	0.43	NA	t CO2e/ton	EPA	

Emissions ktCO2e/kt waste

Waste	pre-treatment	Recovery	Avoided Production	Net "Good" Impact	Source
Metal	0.0021	0.069	0.14	0.0689	(Dahlbo et al. 2015)
Concrete & Mineral	0.00067	0.0026	0.0058	0.00253	(Dahlbo et al. 2015)
Wood	0.0013	0.0064	0.24	0.2323	(Dahlbo et al. 2015)
Miscellaneous	0.0043	0.055	0.15	0.0907	(Dahlbo et al. 2015)

5) Macro-Analysis Computations and Data used

See attached File

6) List of contacted companies for Micro-Analysis

Type of company	Provincia	Cement Producers
Cement Producers	Bergamo	ItalCementi
	Brescia	ItalCementi
	Como	Holcim Italia stazione di macinazione
	Varese	Holcim Italia ciclo completo
	Varese	COLACEM
C&D companies	Udine	Rizzani de Echer
	Parma	Pizzarotti
	Lecco/Milano	Colombo Costruzioni
	Milano	Techbau
	Roma/Milano	Italiana Costruzioni
	Bergamo	Percassi
	Brescia	Sa-fer
	Milano	Borio Mangiarotti
	Como	Nessi&Majocchi
	Brescia	Paterlini
	Milano	Ediltecno
	Bergamo	SMV
	Brescia	CDS Holding
	Milano	Ing Ferrari
	Milano	Mangiavecchi Pedercini
	Como	Guffanti
	Milano	Grassi & Crespi
	Mantova	Bottoli
	Bergamo	Aedificem
	Bergamo	Bonedil
	Bergamo	Brescianini
	Bergamo	Civera Restauri
	Bergamo	Despe
	Bergamo	Edil Kappa Costruzioni
	Bergamo	Edilpeja
	Bergamo	Locatelli Giordano
	Bergamo	Impresa Milesi
	Bergamo	Omnis sas
	Bergamo	PFC
	Bergamo	Vitali s.p.a
	Brescia	Bertoli SPA
	Brescia	Case Bio srl
	Brescia	CBC costruzioni
	Brescia	Cogiedil srl
	Brescia	Faedile
	Brescia	MFG srl
	Brescia	Redil srl
	Como	Toptaglio
	Como	Calcestruzzi Taglio
	Bergamo	Vitali Ecorecuperi Srl
	Bergamo	Cornago srl
	Bergamo	Marchetti Francesco
	Bergamo	Ecologia Dalmine
	Bergamo	Texel
	Bergamo	Monzani
	Brescia	Valli Gestioni Ambientali
	Brescia	Ecogarda
	Brescia	Ecologysnc
	Como	Fratelli Pialli
	Como	Insubria
	Como	Tracer
	Cremona	Ecoeridania
	Cremona	Miglioli
	Cremona	Isacco s.r.l.
	Cremona	Simply s.r.l.
	Cremona	Gobbi Fratelli
	Lecco	Cremona ecologia
	Lecco	Insubria
	Lecco	Comune di Lecco
	Lecco	Fioretti Giuseppe
	Lodi	Frigerio Giuseppe
	Lodi	Recuperi CRP
	Mantova	Ferrari srl
	Mantova	Ecology-system
	Mantova	Rottami metallici Rotamar
	Milano	Miglio (oli esausti)
	Milano	Petrilli
	Milano	Enecol Servizi
	Milano	Inverardi Pietro
	Milano	Sant'ambrogio srl
	Milano	dbs Rottami
	Milano	Nespoli Pallets
	Milano	Ecometalli
	Milano	Martani
	Milano	Enex
	Milano	Galli srl
	Milano	IGM rifiuti
	Monza/Brianza	Innovatec spa
	Monza/Brianza	Cem Ambiente spa
