The current issue and full text archive of this journal is available on Emerald Insight at:
https://www.emerald.com/insight/0025-1747.htm

Exploring industrial symbiosis for circular economy: investigating and comparing the anatomy and development strategies in Italy

Lucrezia Sgambaro, Davide Chiaroni and Emanuele Lettieri
Department of Management, Economics and Industrial Engineering, Politecnico di Milano, Milan, Italy, and
Francesco Paolone
Department of Economics and Law, Universitas Mercatorum, Rome, Italy and LUISS Guido Carli, Rome, Italy

Received 29 April 2023
Revised 24 July 2023
15 October 2023
7 December 2023
1 February 2024
Accepted 1 February 2024

Abstract

Purpose – The purpose of this paper is to investigate the most recurrent variables characterizing the collaborative relationships of industrial symbiosis (IS) (hereinafter also referred to as "anatomic" variables) established in the attempt to adopt circular economy (CE) by collecting evidence from a rich empirical set of implementation cases in Italy.

Design/methodology/approach – The current literature on IS was reviewed, and a content analysis was performed to identify and define the "anatomic" variables affecting its adoption in the circular economy. We followed a multiple-case study methodology investigating 50 cases of IS in Italy and performed a content analysis of the "anatomic" variables characterizing each case.

Findings – This research proposes the "anatomic" variables (i.e. industrial sectors involved, public actors involvement, governmental support, facilitator involvement and geographical proximity) explaining the cases of IS in the circular economy. Each "anatomic" variable is discussed at length based on the empirical evidence collected, with a particular reference to the impact on the different development strategies (i.e. "bottom-up" and "top-down") in the cases observed.

Originality/value – Current literature on IS focuses on a sub-set of variables characterizing collaboration in IS. This research builds on extant literature to define a new framework of five purposeful "anatomic" variables defining IS in the circular economy. Moreover, we also collect and discuss a broad variety of empirical evidence in what is a still under-investigated context (i.e. Italy).

Keywords Case study, Collaboration, Development strategy, Circular economy, Industrial symbiosis

Paper type Research paper

Introduction

Industrial symbiosis (IS) is one of the main applications of the circular economy (CE) paradigm at the meso-level and it implies a close, symbiotic collaboration between the companies involved (Chertow and Ehrenfeld, 2012; Fraccascia *et al.*, 2021a; Herczeg *et al.*, 2018; Neves *et al.*, 2020).

The IS concept originates from biology where symbiosis is defined as "an association of dissimilar organisms in a mutually beneficial relationship" (Schwarz and Steininger, 1997, p. 49). IS stems from that concept applied to the industrial context and refers to the

Management Decision
Emerald Publishing Limited
0025-1747
DOI 10.1108/MD-04-2023-0658

engagement of "traditionally separate entities in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and by-products" (Chertow, 2000, p. 314). Even if rooted in Industrial Ecology, IS is strictly connected to CE (see, e.g. Fraccascia *et al.*, 2021b). Indeed, the IS paradigm aims to (1) value wastes and by-products, and (2) close the loop between resources, materials, and products. In this view, materials, utilities, and by-products that are produced as an output from a process in a company can be introduced as an input in other processes either in the same company or in other ones. Materials, utilities, and by-products exchange is a fundamental practice in the implementation of the IS paradigm and calls for close collaboration between the different companies that are part of the IS (Chertow, 2000; Herczeg *et al.*, 2018; Neves *et al.*, 2020). In order to spot and exploit potential latent synergies (i.e. to understand how to value materials, utilities, and by-products formerly considered as waste), collaboration and knowledge sharing among different companies and stakeholders are key enablers for creating symbiotic collaborations (Chertow and Ehrenfeld, 2012; Mortensen and Kørnøv, 2019). The IS paradigm is thus a collaborative CE paradigm, where different companies jointly collaborate to value materials, utilities, and by-products, formerly disposed because considered as waste, with the ultimate objective of closing resources loops (Agudo *et al.*, 2023; Chertow and Ehrenfeld, 2012; Chertow, 2000; Fraccascia, 2019; Herczeg *et al.*, 2018; Neves *et al.*, 2020).

The extant literature on IS has dealt with either specific IS cases (Oughton *et al.*, 2022; Patala *et al.*, 2020) or multiple case studies (Uusikartano *et al.*, 2022). Past studies argued conceptual frameworks (Baldassarre *et al.*, 2019; Boons *et al.*, 2017), also aimed at identifying drivers and barriers to the implementation of the IS paradigm (Domenech *et al.*, 2019; Herczeg *et al.*, 2018). Scholars pointed out the benefits stemming from the IS paradigm adoption and performance assessment (Agudo *et al.*, 2023; Fraccascia, 2019; Fraccascia *et al.*, 2021a). Past reviews of the extant literature (Mortensen and Kørnøv, 2019; Neves *et al.*, 2020; Schlüter *et al.*, 2022) grounded this research field, also proposing a research agenda for those interested in IS.

Extant literature gives a comprehensive overview of the IS concept. Nonetheless, we believe that the variables characterizing the application of IS paradigms could be further investigated. In particular, previous research focuses on (1) analyzing single variables impacting on collaboration dynamics in IS paradigm (see, e.g. Patala *et al.*, 2020), (2) analyzing the relationship between the development of IS and a small batch of these variables (see, e.g. Uusikartano *et al.*, 2022) and (3) analyzing a small batch of these variables (see, e.g. Domenech *et al.*, 2019, who explore the key characteristics of IS networks in Europe investigating, for instance, the geographical distribution and the network size). Accordingly, current literature on IS focuses on a sub-set of variables characterizing collaboration and the development of IS. An overview and empirical analysis of the several variables characterizing collaboration in IS most recurrent and rooted in extant literature deserves more academic research, as well as the relationship between these variables and the development of IS. We aim to tackle this research gap and offer (1) an overview of the most recurrent variables characterizing the collaboration in IS, (2) an empirical analysis of these variables in order to further advance current understanding about IS (Oughton *et al.*, 2022) and (3) understand if these variables depend on the chosen development strategy of the IS implementation case. We are aware this research should be, on the one hand, context-specific to capture the delicate intertwined relationship among the different variables that characterize IS paradigms, and, on the other hand, based on empirical data (Ahmad *et al.*, 2023; Neves *et al.*, 2020).

Against this background, our study aims at advancing both theory and practice of IS by (1) investigating the key variables that characterize the IS paradigm, (2) the dependence of these key variables on the IS development strategy and (3) gathering empirical evidence about such key variables in the context of IS cases in Italy. Our unit of analysis is thus represented by IS cases in Italy. The choice of Italy as the research locus is based on the need to focus on a homogeneous context, before moving to larger areas (such as the European geographical area), and on a context with an advanced development level of CE principles (in accordance, e.g. with Maranesi and De Giovanni (2020) and Susur *et al.* (2019)). The generalizability of our results to other empirical contexts will be discussed in the last Section of this manuscript, also in terms of limitations.

This manuscript is organized as follows. Section 2 illustrates the state-of-the-art about IS, describing the factors that characterize this CE collaborative paradigm. Section 3 describes the methods and materials used for this study. Section 4 reports the main findings. Section 5 discusses the main findings and the main contributions of this study, also illustrating the limitations as well as the opportunities for future research.

State-of-the-art

Circular economy

The CE has gained momentum both among researchers and practitioners leading to a debate covering different domains, such as strategic, operational and technology management (Centobelli *et al.*, 2020). The CE addresses the current "Linear Economy"– called also the "take-make-dispose" paradigm–which has led to resource depletion and pollution in recent decades. The CE is an alternative paradigm for the economy that fosters environmental sustainability (Baldassarre *et al.*, 2019; Boons *et al.*, 2017; Chiaroni *et al.*, 2021). Environmental sustainability is also one of the priorities of policy makers, who introduced, for instance, dedicated reporting schemes (Paolone *et al.*, 2020, 2021). While Linear Economy is based on an open cycle of resources, CE aims at closing this loop through the skillful combination of technological cycles and managerial practices (Bocken *et al.*, 2016; Centobelli *et al.*, 2020; Su *et al.*, 2013). The adoption of CE has been investigated at different levels. The first level is the *micro-level*. The *micro-level* refers to the application of the CE paradigm by the single company, which aims to transition from a linear to the CE in its production systems through different circular management practices. The second level is the *meso-level*. The *meso-level* refers to the application of the CE paradigm by a network of companies (business ecosystem), in which the companies involved cooperate to apply CE principles jointly within the network by leveraging latent synergies among the production processes. The third and last level is the *macro-level*. The *macro-level* refers to the application of CE on a larger scale, i.e. city, province, region, and nationwide; it requires a paradigmatic shift from the Linear to the CE not only in the industrial sector but also in all other sectors and the social and cultural system (Aarikka-Stenroos *et al.*, 2022; Franzò *et al.*, 2021; Ghisellini *et al.*, 2016; Merli *et al.*, 2018).