	Pavia	Ferbi Metal
	Pavia	ASM isa
	Varese	Sorri
	Varese	Bresaola Rottami
	Varese	Serraglia
MSW waste collectors	Bergamo, Brescia, Como	Aprica (A2A)
	Brescia, Cremona, Lodi	Linea Gestioni (A2A)
	Brescia, Mantova	Ecospurghi Milani
	Cremona, Como, Lecco, Lodi, Mantova, Pavia, Milano, Monza, Sondrio	Rimeco
	Lecco	Silea S.P.A
	Mantova	Tea S.P.A
	Milano	Amsa (A2A)
	Milano, Pavia	Verde
	Monza/Brianza	Sangalli Giancarlo Srl
	Pavia	ASM
	Sondrio	Secam S.P.A.
	Varese	Aspem (A2A)
Centrali		Edison
		(relazioni esterne e comunicazione)
Chemical Producers	Bergamo	Radici Group
	Bergamo	Polynt
	Bergamo	Siad
	Bergamo	Sabo
	Brescia	Comet srl
	Como	Ecosfera srl
	Cremona	Sogis
	Cremona	COIM group
	Lecco	Maltiriva-Praxair
	Mantova	Maltiriva-Praxair
	Mantova	Sadepan
	Milano	Azienda Chimica Milanese
	Milano	Eni Versalis
	Milano	Mapei
	Milano	Gruppo Bracco
	Milano	P&R group
	Milano	Eingemann & Veronelli SPA
	Milano	Mare Holding SPA
	Milano	Oleotecnica SPA
	Milano	RDC srl
	Monza/Brianza	Gruppo SOL
	Monza/Brianza	Gruppo Sapio
	Varese	INSUD PHARMA
	Varese	Gruppo Lamberti
Rubbers Producers	Bergamo	Eldan Recycling
	Bergamo	Unigomma
	Brescia	TovoGomma
	Milano	Pirelli
	Varese	Special Rubber
Settore Termovalorizzazione (competenza regionale)	BS	A2a
	BG	
	MI	
	VA	ACCAM
	CO	ACSM-AGAM
	MB	Brianza energia e ambiente
	MI	CORE
	CR	Linea Reti e impianti
	PV	Lomellina Energia
	MI	Prima
	BG	A (rifiuti energia e ambient
	LC	SILEA
Acciaierie	MN	Mercegaglia carbon steel
	MI	ArcelorMittal
	CR	Acciaieria Arvedi
	CR	Carlo Colombo
	BG	Tenaris Dalmine
	BS	Alfa Acciai
	BS	Tecnofil
	BS	Ferapli Siderurgica
	BS (cerveno)	Riva Acciaio
	BS (malegno)	
	BS (sellero)	
	CN	
	VA	
	BS	Trafilerie carlo Gnutti
	BS	Raffmetal
	BS	Ori Martin Spa
	PV	Intals spa
	BG	Somet Spa
	MB	Acciai Vender
	LC	Rodacciai
	BS	Ferriera Valsabbia
	BS	Almag
	BS	Duferdofin
	BS	Feinrohren
	MI (bresso)	Noveris
	MI (pieve)	
	BS	Eural Gnutti
Utilizzatori d'acciaio	BG	Fonderie Mario mazzucconi
	BS	Foma Spa
	MI	Perar Spa
Cartiere	BG	Cartiere Pigna
	LC	Cartiere dell'Adda
	BS	Burgo Group
	BS	Cartiera del chiese
	VA	Cartaria varesina
	PV	Cartiere Cama
	MI	Cartiere di Cologno
	BS	Cartiera di nave
	VA	Cartiera di varese
	VA	Cartiera fornaci
	VA	Cartiera merati
	VA	Cartiera Lombarda
	MI	Cartiera Palm
	VA	Cartiera Olona
	MN	Cartiera Mantovana
	BS	Monteverdi carval
	LC	Casalini e Viscardi
	LC	Cima Paper
	MN	Grossi carta
	MI	Gruppo Cordenons
	LC	ICMA
	BG	Errebi rotolificio

7) Questionnaire Form

A

Questionario volto a testare opportunità e barriere nello sviluppo della Simbiosi Urbana Industriale - Politecnico di Milano

Il seguente questionario verrà utilizzato esclusivamente a scopo di ricerca, al fine di comprendere quali sono le possibilità connesse al riutilizzo dei materiali di scarto generati sia in contesto urbano che industriale, principalmente per quanto riguardo il settore Edilizio e quelli a esso associati. Tale analisi rientra nella sfera della cosiddetta simbiosi "urbana-industriale", ovvero la creazione di sinergie per favorire nuovi scambi di materiali tra attori operanti in contesti apparentemente diversi. Per stabilire la fattibilità degli scambi trasversali di risorse abbiamo bisogno di semplici informazioni riguardanti i principali drivers & barriere che le aziende operanti nel territorio Lombardo incontrano quando si trovano a:

Processo 1: RIUTILIZZARE MATERIE PRIME SECONDE, ovvero l'utilizzare al posto delle "convenzionali materie prime" gli scarti/derivati/sottoprodotti provenienti da ALTRE AZIENDE (sia operanti nel proprio settore sia non).

Processo 2: SMALTIRE CORRETTAMENTE I RIFIUTI (inclusi i PROPRI SOTTOPRODOTTI non riutilizzabili internamente) in modo da massimizzarne l'utilità. Es. I propri scarti potrebbero essere riutilizzati da altri attori operanti in settori diversi invece di essere spediti nelle discariche.

Il questionario è diviso in tre brevi sezioni:

-Sezione 1: Informazioni Generali riguardo l'azienda (30 s)

-Sezione 2: Analisi Drivers & Barriere per il processo di RIUTILIZZO MATERIE PRIME SECONDE (4 min)

-Sezione 3: Analisi Drivers & Barriere per il processo di SMALTIMENTO RIFIUTI (4 min)

Grazie in anticipo per la collaborazione.

POLITECNICO MILANO 1863

Sezione 1: Informazioni Generali Riguardo la Vostra Azienda

Nome Azienda:

Numero di Dipendenti *

- ◯ <10
- ◯ 11-50
- ◯ 51-200
- ◯ 201-500
- ◯ 501-1000
- ◯ >1000

Province Lombarde in cui l'azienda opera

	BG	BS	CO	CR	LC	LO	MN	MI	MB	PV	SO	VA
Stabilimenti	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Magazzini	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Sede Legale	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Uffici Amministrativi	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Sezione 2: Processo 1 - RIUTILIZZO DI MATERIE PRIME SECONDE

Questa sezione è relativa al processo di "riutilizzo delle materie prime seconde", ovvero l'utilizzare al posto delle "convenzionali materie prime" gli scarti/derivati provenienti da altre aziende (sia operanti nel proprio settore sia non).

COSA INTENDIAMO: Per MATERIE PRIME si intende i materiali che sono alla base per la produzione di altri beni tramite l'utilizzo di opportune lavorazioni e processi industriali che permettono di ottenere il prodotto finale desiderato. Invece, per MATERIE PRIME SECONDE (DERIVATI/SOTTOPRODOTTI) si intende quelle (PRODOTTE DA TERZI) costituite da sfridi di lavorazione delle materie prime oppure da materiali derivati dal recupero e dal riciclaggio dei rifiuti. Un esempio molto comune è lo zolfo di scarto risultato a seguito dell'estrazione dei metalli dai suoi composti metalliferi (solfuri di piombo, di rame ecc...) che viene riutilizzato e smerciato ad un prezzo più basso rispetto allo zolfo nativo, alimentando quello che è definito mercato delle materie prime secondarie.