Industrial symbiosis

The literature about IS is rooted in Industrial Ecology, where it was first investigated starting from the late 1980s driven by concerns about the environmental sustainability of the mainstream industrial system (Frosch and Gallopoulos, 1989). Industrial Ecology aimed thus at reducing the impact on the environment by considering industrial systems as an ecosystem, where wastes from an industrial process could be considered as raw materials for another industrial process to close the resources loop (Ehrenfeld and Gertler, 1997; Frosch and Gallopoulos, 1989). It is worth mentioning that, even though the IS concept stems from biology and is rooted in Industrial Ecology, the IS concept is strictly linked to CE for three main reasons. First, IS represents one of the main application of CE at meso-level (see, e.g. Ghisellini *et al.*, 2016). Second, there are several contributions (see, e.g. Bocken *et al.*, 2016; Homrich *et al.*, 2018; Merli *et al.*, 2018) that address IS as one of the strategies to implement circular business model for closing the loop. Third and last, IS is a paradigm through which CE principles could be practically implemented (see, e.g. Domenech *et al.*, 2019).

The concept of IS leverages symbiotic collaboration and linkages among different companies to close the loop (Ehrenfeld and Gertler, 1997). These symbiotic collaborations and linkages represent key characteristics of Eco-Industrial Parks, defined as companies located close to one another "that form partnerships to exchange resources to increase resource utilization and reduce environmental impact" (Dai *et al.*, 2022). "Close proximity" is thus a key characteristic of Eco-Industrial Parks (Chertow, 2000; Côté and Cohen-Rosenthal, 1998; Dai *et al.*, 2022). Besides, Eco-Industrial Parks can originate either from the ex-post application of Eco-Industrial Parks characteristics to already existing Industrial Parks or from the *ex ante* planning and design of Industrial Park according to Eco-Industrial Parks characteristics (Chertow, 2000; Susur *et al.*, 2019). IS and Eco-Industrial Parks are strictly related (Bai *et al.*, 2014; Chertow, 2000; Neves *et al.*, 2020). IS principles are applied in Eco-Industrial Parks. The symbiotic relationship between the companies involved in an Eco-Industrial Park enable to value by-products and thus to close-the-loop (Bai *et al.*, 2014; Neves *et al.*, 2020). Close geographical proximity among the involved companies was initially considered a "hallmark" to apply IS (Chertow, 2000; Ehrenfeld and Gertler, 1997). However, geographical proximity was no more considered a milestone criterion with the late advancement of literature (Lombardi and Laybourn, 2012).

From a development strategy perspective, two main avenues for the foundation of IS implementation cases can be distinguished between self-organizing cases and facilitated cases. Self-organized cases are characterized by spontaneous agreements among the involved organizations, among the operating actors that will exchange resources. Conversely, facilitated cases are characterized by the presence of an organization (private or public) in charge of managing and facilitating (officially, disclosing it, or unofficially, without disclosing it) the implementation of IS (Bellantuono *et al.*, 2017; Côté and Cohen-Rosenthal, 1998; Dai *et al.*, 2022).

We label these two development strategies as "*bottom-up*", referring to self-organizing cases, and "*top-down*", referring to facilitated cases (following Dai *et al.*, 2022).

Identifying the variables characterizing collaboration in industrial symbiosis

To implement IS, by-products, materials, and utilities produced as output of a production process should be available to be valued and reintroduced as input into another production process. IS leads thus to environmental benefits, by closing the resources loop. Symbiotic exchanges represent the sufficient and necessary condition to implement IS. Symbiotic exchanges are needed to convert an output considered as waste into a valuable input. Besides, symbiotic exchanges are sufficient to identify an IS case. However, it should be noted that to implement symbiotic exchanges the different companies involved in IS have to collaborate. Collaboration among the companies involved in IS is a necessary condition for the implementation of symbiotic exchanges and thus IS. Collaboration enables symbiotic exchanges because it fosters the relationship among different actors. Nonetheless, collaboration between different companies does not qualify an IS case.

Symbiotic exchanges can be quite complex in nature and involving different sectors. Indeed, different *industrial sectors* often collaborate in IS cases to benefit from the possibility to use the output of one industrial sector as an input of another industrial sector. Thus, formerly considered industrial wastes are valued as input into other industrial processes (Chertow and Ehrenfeld, 2012; Mortensen and Kørnøv, 2019; Neves *et al.*, 2020; Oughton *et al.*, 2022).

Collaboration can be also characterized by the *geographical proximity* among the set of companies involved in IS (as already highlighted in previous Sections) (Chertow and Ehrenfeld, 2012; Jensen, 2016; Jensen *et al.*, 2011; Shi *et al.*, 2010; Velenturf and Jensen, 2016).

Different actors, other than companies, can collaborate in IS. On the one hand, these actors include *public actors*. They refer to the involvement of public entities such as municipalities and public-owned consortia. Public actors can support the collaboration of the organization involved in the implementation of IS by doing, e.g. managerial and administrative activities (Chertow and Ehrenfeld, 2012; Mortensen and Kørnøv, 2019; Uusikartano *et al.*, 2022).

On the other hand, these actors include *facilitators*. It refers to a non-public actor [1] which supports the collaboration among the organizations involved in the IS implementation case. Accordingly, for instance, a facilitator could be represented by a university involved in the emergence of IS in order to assess its feasibility and support the organizations in the actual implementation of IS (Patala *et al.*, 2020; Schlüter *et al.*, 2022; Walls and Paquin, 2015).

Collaboration could also be supported through an economic support. *Governmental support* (e.g. incentives) could support the collaboration among different actors by providing the needed financial support. Governmental support differs from the involvement of public actor. The former refers to incentives, supporting schemes providing economic support to the involved organizations. The latter refers to the involvement of a public entity (e.g. a municipality) in the IS implementation case (Chertow and Ehrenfeld, 2012; Herczeg *et al.*, 2018; Mortensen and Kørnøv, 2019).

Table 1 reports thus the most recurrent variables characterizing collaboration in IS, which have been identified by reviewing extant academic literature. Table 1 describes these variables–that we label as "anatomic" variables–that must be considered while analyzing cases of implementation of IS. By "anatomic" variables we mean the variables characterizing the collaboration in Industrial Symbiosis. Therefore, they are key variables. However, we named them "anatomic" variables to emphasize that these variables influence the way actors collaborate, thus the way collaboration "lives". This list of variables will constitute the theoretical framework for our empirical investigation in the specific context of Italy.

"Anatomic" variable	Definition	Main references
Industrial sectors involved	It refers to the different types of industrial sectors (e.g. manufacturing, agriculture, etc.) involved in each Industrial Symbiosis implementation case	Ahmad *et al.* (2023), Chertow and Ehrenfeld (2012), Mortensen and Kørnøv (2019), Neves *et al.* (2020), Oughton *et al.* (2022)
Public actors involvement	It refers to the involvement of public entities (e.g. municipalities, publicly-owned consortia and public research institution) in each Industrial Symbiosis implementation case	Boons *et al.* (2017), Chertow and Ehrenfeld (2012), Herczeg *et al.* (2018), Mortensen and Kørnøv (2019), Oughton *et al.* (2022), Uusikartano *et al.* (2022)
Governmental support	It refers to the economic support (e.g. through support schemes, incentives) provided by a governmental entity to each Industrial Symbiosis implementation case	Chertow and Ehrenfeld (2012), Herczeg *et al.* (2018), Mortensen and Kørnøv (2019)
Facilitator involvement	It refers to the involvement of a facilitator (i.e. an actor supporting the collaboration among the involved companies) in each Industrial Symbiosis implementation case	Boons *et al.* (2017), Chertow and Ehrenfeld (2012), Mortensen and Kørnøv (2019), Patala *et al.* (2020), Schlüter *et al.* (2022), Walls and Paquin (2015)
Geographical proximity	It refers to the geographical distance among the companies involved in each Industrial Symbiosis implementation case. In particular, if the involved companies are located within a radius distance of around 30 km (a value reported as the average reference distance by Jensen, 2016; Jensen *et al.*, 2011; Shi *et al.*, 2010), then geographical proximity is validated	Boons *et al.* (2017), Chertow and Ehrenfeld (2012), Chertow (2000), Domenech *et al.* (2019), Herczeg *et al.* (2018), Jensen (2016), Jensen *et al.* (2011), Mortensen and Kørnøv (2019), Neves *et al.* (2020), Shi *et al.* (2010), Velenturf and Jensen (2016)

Source(s): Authors' own creation

Table 1. Definition of the "anatomic" variables characterizing industrial symbiosis implementation cases

Materials and methods

A narrative literature review was performed (Fan *et al.*, 2022). We started from a small batch of articles on IS by main contributing authors (e.g. Chertow M. R., Lombardi D. R., Neves A.). Both backwards and forward snowball sampling methods were then applied to review literature on IS. Thanks to the narrative literature review it was possible, on the one side, to define the concept of IS and, on the other side, to identify the variables that characterize the collaborative relationship in IS, hereinafter referred to as "anatomic" variables. Through the narrative literature review, we gathered the articles dealing with collaboration in IS (see, e.g. Chertow and Ehrenfeld, 2012; Domenech *et al.*, 2019; Mortensen and Kørnøv, 2019; Patala *et al.*, 2020; Uusikartano *et al.*, 2022). A content analysis (Weber, 1990) was performed on the collected articles to triangulate and cluster the information provided by different articles. We identified the variables characterizing collaboration, either explicitly mentioned or implicitly mentioned through the analysis performed by the articles' authors. We did not aim to collect all the variables characterizing IS. We put major emphasis on the variables more related to the collaborative relationship among different actors in IS implementation cases. Accordingly, we focused on inter-firm collaboration dynamics. We adopted an exploratory approach. We did a convenient selection of the variables most recurrent in extant literature to include the variables characterizing collaboration most rooted in IS literature. For instance, we excluded from our analysis the variables with no impact on collaboration, such as the capital-intensiveness of the considered sector, the innovative level of the considered company, the availability of skilled workforce. We identified five different variables characterizing collaboration in IS. Lastly, we labeled those variables as "anatomic" variables.