FATTORI PROCESSO 1

Secondo il punto di vista della vostra azienda, assegnare un valore da 1 (fattore poco influente) a 5 (fattore molto influente) ai FATTORI di seguito elencati riguardo "il RIUTILIZZO DI MATERIE PRIME SECONDE (Derivati/Scarti/Sottoprodotti provenienti da altre aziende della stessa industria o di industrie differenti) per rimpiazzare nuove materie prime".

COSA INTENDIAMO: Ogni fattore può agire da driver o da barriera (o da entrambi), ossia influenzare positivamente o negativamente (o in ambedue i modi) il processo in questione. Durante l'intervista ci piacerebbe poi discutere in breve come ognuno di essi si qualifica dalla prospettiva della vostra azienda e in che modo agisce.

	1	2	3	4	5	Non applicabile
Composizione (Omogenea/Eterogenea) degli scarti generati da terzi	○	○	○	○	○	○
Disponibilità/Indisponibilità Tecnologia	○	○	○	○	○	○
Livello di Standardizzazione della Tecnologia	○	○	○	○	○	○
Consapevolezza/Informazioni riguardo potenzialità	○	○	○	○	○	○
Piattaforma digitale su cui comprare/vendere gli scarti/sottoprodotti	○	○	○	○	○	○
Costo Materie Prime, Energia e Lavoro	○	○	○	○	○	○
CAPEX per tecnologie necessarie	○	○	○	○	○	○
Qualità dei prodotti in caso di riutilizzo di scarti	○	○	○	○	○	○
Gestione costi di Transazione (Vincoli Contrattuali etc..)	○	○	○	○	○	○
Impatto nel lungo termine	○	○	○	○	○	○
Lontananza Geografica/Logistica	○	○	○	○	○	○
Volatilità della Fornitura	○	○	○	○	○	○
Cooperazione e Coordinazione con Attori Diversi	○	○	○	○	○	○
Specificità dei siti industriali	○	○	○	○	○	○
Norme vietanti l'utilizzo di sostante pericolose	○	○	○	○	○	○
Riduzione Costi/Aumento Margini	○	○	○	○	○	○
Opportunità di Investimento per azienda	○	○	○	○	○	○
Favorire/Aumentare Occupazione	○	○	○	○	○	○
Favorire sviluppo area circostante	○	○	○	○	○	○

Legislazione “Green”	○	○	○	○	○	○
Incentivi su riutilizzo scarti/ tasse su estrazione materie prime	○	○	○	○	○	○
Coinvolgimento della comunità/contesto urbano	○	○	○	○	○	○
Riduzione Sprechi/materiale nelle discariche/Preservare Risorse Naturali	○	○	○	○	○	○
Salute persone e qualità dell’aria	○	○	○	○	○	○

Nel caso aveste commenti/dubbi da fare o se voleste specificare altri fattori riguardo il Processo 1 assenti nella lista:

Sezione 3: Processo 2 - Smaltimento di Scarti

Questa sezione è relativa al processo di SMALTIMENTO DEGLI SCARTI (inclusi i PROPRI SOTTOPRODOTTI non riutilizzabili internamente) cercando di massimizzare la loro utilità. Es. I propri scarti potrebbero essere riutilizzati da altri attori operanti in settori diversi invece di essere spediti nelle discariche.

FATTORI PROCESSO 2

Secondo il punto di vista della vostra azienda, assegnare un valore da 1 (fattore poco influente) a 5 (fattore molto influente) ai FATTORI di seguito elencati riguardo la massimizzazione dell'utilità durante il processo di "SMALTIMENTO DEGLI SCARTI" (inclusi i PROPRI SOTTOPRODOTTI non riutilizzabili internamente).

COSA INTENDIAMO: Ogni fattore può agire da driver o da barriera (o da entrambi), ossia influenzare positivamente o negativamente (o in ambedue i modi) il processo in questione. Durante l'intervista ci piacerebbe poi discutere in breve come ognuno di essi si qualifica dalla prospettiva della vostra azienda e in che modo agisce.