We considered both academic and empirical sources of evidence to identify the most relevant cases of IS implementation in Italy. We qualify an IS implementation case as a collaboration between at least two different entities (or at least two different business units belonging to the same company, considering big companies) that perform symbiotic exchanges between each other.

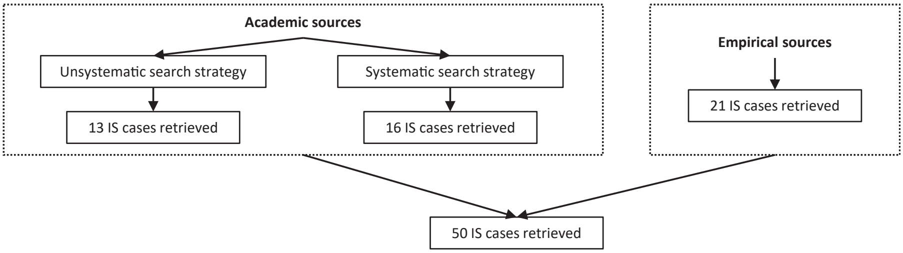
First, we reviewed current academic literature by applying both an unsystematic and a systematic search strategy (Fan *et al.*, 2022; Kraus *et al.*, 2022). As for the unsystematic search, we started from a small number of contributions on IS and we applied both backwards and forward snowball sampling methods to gather IS implementation cases in the Italian context, of which extant literature already gives evidence. As for the systematic search, we selected the Scopus database given its broad coverage of journals on CE, industrial ecology, and IS topics. We selected the keywords of IS or eco-industrial park* and Ital* (not to miss relevant contributions) collecting more than 60 articles which were then manually filtered by reviewing, first, titles and abstracts, and second, full texts to include only contributions that were relevant to our objectives. To filter the retrieved articles, we applied both exclusion and inclusion criteria. We excluded articles with only a theoretical perspective on the IS concept, with only a technical, engineering focus. Conversely, we included articles providing real-world cases of implementation of IS in Italy, providing not only technical information on industrial process but also managerial information about the actors involved and the collaboration dynamics in the implementation case. We gathered evidence of 13 IS implementation cases in Italy through the unsystematic search strategy and of 16 cases through the systematic search strategy. We thus gathered information on 29 IS implementation cases in Italy though both search strategies.

Second, to enlarge this sample and collect more evidence on the practical implementation of IS in Italy, we also considered two empirical sources providing information on the application of the IS paradigm in Italy. The first empirical source refers to the Symbiosis Users Network (SUN), which is the first Italian network on IS, involving almost 40 partners representing industrial, governmental and research entities. The second empirical source refers to the Italian Chambers of Commerce, which promote the knowledge sharing of virtuous cases and best practices referring to the IS paradigm in Italy. Overall, we gathered evidence of 27 IS implementation cases in Italy. Thereafter, we removed duplicates of which we already gathered evidence through academic sources. We thus gathered evidence of 21 additional IS implementation cases in Italy.

Combining and triangulating the academic and empirical sources enabled us to gather evidence of 50 IS implementation cases in Italy. Figure 1 presents a schematic representation of the IS cases retrieved from academic and empirical sources.

Thereafter, we implemented a multiple-case study research design for collecting evidence about the variables included in our theoretical framework (Eisenhardt, 1989). Each IS implementation case was analyzed through secondary sources of information and data (e.g. academic articles, companies' websites, sectorial reports, and press releases). Professional full-text journal databases, such as LexisNexis, were used to support our research. We collected and analyzed an overall of about 150 sources among academic articles, companies' websites, sectorial reports and almost press releases.

Table 2 provides an overview of the different secondary sources analyzed and distinguishes between "top-down" and "bottom-up" IS implementation cases. The information retrieved from the different sources was then clustered and triangulated through content analysis (Weber, 1990). Hence, we collected relevant information on the "anatomic" variables characterizing the identified IS implementation cases in Italy (refer to Table 1). A particular focus is deserved by the "anatomic" variable referring to geographical proximity. In particular, the precise geographical location of the headquarters of the companies involved in each IS implementation case has been determined through Google Maps and Google Earth applications. Only if the headquarters of the involved companies were located within a radius equal or lower than 30 km (considered as the average reference distance), then geographic proximity was validated.



Source(s): Authors' own creation

Figure 1. The industrial symbiosis implementation cases in Italy retrieved from academic and empirical sources

Secondary sources considered		Sources considered for "bottom-up" industrial symbiosis implementation cases	Sources considered for "top-down" industrial symbiosis implementation cases
Total secondary sources considered [#]		105	50
Considered secondary sources by typology [%]	academic articles	16%	36%
	companies' websites	54%	46%
	sectorial reports	11%	8%
	press releases	18%	10%

Source(s): Authors' own creation

Table 2. Numerosity and typology of considered secondary sources for "bottom-up" and "top-down" industrial symbiosis implementation cases in Italy

Table 3 presents a preliminary synoptic overview of the retrieved IS implementation cases in Italy in terms of (1) total number of involved companies, (2) number of companies involved in the same case, (3) total number of involved sectors, (4) number of sectors involved in the same case, and (4) the breakdown by geographical area. In Table 3 we reported contextual information for the whole sample of IS implementation cases, for "bottom-up" cases, referring to self-organizing cases, and for "top-down" cases, referring to facilitated cases.

Data show that the majority of IS implementation cases in Italy refer to "bottom-up" cases, i.e. to self-organizing cases sprouting from spontaneous initiatives. "Bottom-up" IS implementation cases account for 70% of the total cases, whereas "top-down" cases for the remaining 30%. Even though the number of IS implementation cases in Italy is higher for the "bottom-up" cases, the "top-down" cases involve a larger number of companies. Indeed, "top-down" cases involve more than one thousand companies, whereas "bottom-up" cases involve more than one hundred companies. The total IS implementation cases in Italy involve therefore more than one thousand and one hundred companies. The majority of cases involve between two and four different companies, which are close to each other (this insight is consistent with what reported, e.g. by Domenech *et al.* (2019), who posit that local networks involve a smaller number of companies). The 27% of "top-down" cases involve more than one hundred companies, whereas none of "bottom-up" cases involve more than one hundred companies. Lastly, 3% "bottom-up" cases involve one single company, which implements IS practices internally, i.e. exchanges are implemented between different business units of the same company.

Contextual information		Total industrial symbiosis implementation cases	"Bottom-up" industrial symbiosis implementation cases	"Top-down" industrial symbiosis implementation cases
Total number of industrial symbiosis cases in Italy [#]		50	35	15
Total number of involved companies [#]		>1,100	>100	>1,000
Number of companies involved in the same case [%]	1	2%	3%	0%
	2–5 (excluded)	52%	57%	40%
	5–10 (excluded)	20%	20%	20%
	10–100 (excluded)	18%	20%	13%
	≥100	8%	0%	27%
Total number of involved sectors [#]		8	7	7
Number of sectors involved in the same case [%]	1	10%	14%	3%
	2	38%	35%	42%
	3	38%	41%	32%
	4	11%	11%	11%
	5	4%	0%	13%
Industrial symbiosis cases in Northern Italy [%]		36%	26%	60%
Industrial symbiosis cases in Central Italy [%]		30%	31%	27%
Industrial symbiosis cases in Southern Italy [%]		34%	43%	13%

Source(s): Authors' own creation

Table 3.
Total, "bottom-up" and "top-down" industrial symbiosis implementation cases in Italy: contextual information

The distribution of the total IS implementation cases seems rather even throughout the Italian peninsula, with the Northern, Central and Southern areas accounting for 36%, 30 and 34% respectively. The distribution of the "bottom-up" IS implementation cases shows a prevalence of Southern Italy accounting for 43% of the total. Conversely, the distribution of the "top-down" IS implementation cases is rather uneven in favor of Northern Italy, accounting for 60% of the total.

Annex provides contextual information, "anatomic" variables and development strategy and a brief description for each of the 50 IS implementation cases in Italy.

Findings

In the following sections, we report evidence about the "anatomic" variables characterizing the collaborative relationship of IS implementation cases in Italy, considering first each "anatomic" variable separately, and then the most occurrent "anatomic" variable in the two development strategies.

"Anatomic" variables of industrial symbiosis implementation cases in Italy

Table 4 presents a synoptic overview of the "anatomic" variables for the retrieved IS implementation cases in Italy. In Table 4 we reported the "anatomic" variables for the whole sample of IS implementation cases, for "bottom-up" cases and for "top-down" cases.