	1	2	3	4	5	Non applicabile
Composizione (Omogenea/Eterogenea) degli scarti generati da terzi						
Disponibilità/Indisponibilità Tecnologia						
Livello di Standardizzazione della Tecnologia						
Piattaforma digitale su cui comprare/vendere gli scarti/sottoprodotti						
Costo di Smaltimento						
Consapevolezza rispetto ai danni generati in caso di inefficiente smaltimento						
Legislazione ("Green")						
Supporto e Controllo da parte delle autorità						
Impatto nel lungo termine						
Aspetti Logistici						
Cooperazione e Coordinazione con Attori Diversi						
Immagine Green Azienda						
Norme vietanti l'utilizzo di sostante pericolose						
Opportunità di Investimento per azienda						
Multe e sanzioni						
Coinvolgimento della comunità/contesto urbano						
Benfici Ambientali/materiale nelle discariche						

Nel caso aveste commenti/dubbi da fare o se voleste specificare altri fattori riguardo il Processo 2 assenti nella lista:

Grazie Per la Gentile Collaborazione!

8) Interview Protocol

C&D related actors

		Actors					
	Questions	**C&D actors**	**Related to C&D**	**Consultancy**	**Public Institutions**	**Experts**	**Purpose of the Question**
0)	Number of employees and hubs in Lombardy	√	√				To be used in context definition
1)	Does your company know about UIS?	√	√	√	√		To be used in context definition
	If you know: Has your company ever being involved in UIS projects?	√	√	√	√	√	To be used in context definition
2)	What are the main Raw Materials, Semi-finished products that you use to supply your production activities?	√	√				Input
	Does your company uses waste or by-products coming from other companies as a Raw Materials substitute? If yes, indicate the quantities.	√	√				To understand wheter there are current synergies input-side
	Please, explain how these waste or by-products might substitute your RM and in which %.	√	√			√	Current and Potential practices
3)	What is the quantity of products you produce per year, and the proportion of by-products generated per each unit of product produced?	√	√				Output
	How does the company sells/uses by-products generated?	√	√				To understand wheter there are current synergies output-side
4)	What are the types of waste that your company generates yearly? Please, indicate quantity.	√	√				Waste
	What types of activities does your company perform for waste disposal? What are the logistics channels?	√	√				Understand current practices
	Please, explain how your by-products/waste might substitute some RM in other industries and in which %.	√	√			√	Current and Potential practices
6)	Survey on Drivers & Barriers for UIS (by-products and waste reutilization)	√	√	√	√	√	D&B prioritization
	Discuss the Drivers and the Barriers that your company has come across with and their relationships	√	√	√	√	√	To better understand the impact of D&B in Lombardy

Consultancy and Public Institution actors

		Actors					
	Questions	**C&D actors**	**Related to C&D**	**Consultancy**	**Public Institutions**	**Experts**	**Purpose of the Question**
1)	Does your company know about UIS?	√	√	√	√		To be used in context definition
2)	If you know: Has your company ever being involved in UIS projects?			√	√	√	Projects run in Italy
	Can you explain us what the foucs of your analysis what the findings where?			√	√	√	Projects run in Italy
3)	If you know any, could you tell us about most common by-products/waste reusing options currently explored/unknown/emerging within the C&D sector?	√	√	√	√	√	Current and Potential practices
4)	Could you please indicate us some publicy available data sources about waste in Lombardy region?			√	√	√	Data Collection
	Do you know sources where we could get precise resources substitution factor related to the C&D sector? Ex. The % of cement RM that can be substituted by using clinker.			√	√	√	Data Collection
5)	Survey on Drivers & Barriers for UIS (by-products and waste reutilization)	√	√	√	√	√	D&B prioritization
	Discuss the Drivers and the Barriers that your company has come across with and their relationships	√	√	√	√	√	To better understand the impact of D&B in Lombardy
6)	Do you think that ours is a good approach to UIS? What would you do differently?			√		√	Get feedbacks and insights on the methodology