In the following paragraphs, each "anatomic" variable is considered separately and analyzed for total, "bottom-up" and "top-down" IS implementation cases in Italy.

"Anatomic" variables		Total industrial symbiosis implementation cases [%]	"Bottom-up" industrial symbiosis implementation cases [%]	"Top-down" industrial symbiosis implementation cases [%]
Industrial sector involved	Manufacturing	52	55	45
	Water supply, sewerage, waste management and remediation activities	20	18	26
	Professional, scientific and technical activities	8	5	15
	Agriculture, fishing and forestry	6	8	2
	Construction	6	7	4
	Education	4	4	4
	Wholesale and retail trade	2	3	–
	Electricity	1	–	4
Public actor involvement	✓	40	26	73
	×	60	74	27
Governmental support	✓	16	17	13
	×	84	83	87
Facilitator involvement	✓	38	23	73
	×	62	77	27
Geographical proximity	✓	72	69	80
	×	28	31	20

Source(s): Authors' own creation

Table 4. Total, "bottom-up" and "top-down" industrial symbiosis implementation cases in Italy: "anatomic" variables

Industrial sectors involved. Eight different industrial sectors are involved in the total IS implementation cases in Italy. The industrial sectors are classified following the Italian ATECO classification (ISTAT, 2009). "Bottom-up" cases involve all but one (i.e. electricity sector) industrial sectors; similarly, "top-down" involve all but one (i.e. wholesale and retail trade sector) industrial sectors. The manufacturing sector, which refers to the transformation of materials into final products, is the main sector involved, respectively accounting for 52%, 55 and 45% of the total, "bottom-up" and "top-down" IS implementation cases. Among the manufacturing sectors, the main ones are the food and beverage sector and the chemical sector. The second most important sector is the one referring to water supply, sewerage, waste management, and remediation activities, respectively accounting for 20%, 18 and 26% of the total, "bottom-up" and "top-down" IS implementation cases. The sector referring to professional, scientific, and technical activities is the third most involved sector accounting respectively for 8%, 5 and 15% of the total, "bottom-up" and "top-down" IS implementation cases. The other sectors being involved (i.e. (1) agriculture, fishing, and forestry, (2) construction, (3) education, (4) wholesale and retail trade, (5) electricity) account for less than 10% of total, "bottom-up" and "top-down" IS implementation cases. The relevance of the manufacturing sector and of the sector referring to water supply, sewerage, waste management and remediation activities emerged also in Neves *et al.* (2020). Besides, we report also the relevance of the sector referring to professional, scientific and technical activities, whereas Neves *et al.* (2020) did not considered this sector as a main one in favor of electricity and agriculture sector. We mention, for instance, an interesting case, in which the sector referring to professional, scientific, and technical activities was involved together with the food and beverage sector. This example shows the role of collaboration between different actors to value resources and close the loop. Different manufacturing companies active in the food and beverage sector were looking for the possibility to value the by-products produced as outputs of their production processes. A company operating professional, scientific and technical activities was involved to assess different options to value those by-products from a technical and economic feasibility perspective. The possibility to value those by-products in the bio-fuels industry was identified among the most attractive ones. The possibility to involve a company operating in the bio-fuels industry pulled the companies operating in the food and beverage sector to choose this outlet.

Public actors' involvement. The involvement of a public actor refers to the involvement of public entities such as municipalities, public education and research entities, and public-owned consortia. Public actors are not involved in the majority of total and "bottom-up" IS implementation cases in Italy. 60% of the total and 74% of "bottom-up" IS implementation cases in Italy do not involve any public actor. Conversely, the majority of "top-down" IS implementation cases in Italy involve public actors (i.e. 73% of total cases). The involvement of public actors has been considered crucial in IS, especially in facilitating the emergence of "top-down" cases (see, e.g. Uusikartano *et al.*, 2022), in line with findings reported in Table 4. The involvement of public actors is relevant, for example, in district heating cases. In these cases, by-products of the manufacturing sector are valued to produce heat, which must be distributed across the buildings of the close municipality. Thus, public actors are involved in these cases to support the development of the district heating pipeline, easing the bureaucratic process to the development of the pipeline. For instance, in one of the retrieved cases the public actor was involved to value the wood processing wastes produced by a company operating near a city in Northern Italy. The collaboration between the company and the public actor enabled to unfold the possibility to use the wood processing wastes to fuel the local district heating network and thus provide heat to several residents of the nearby city.

Governmental support. Governmental support refers to the availability of support schemes, incentives, investment funds or other supporting mechanisms aimed to support the companies involved in the IS implementation cases from an economic perspective. The large majority of total, "bottom-up" and "top-down" IS implementation cases in Italy have not benefited from governmental support. There was no governmental support respectively, in 84%, 83 and 87% of the total, "bottom-up" and "top-down" IS implementation cases in Italy. Governmental support has been identified as a relevant driver on which to act to promote the adoption of both CE and IS. Moreover, the governmental support should be consistently designed by the governmental entities operating at different geographical scale (Neves *et al.*, 2020). Even though governmental support is not much developed in the specific Italian context, it could be leveraged to raise companies' awareness of IS advantages (Herczeg *et al.*, 2018; Mortensen and Kørnøv, 2019) and thus support further development of this paradigm in Italy. Even though governmental support is not widespread in the IS implementation cases in Italy, it should be mentioned that it could represent a trigger to implement the IS paradigm. The availability of supporting and incentive schemes could be the lever through which the diffusion of the IS paradigm can be promoted even among more skeptical companies, and especially among companies who lack the financial resources to implement the IS paradigm. This last point holds particularly true for start-ups. For instance, governmental support was crucial for a start-up operating in the chemical sector, which developed a prototype to value an olive oil by-product. Through governmental support, the start-up was able to further develop the prototype, collect the olive oil by-product from different local agricultural companies and extract valuable organic molecules from it.

Facilitator involvement. The involvement of a facilitator refers to the involvement of an entity acting as coordinator of the IS network, managing the relationship among all the involved companies. A facilitator is involved in the majority of "top-down" cases (i.e. 73% of total "top-down" cases). The facilitator has therefore a fundamental role in "top-down" cases (coherently to Patala *et al.*, 2020). Considering "bottom-up" cases, a facilitator is involved in the 23% of total "bottom-up" cases. Regarding the role performed by the facilitator, it acts mostly (i.e. in over 90% of the cases) as the managerial and/or technical coordinator supporting and engaging all the different companies and stakeholders involved in the case. Moreover, this managerial and/or technical coordinator role is mostly performed by professionals or education institution (i.e. in over 70% of the cases). For instance, a successful implementation of IS principles was driven by the technical and managerial coordinator role performed by an education institution. A steel mill was looking for a way to value one of the by-products coming from its production process. The local university was involved in order to assess the technical feasibility of valuing those by-products and find possible outlets in which they could be reintroduced as input. The technical feasibility study validated the possibility to value those by-products and to introduce them as an input for the cement production process. The university then supported the steel mill by contacting several companies belonging to the cement industry and by engaging them in this symbiotic exchange. In this case, the facilitator was represented by an education institution, and it coordinated the actual implementation of symbiotic exchanges from both a technical and managerial perspective. To conclude, the facilitator's role in supporting the managerial and/or technical coordination activities is a driver to increase the number of companies involved in the same case. Indeed, the majority of "top-down" cases involve a facilitator, and almost 30% of "top-down" cases involve in the same case more than one hundred companies, suggesting that there may exist a connection between facilitator involvement and the number of companies involved.

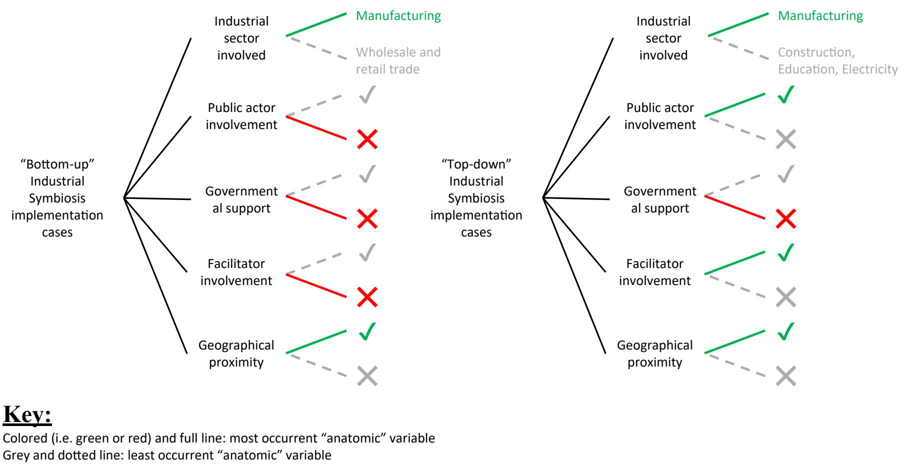
Geographical proximity. The relevance of geographical proximity was initially considered as fundamental in the seminal contribution by Chertow (2000) and then questioned over time (see, e.g. Lombardi and Laybourn, 2012). Our findings confirm the paramount relevance of geographical proximity. Indeed, the large majority of total, "bottom-up" and "top-down" IS implementation cases in Italy involve companies with geographical proximity (i.e. the involved companies are within an average radius of 30 km, identified as a reference distance value, e.g. by Jensen, 2016). Respectively, 72%, 69 and 80% of the total, "bottom-up" and "top-down" IS implementation cases in Italy involve companies with geographical proximity. For instance, geographical proximity is relevant in IS cases involving companies operating in the agricultural sector. Local agricultural companies involved in IS implementation cases in Italy are mainly small and medium size companies. In these cases, an innovative company found a new way to value the agricultural by-products, but it needs a constant and steady flow of agricultural by-products. Therefore, by-products coming from different agricultural companies must be grouped to collect enough quantities. Being geographically close could be a relevant lever to reduce managerial complexity in agricultural by-products handling and transportation. A quite interesting counter case shows that the need for geographical proximity might be overcome by new digital technologies, such as networking platforms. Platforms have been acknowledged also as a risk-mitigation tool (Caporuscio *et al.*, 2023). For instance, a textile networking platform connects companies operating in the collection and sorting of used garments with tailors and designers. Through the networking platform used garments are collected, sorted through the adoption of Artificial Intelligence, and then distributed to a network of more than twenty tailors and designers distributed across the whole country, who make them wearable again.

The "anatomy" of industrial symbiosis implementation cases in Italy

This Section summarizes the "anatomy" of IS implementation cases in Italy. In Section 2, we presented the two development strategies for IS, namely, "bottom-up" and "top-down". We focus here on these two development strategies to investigate whether a certain "anatomic" variable is more occurrent when a specific development strategy is followed. Thereafter, we try to investigate the rationale behind the prevalence of that "anatomic" variable under a specific development strategy. We aim thus to identify the most relevant "anatomic" variables to be pursued when following a specific development strategy.

Figure 2 shows the most and the least occurrent value for each analyzed "anatomic" variable for "bottom-up" and "top-down" IS implementation cases in Italy. The most occurrent variable is defined as the value of the "anatomic" variable with the maximum occurrence value. The least occurrent variable is defined as the value of the "anatomic" variable with the minimum occurrence value.

Given the most and least occurrent "anatomic" variables reported in Figure 2, it is possible to group them in two clusters. The first cluster refers to development-dependent variables. These variables vary depending on the development strategy of the IS implementation cases in Italy (i.e. "bottom-up" and "top-down"). Public actors' and facilitators' involvement are development-dependent variables. Most of the sole "top-down" IS implementation cases in Italy meet these two variables. The involvement of a facilitator or a public actor is thus relevant in the implementation of "top-down" cases given that these two actors could support the development of the IS implementation cases. Indeed, the involvement of a facilitator or a public actor makes it easier to involve a larger number of companies in "top-down" IS implementation cases in Italy. The facilitator and/or the public actor (depending on the peculiarities of each case) act as a coordinator and can more easily engage a larger number of companies handling the managerial complexity (without any managerial burden for the companies involved in the practical implementation of IS). Besides, the facilitator and/or the



Source(s): Authors' own creation

Figure 2. The most and least occurrent "anatomic" variables of "bottom-up" and "top-down" industrial symbiosis implementation cases in Italy

public actor raise awareness of IS' benefits and build trust between the different companies involved in the IS paradigm (consistently with Patala *et al.* (2020) and Uusikartano *et al.* (2022)). For instance, the involvement of public-owned consortia could facilitate the implementation of IS by easing the administrative burden for the companies involved, which could thus focus on the activities enabling to implement symbiotic exchanges.

The second cluster refers to development-independent "anatomic" variables. These variables do not vary depending on the development strategy of the IS implementation cases in Italy (i.e. "bottom-up" and "top-down"). The industrial sector, governmental support and geographical proximity belong to this group of variables. Companies involved in IS implementation cases in Italy are characterized by geographical proximity, which emerges as a key characteristics (consistently with Chertow, 2000) of IS implementation cases in Italy regardless of the development strategy. The low level of governmental support does not provide clear incentives to companies willing to implement IS principles. This result could be affected by the low level of development of national policies on IS (coherently to Neves *et al.*, 2020). Indeed, the regulatory framework was only recently updated with the new National Strategy for CE (Ministero della Transizione Ecologica, 2022). Neither the low governmental support nor the unclear regulatory framework indicate effective ways through which to implement IS to the Italian companies. Consequently, most of Italian IS implementation cases involve the same sector (i.e. the manufacturing sector) and companies characterized by geographical proximity, which self-organize, and implement IS principles.

Discussion and conclusion

Key contributions

This article's contributions to extant literature in the field of CE and IS are threefold: (1) we improve characterizing IS by proposing a set of variables to describe the anatomy of IS, (2) we gathered a rich evidence of IS implementation cases in Italy and we characterized the gathered cases with respect to the "anatomic" variables (3) we discussed the relationship between the "anatomic" variables and the development strategies (top-down and bottom-up) of IS cases.

From the academic research point of view, we further advance the debate about the application of CE at meso level focusing on IS. We provide a research framework, which analyzes the "anatomic" variables characterizing collaboration in IS. This analysis could be the starting point to dig deeper into the application of CE at meso level enabled by collaboration. The "anatomic" variables offer an answer to the quest for additional research argued by Ahmad *et al.* (2023), Neves *et al.* (2020). Moreover, these "anatomic" variables have been analyzed with reference to a particular and rich empirical context.

We distinguished these "anatomic" variables in two clusters: development-depend and development-independent variables. The development-dependent variables are represented by public actors' involvement and facilitator involvement. We identified these two "anatomic" variables as development-dependent variables because most of the sole "top-down" IS implementation cases in Italy meet these two variables. The role of a facilitator and/or a public actor was found important, especially for "top-down" cases, by handling managerial complexity and promoting awareness and trust among the involved companies (merging what stems from Patala *et al.*, 2020, with Uusikartano *et al.*, 2022).

The development-dependent variables are represented by industrial sectors involved, governmental support and geographical proximity. We identified these three "anatomic" variables as development-independent variables because they do not vary between "top-down" and "bottom-up" development strategies of the IS implementation cases in Italy. Through this empiric analysis of the "anatomic" variables, we first of all validated the paramount relevance of the manufacturing sector, involved in the majority of Italian cases (consistently with what reported by Neves *et al.*, 2020). Our empirical findings highlight the low level of governmental support for IS in Italy, suggesting policymakers a lever on which to act to promote the deployment of IS among Italian companies – the recent National Strategy for CE (Ministero della Transizione Ecologica, 2022) could be an important keystone in the governmental support path. At the same time, we highlighted policy makers have a potential role in (1) easing the bureaucratic and administrative procedures connected with IS implementation (e.g. with specific norms on secondary raw materials usage) and (2) providing incentive schemes to companies willing to implement IS but lacking proper financial means (e.g. start-ups). Lastly, empirical evidence reports the importance of geographical proximity among the involved companies. Indeed, even if the minority of Italian cases involve companies with no geographical proximity, this "anatomic" variable is still nowadays a paramount variable in IS confirming the seminal definition by Chertow (2000), in contrast with Lombardi and Laybourn (2012).

Implications for scholars, managers, and policy makers

We believe that this article presents relevant implications for researchers, practitioners, and policy makers. From an academic standpoint, we strengthen the paramount role of collaborative relationship to implement CE at meso level, with reference to IS implementation. Besides we posit that the collaborative relationship can be characterized by five "anatomic" variables whose values differ based on the development strategy of the IS implementation. From a managerial standpoint, this article can represent a practical guideline for managers looking for how to implement IS. For instance, managers can grasp from this article the most relevant industrial sectors to be involved to implement IS. From a policy maker standpoint, this article represents a call for action. Indeed, we posit that governmental support is not yet fully developed to support properly the development of IS. Therefore, we suggest policy makers to focus on IS supporting schemes to promote the deployment of IS.

Limitations

Our contributions should be interpreted in the light of their limitations. The first limit refers to the application of our theoretical framework to a single Country, and this limits the generalizability of results. Even though we argue that the framework can be generalizable to other socio-technical contexts, the occurrence of the "anatomic variables" could significantly differ from Country to Country. Besides, the distribution of the overall IS cases is rather even throughout the Italian peninsula. However, the "bottom-up" cases and the "top-down" cases are more focused, respectively, on Southern and Northern Italy. This uneven distribution of "bottom-up" and "top-down" cases could represent a further limitation to the generalizability of results and an avenue for future research. In this view, we call for future research to identify and compare the values of the "anatomic" variables characterizing the IS paradigm in other geographical areas (i.e. other countries and/or larger areas such as the European Union).

Moreover, a sample of geographical areas at different development stages of their IS paradigm could be compared to better capture the potential relative relevance that the variables might assume at different stages. In this view, we argue for further longitudinal investigations of IS paradigms. The observation over time of the "anatomic" variables in both "bottom-up" and "top-down" IS implementation cases can unveil what variables–and, consequently, what policies and incentives–should be prioritized to facilitate the growth and sustainability over time of the cases of IS. Finally, there could have been an interpretation bias in analyzing the extant literature to identify the "anatomic" variables and design the theoretical framework that collects the main characteristics of an IS paradigm. In this view, further academic research should confirm or deny our list of "anatomic" variables, also based on empirical evidence from other Countries.

Future research avenues

Future avenues for future research emerge by broadening the scope of our work. First, a deeper investigation into the relationships among the micro, meso and macro implementation levels of CE could be performed. Indeed, a single company (i.e. micro-level) could be active at a national scale (i.e. macro-level) but also at a continent or global level. In the same way, a network of companies could involve companies operating in the same country or beyond, in different continents. Therefore, the boundaries to distinguish among micro, meso and macro level could be further investigated to advance a clearer definition of the different implementation levels of CE. Second, a deeper investigation into the relationships between the companies' headquarters geographical distance and IS implementation could be performed. The "anatomic" variable referring to geographical proximity deserves additional research efforts, for instance further studies could focus on (1) confirming or questioning the reference average distance and (2) on performing sensitivity analysis on the reference average distance. Third, the role of unofficial facilitators was not investigated in this article. In particular, unofficial facilitators refer to stakeholders who, even though not formally recognized and appointed as facilitators, actually perform such role (Schlüter *et al.*, 2022). Therefore, a deeper investigation into the "anatomic" variable referring to the facilitator's involvement distinguishing between official and unofficial facilitators could deserve further academic research. Fourth, we considered two development strategies (i.e. "top-down" and "bottom-up"). However, these two strategies are not dichotomic and mixed approaches are applicable even though not investigated in this paper. Further studies could thus tackle mixed approaches by focusing, for instance, on those in which bottom-up development is facilitated through top-down methods. Fifth and last, we selected the "anatomic" variables as the ones most recurrent in IS literature. Accordingly, further research could focus on broadening the set of "anatomic" variables to be considered.

Despite the above limitations, we argue that our study could contribute to a better understanding of the IS phenomenon as an emerging paradigm for a sustainable future.

Note

1. Facilitators could be not only non-public actors but also public actors in geographical contexts other than Italy.

References

Aarikka-Stenroos, L., Chiaroni, D., Kaipainen, J. and Urbinati, A. (2022), "Companies' circular business models enabled by supply chain collaborations: an empirical-based framework, synthesis, and research agenda", *Industrial Marketing Management*, Vol. 105 No. December 2020, pp. 322-339, doi: 10.1016/j.indmarman.2022.06.015.

Agudo, F.L., Bezerra, B.S. and Gobbo Júnior, J.A. (2023), "Symbiotic readiness: factors that interfere with the industrial symbiosis implementation", *Journal of Cleaner Production*, Vol. 387 January, 135843, doi: 10.1016/j.jclepro.2023.135843.

Ahmad, F., Bask, A., Laari, S. and Robinson, C.V. (2023), "Business management perspectives on the circular economy: present state and future directions", *Technological Forecasting and Social Change*, Vol. 187 No. October 2022, 122182, doi: 10.1016/j.techfore.2022.122182.

Bai, L., Qiao, Q., Yao, Y., Guo, J. and Xie, M. (2014), "Insights on the development progress of National Demonstration eco-industrial parks in China", *Journal of Cleaner Production*, Vol. 70, pp. 4-14, doi: 10.1016/j.jclepro.2014.01.084.

Baldassarre, B., Schepers, M., Bocken, N., Cuppen, E., Korevaar, G. and Calabretta, G. (2019), "Industrial Symbiosis: towards a design process for eco-industrial clusters by integrating Circular Economy and Industrial Ecology perspectives", *Journal of Cleaner Production*, Vol. 216, pp. 446-460, doi: 10.1016/j.jclepro.2019.01.091.

Bellantuono, N., Carbonara, N. and Pontrandolfo, P. (2017), "The organization of eco-industrial parks and their sustainable practices", *Journal of Cleaner Production*, Vol. 161 No. September 2015, pp. 362-375, doi: 10.1016/j.jclepro.2017.05.082.

Bocken, N., de Pauw, I., Bakker, C. and van der Grinten, B. (2016), "Product design and business model strategies for a circular economy", *Journal of Industrial and Production Engineering*, Vol. 33 No. 5, pp. 308-320, doi: 10.1080/21681015.2016.1172124.

Boons, F., Chertow, M., Park, J., Spekkink, W. and Shi, H. (2017), "Industrial symbiosis dynamics and the problem of equivalence: proposal for a comparative framework", *Journal of Industrial Ecology*, Vol. 21 No. 4, pp. 938-952, doi: 10.1111/jiec.12468.

Caporuscio, A., Schiavone, F., Bernhard, F. and Escobar, O. (2023), "The role of B2B digital platforms for managing future worldwide crisis. A strategic sensitivity framework for exploiting the breakthrough technological innovations", *Technological Forecasting and Social Change*, Vol. 194 July, 122741, doi: 10.1016/j.techfore.2023.122741.

Centobelli, P., Cerchione, R., Chiaroni, D., Del Vecchio, P. and Urbinati, A. (2020), "Designing business models in circular economy: a systematic literature review and research agenda", *Business Strategy and the Environment*, Vol. 29 No. 4, pp. 1734-1749, doi: 10.1002/bse.2466.

Chertow, M.R. (2000), "Industrial symbiosis: literature and taxonomy", *Annual Review of Energy and the Environment*, Vol. 25 No. 1, pp. 313-337, doi: 10.1146/annurev.energy.25.1.313.

Chertow, M. and Ehrenfeld, J. (2012), "Organizing self-organizing systems: toward a theory of industrial symbiosis", *Journal of Industrial Ecology*, Vol. 16 No. 1, pp. 13-27, doi: 10.1111/j.1530-9290.2011.00450.x.

Chiaroni, D., Vecchio, P.D., Peck, D., Urbinati, A. and Vrontis, D. (2021), "Digital technologies in the business model transition towards a circular economy", *Resources, Conservation and Recycling*, Vol. 168, 105286, doi: 10.1016/j.resconrec.2020.105286.

Côté, R.P. and Cohen-Rosenthal, E. (1998), "Designing eco-industrial parks: a synthesis of some experiences", *Journal of Cleaner Production*, Vol. 6 Nos 3-4, pp. 181-188, doi: 10.1016/s0959-6526(98)00029-8.

Dai, Y., Day, S., Masi, D. and Gölgeci, I. (2022), "A synthesised framework of eco-industrial park transformation and stakeholder interaction", *Business Strategy and the Environment*, Vol. 31 No. 7, pp. 3122-3151, doi: 10.1002/bse.3067.

Domenech, T., Bleischwitz, R., Doranova, A., Panayotopoulos, D. and Roman, L. (2019), "Mapping industrial symbiosis development in Europe_ typologies of networks, characteristics, performance and contribution to the circular economy", *Resources, Conservation and Recycling*, Vol. 141 February 2019, pp. 76-98, doi: 10.1016/j.resconrec.2018.09.016.

Ehrenfeld, J. and Gertler, N. (1997), "Industrial ecology in practice", *Journal of Industrial Ecology*, Vol. 1 No. 1, pp. 67-79, doi: 10.1162/jiec.1997.1.1.67.

Eisenhardt, K.M. (1989), "Building theories from case study research", *The Academy of Management Review*, Vol. 14 No. 4, pp. 532-550, doi: 10.2307/258557.

Fan, D., Breslin, D., Callahan, J.L. and Iszatt-White, M. (2022), "Advancing literature review methodology through rigour, generativity, scope and transparency", *International Journal of Management Reviews*, Vol. 24 No. 2, pp. 171-180, doi: 10.1111/ijmr.12291.

Fraccascia, L. (2019), "The impact of technical and economic disruptions in industrial symbiosis relationships: an enterprise input-output approach", *International Journal of Production Economics*, Vol. 213 No. January 2018, pp. 161-174, doi: 10.1016/j.ijpe.2019.03.020.

Fraccascia, L., Giannoccaro, I. and Albino, V. (2021a), "Ecosystem indicators for measuring industrial symbiosis", *Ecological Economics*, Vol. 183 No. June 2020, 106944, doi: 10.1016/j.ecolecon.2021.106944.

Fraccascia, L., Yazdanpanah, V., van Capelleveen, G. and Yazan, D.M. (2021b), "Energy-based industrial symbiosis: a literature review for circular energy transition", *Environment, Development and Sustainability*, Vol. 23 No. 4, pp. 4791-4825, doi: 10.1007/s10668-020-00840-9.

Franzò, S., Urbinati, A., Chiaroni, D. and Chiesa, V. (2021), "Unravelling the design process of business models from linear to circular: an empirical investigation", *Business Strategy and the Environment*, Vol. 30 No. 6, pp. 2758-2772, doi: 10.1002/bse.2892.

Frosch, R.A. and Gallopoulos, N.E. (1989), "Strategies for Manufacturing the impact of industry on the environment", *Scientific American*, Vol. 261 No. September, pp. 144-153, doi: 10.1038/scientificamerican0989-144.

Ghisellini, P., Cialani, C. and Ulgiati, S. (2016), "A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems", *Journal of Cleaner Production*, Vol. 114, pp. 11-32, doi: 10.1016/j.jclepro.2015.09.007.

Herczeg, G., Akkerman, R. and Hauschild, M.Z. (2018), "Supply chain collaboration in industrial symbiosis networks", *Journal of Cleaner Production*, Vol. 171, pp. 1058-1067, doi: 10.1016/j.jclepro.2017.10.046.

Homrich, A.S., Galvão, G., Abadia, L.G. and Carvalho, M.M. (2018), "The circular economy umbrella: trends and gaps on integrating pathways", *Journal of Cleaner Production*, Vol. 175, pp. 525-543, doi: 10.1016/j.jclepro.2017.11.064.

ISTAT (2009), "Classificazione delle attività economiche Ateco 2007".

Jensen, P.D. (2016), "The role of geospatial industrial diversity in the facilitation of regional industrial symbiosis", *Resources, Conservation and Recycling*, Vol. 107, pp. 92-103, doi: 10.1016/j.resconrec.2015.11.018.

Jensen, P.D., Basson, L., Hellawell, E.E., Bailey, M.R. and Leach, M. (2011), "Quantifying 'geographic proximity': experiences from the United Kingdom's national industrial symbiosis programme", *Resources, Conservation and Recycling*, Vol. 55 No. 7, pp. 703-712, doi: 10.1016/j.resconrec.2011.02.003.

Kraus, S., Breier, M., Lim, W.M., Dabić, M., Kumar, S., Kanbach, D., Mukherjee, D., Corvello, V., Piñeiro-Chousa, J., Liguori, E., Palacios-Marqués, D., Schiavone, F., Ferraris, A., Fernandes, C. and Ferreira, J.J. (2022), "Literature reviews as independent studies: guidelines for academic practice", *Review of Managerial Science*, Vol. 16 No. 8, pp. 2577-2595, doi: 10.1007/s11846-022-00588-8.

Lombardi, D.R. and Laybourn, P. (2012), "Redefining industrial symbiosis: crossing academic-practitioner boundaries", *Journal of Industrial Ecology*, Vol. 16 No. 1, pp. 28-37, doi: 10.1111/j.1530-9290.2011.00444.x.

Maranesi, C. and De Giovanni, P. (2020), "Modern circular economy: corporate strategy, supply chain, and industrial symbiosis", *Sustainability (Switzerland)*, Vol. 12 No. 22, pp. 1-25, doi: 10.3390/su12229383.

Merli, R., Preziosi, M. and Acampora, A. (2018), "How do scholars approach the circular economy? A systematic literature review", *Journal of Cleaner Production*, Vol. 178, pp. 703-722, doi: 10.1016/j.jclepro.2017.12.112.

Ministero della Transizione Ecologica (2022), "Strategia Nazionale Per l'Economia Circolare".

Mortensen, L. and Kørnøv, L. (2019), "Critical factors for industrial symbiosis emergence process", *Journal of Cleaner Production*, Vol. 212, pp. 56-69, doi: 10.1016/j.jclepro.2018.11.222.

Neves, A., Godina, R., Azevedo, S.G. and Matias, J.C.O. (2020), "A comprehensive review of industrial symbiosis", *Journal of Cleaner Production*, Vol. 247, 119113, doi: 10.1016/j.jclepro.2019.119113.

Oughton, C., Kurup, B., Anda, M. and Ho, G. (2022), "Industrial symbiosis to circular economy: what does the literature reveal for a successful complex industrial area?", *Circular Economy and Sustainability*, Vol. 2 No. 4, pp. 1317-1344, doi: 10.1007/s43615-022-00153-1.

Paolone, F., Sardi, A., Sorano, E. and Ferraris, A. (2020), "Integrated processing of sustainability accounting reports: a multi-utility company case study", *Meditari Accountancy Research*, Vol. 29 No. 4, pp. 985-1004, doi: 10.1108/MEDAR-01-2020-0667.

Paolone, F., Granà, F., Martiniello, L. and Tiscini, R. (2021), "Environmental risk indicators disclosure and value relevance: an empirical analysis of Italian listed companies after the implementation of the Legislative Decree 254/2016", *Corporate Social Responsibility and Environmental Management*, Vol. 28 No. 5, pp. 1471-1482, doi: 10.1002/csr.2181.

Patala, S., Salmi, A. and Bocken, N. (2020), "Intermediation dilemmas in facilitated industrial symbiosis", *Journal of Cleaner Production*, Vol. 261, 121093, doi: 10.1016/j.jclepro.2020.121093.

Schlüter, L., Mortensen, L., Drustrup, R., Gjerding, A.N., Kørnøv, L. and Lyhne, I. (2022), "Uncovering the role of the industrial symbiosis facilitator in literature and practice in Nordic countries: an action-skill framework", *Journal of Cleaner Production*, Vol. 379 October, 134652, doi: 10.1016/j.jclepro.2022.134652.

Schwarz, E.J. and Steininger, K.W. (1997), "Implementing nature's lesson: the industrial recycling network enhancing regional development", *Journal of Cleaner Production*, Vol. 5 Nos 1-2, pp. 47-56, doi: 10.1016/s0959-6526(97)00009-7.

Shi, H., Chertow, M. and Song, Y. (2010), "Developing country experience with eco-industrial parks: a case study of the Tianjin Economic-Technological Development Area in China", *Journal of Cleaner Production*, Vol. 18 No. 3, pp. 191-199, doi: 10.1016/j.jclepro.2009.10.002.

Su, B., Heshmati, A., Geng, Y. and Yu, X. (2013), "A review of the circular economy in China: moving from rhetoric to implementation", *Journal of Cleaner Production*, Vol. 42, pp. 215-227, doi: 10.1016/j.jclepro.2012.11.020.

Susur, E., Martin-Carrillo, D., Chiaroni, D. and Hidalgo, A. (2019), "Unfolding eco-industrial parks through niche experimentation: insights from three Italian cases", *Journal of Cleaner Production*, Vol. 239, 118069, doi: 10.1016/j.jclepro.2019.118069.

Uusikartano, J., Saha, P. and Aarikka-Stenroos, L. (2022), "The industrial symbiosis process as an interplay of public and private agency: comparing two cases", *Journal of Cleaner Production*, Vol. 344 No. July 2021, 130996, doi: 10.1016/j.jclepro.2022.130996.

Velenturf, A.P.M. and Jensen, P.D. (2016), "Promoting industrial symbiosis: using the concept of proximity to explore social network development", *Journal of Industrial Ecology*, Vol. 20 No. 4, pp. 700-709, doi: 10.1111/jiec.12315.

Walls, J.L. and Paquin, R.L. (2015), "Organizational perspectives of industrial symbiosis: a review and synthesis", *Organization and Environment*, Vol. 28 No. 1, pp. 32-53, doi: 10.1177/1086026615575333.

Weber, R.P. (1990), "Basic content analysis", *Sage*, Vol. 82 No. 397, doi: 10.2307/2289192.

Annex

Table A1. Industrial symbiosis implementation cases in Italy

Id	Involved companies [#]	Involved sectors [#]	Involved sectors – classification[1]	Geographical area	Public actors involvement	Facilitators involvement	Governmental support	Geographical proximity	Development strategy	Brief description
1	4	2	Manufacturing; Professional, scientific and technical activities	Northern Italy	✓	✓	X	✓	Top-down	The slag produced as a by-product of the steel production is used to produce polymeric components, such as vulcanized plastics
2	3	2	Manufacturing; Professional, scientific and technical activities	Northern Italy	✓	✓	X	✓	Top-down	Glucose and xylose are the main sugars released during the pre-treatment and hydrolysis processes of various residual lignocellulosic biomasses (residues from corn cultivation, wheat stubble and sugar processing waste). Vitamin B9 (folic acid) is synthesized from sugar cane processing waste through the usage of biotechnologies

(*continued*)

Table A1.

Id	Involved companies [#]	Involved sectors [#]	Involved sectors – classification[1]	Geographical area	Public actors involvement	Facilitators involvement	Governmental support	Geographical proximity	Development strategy	Brief description
3	3	2	Manufacturing; Water supply, sewerage, waste management and remediation activities	Southern Italy	✓	X	X	✓	Bottom-Up	Industrial inert wastes are collected and used to produce, on the one side, building materials and, on the other side, energy through a waste-to-energy process. In particular, the energy produced is used by the local cement production plant instead of traditional energy sources
4	3	3	Construction; Professional, scientific and technical activities; Water supply, sewerage, waste management and remediation activities	Southern Italy	X	✓	X	X	Bottom-Up	A recycling system for plasterboard has been created, which allows to recover the plaster and give it new life while keeping its chemical-physical qualities intact. Plaster recovered from rubble and inert waste is used to create new plasterboard panels and other products

(*continued*)

Id	Involved companies [#]	Involved sectors [#]	Involved sectors – classification[1]	Geographical area	Public actors involvement	Facilitators involvement	Governmental support	Geographical proximity	Development strategy	Brief description
5	3	2	Manufacturing; Agriculture, fishing and forestry	Southern Italy	X	X	X	X	Bottom-Up	Establishment of a new plant to value the integument (i.e. a by-product of almonds' processing) collected from local agricultural companies. The new plant receives as input the integument to produce supplements for human use and antioxidant polyphenols to be used in natural cosmetics
6	3	2	Manufacturing; Agriculture, fishing and forestry	Southern Italy	✓	X	X	X	Top-down	Poultry wastes and manure are collected and used in order to produce a fertilizer

(*continued*)

Table A1.

Table A1.

Id	Involved companies [#]	Involved sectors [#]	Involved sectors – classification[1]	Geographical area	Public actors involvement	Facilitators involvement	Governmental support	Geographical proximity	Development strategy	Brief description
7	5	4	Construction; Water supply, sewerage, waste management and remediation activities; Education; Manufacturing	Northern Italy	✓	X	X	X	Bottom-Up	Inert wastes are collected and valorized to produce materials for road maintenance. In particular, asphalt is produced using technologies based on the usage of high temperature heat and recycled materials (industrial waste or dismantled pavement)
8	2	1	Construction	Southern Italy	X	X	X	X	Bottom-Up	Inert construction and demolition wastes are collected and valorized to produce new building elements
9	2	1	Construction	Northern Italy	X	X	X	X	Bottom-Up	Inert construction and demolition wastes are collected and valorized to produce new building elements

(*continued*)

Id	Involved companies [#]	Involved sectors [#]	Involved sectors – classification[1]	Geographical area	Public actors involvement	Facilitators involvement	Governmental support	Geographical proximity	Development strategy	Brief description
10	7	2	Manufacturing; Water supply, sewerage, waste management and remediation activities	Northern Italy	✓	X	X	✓	Top-down	Sewage sludge is collected and used in various manufacturing sectors such as, cement and fertilizers sectors
11	5	3	Manufacturing; Water supply, sewerage, waste management and remediation activities; Professional, scientific and technical activities	Northern Italy	✓	✓	X	✓	Bottom-Up	Industrial symbiosis based on the collaboration between private and public actors. Thanks to the collaboration between private companies and public actors, it is possible to optimize water management through the implementation of circular principles
12	4	3	Manufacturing; Water supply, sewerage, waste management and remediation activities; Professional, scientific and technical activities	Northern Italy	X	✓	X	X	Top-down	Biological wastes and by-products (such as, vegetable oils, animal fats and used cooking oils) are collected and valued to produce biofuels

(*continued*)

Table A1.

Table A1.

Id	Involved companies [#]	Involved sectors [#]	Involved sectors – classification[1]	Geographical area	Public actors involvement	Facilitators involvement	Governmental support	Geographical proximity	Development strategy	Brief description
13	4	2	Manufacturing; Water supply, sewerage, waste management and remediation activities	Southern Italy	X	X	X	X	Bottom-Up	Biological wastes and by-products (such as, vegetable oils, animal fats and used cooking oils) are collected and valued to produce biofuels, especially bio-methane
14	2	1	Manufacturing	Northern Italy	X	X	X	✓	Bottom-Up	The slag produced as a by-product of the steel production process is used to produce asphalt or it is reintroduced in the steel production process as a secondary raw material
15	5	4	Manufacturing; Education; Water supply, sewerage, waste management and remediation activities; Wholesale and retail trade	Southern Italy	✓	✓	X	X	Bottom-Up	Wastes collected from large-scale retail trade and organic wastes collected from agricultural companies are used as a biomass to produce energy through an anaerobic digester

(continued)

Id	Involved companies [#]	Involved sectors [#]	Involved sectors – classification[1]	Geographical area	Public actors involvement	Facilitators involvement	Governmental support	Geographical proximity	Development strategy	Brief description
16	3	2	Manufacturing; Professional, scientific and technical activities	Central Italy	✓	✓	✓	✓	Bottom-Up	A company producing kitchen composite products and whitegoods produces also wastes and by-products as its production process' output. These wastes and by-products are reused by another company producing coffee machines as input of its production process
17	4	2	Manufacturing; Agriculture, fishing and forestry	Northern Italy	✓	X	X	✓	Bottom-Up	The waste heat from the steel production process is used to heat up the water of a local aquaculture farm. The wastewater in output of the aquaculture farm is used by local agricultural companies for irrigation

(continued)

Table A1.

Table A1.

Id	Involved companies [#]	Involved sectors [#]	Involved sectors – classification[1]	Geographical area	Public actors involvement	Facilitators involvement	Governmental support	Geographical proximity	Development strategy	Brief description
18	5	2	Manufacturing; Water supply, sewerage, waste management and remediation activities	Northern Italy	X	X	X	✓	Bottom-Up	Production of cosmetics from organic wine waste (i.e. pomace) collected from local agricultural companies. Production of accessories and furnishing accessories made through the recovery and reuse of post-consumer wine bottles
19	2	1	Water supply, sewerage, waste management and remediation activities	Central Italy	✓	X	X	✓	Top-down	Municipal wastes are collected, and different recovery strategies are implemented, such as energy recovery, composting plant

(continued)

Id	Involved companies [#]	Involved sectors [#]	Involved sectors – classification[1]	Geographical area	Public actors involvement	Facilitators involvement	Governmental support	Geographical proximity	Development strategy	Brief description
20	3	2	Manufacturing; Education	Southern Italy	✓	✓	X	✓	Bottom-Up	A new type of biscuit has been produced by replacing about 30% of the type "0" flour from the basic recipe with a flour obtained from the grains, which are the by-products of the craft beer production process collected from a local brewery
21	1	1	Manufacturing	Central Italy	X	X	✓	✓	Bottom-Up	The by-products of steel processing are valued using special laser cutting and press-bending machines, through which it is possible to create design accessories such as: book rests, paper holders and mobile phone holders

(*continued*)

Table A1.

Table A1.

Id	Involved companies [#]	Involved sectors [#]	Involved sectors – classification[1]	Geographical area	Public actors involvement	Facilitators involvement	Governmental support	Geographical proximity	Development strategy	Brief description
22	10+	3	Manufacturing; Agriculture, fishing and forestry; Wholesale and retail trade	Southern Italy	X	X	X	✓	Bottom-Up	Fruit and vegetable waste from the large-scale retail trade are collected and used by a local farmer, who breed snails. Livestock waste is used by the local farm for the self-production of vermicompost, which is reused as a natural organic soil improver to restore and increase the yield of the fields
23	10+	2	Manufacturing; Water supply, sewerage, waste management and remediation activities	Central Italy	X	X	X	✓	Bottom-Up	Expanded polystyrene waste is collected at the local production points. The collected expanded polystyrene waste is then crushed and reintroduced into the manufacturing process as secondary raw materials

(continued)

Table A1.

Id	Involved companies [#]	Involved sectors [#]	Involved sectors – classification[1]	Geographical area	Public actors involvement	Facilitators involvement	Governmental support	Geographical proximity	Development strategy	Brief description
24	5	3	Manufacturing; Water supply, sewerage, waste management and remediation activities; Education	Southern Italy	✓	✓	X	✓	Bottom-Up	Recovery of fish waste deriving from fish processing industrial processes. The goal is to transform them into precious resources for the nutraceutical sector (for example, products with high added value of omega 3), for agriculture (organic fertilizers), and in other sectors (bioenergy)
25	7	2	Manufacturing; Agriculture, fishing and forestry	Central Italy	X	X	✓	✓	Bottom-Up	Recovery of food processing by-products to produce paper. An innovative packaging material with cereal and legume peels has been developed

(*continued*)

Table A1.

Id	Involved companies [#]	Involved sectors [#]	Involved sectors – classification[1]	Geographical area	Public actors involvement	Facilitators involvement	Governmental support	Geographical proximity	Development strategy	Brief description
26	10+	1	Manufacturing	Northern Italy	X	X	X	X	Bottom-Up	Food surplus, in particular bread that is collected from restaurants, bakeries, and large-scale retail trade, is reintroduced as input in the beer production process. Beer production by-products, known as "grains", are used to produce bakery products, by upcycling "grains" that usually become animal feed or are disposed of
27	2	2	Manufacturing; Water supply, sewerage, waste management and remediation activities	Central Italy	X	X	X	✓	Bottom-Up	Recycled PET, collected by waste management companies, is reused as internal insulation material to produced prefabricated infill panels for industrial and/or commercial buildings

(*continued*)

Id	Involved companies [#]	Involved sectors [#]	Involved sectors – classification[1]	Geographical area	Public actors involvement	Facilitators involvement	Governmental support	Geographical proximity	Development strategy	Brief description
28	10+	1	Manufacturing	Northern Italy	X	✓	X	X	Bottom-Up	Used clothes are collected, sorted and distributed in a network of tailors and designers, who make them wearable again
29	2	2	Manufacturing; Water supply, sewerage, waste management and remediation activities	Central Italy	X	X	✓	✓	Bottom-Up	Linoleum by-products from both production and installation processes are collected and valued. The linoleum is reused to replace virgin raw material, while the jute substrate is reused as biomass to produce energy

(*continued*)

Table A1.

Table A1.

Id	Involved companies [#]	Involved sectors [#]	Involved sectors – classification[1]	Geographical area	Public actors involvement	Facilitators involvement	Governmental support	Geographical proximity	Development strategy	Brief description
30	4	3	Manufacturing; Agriculture, fishing and forestry; Wholesale and retail trade	Southern Italy	X	X	X	✓	Bottom-Up	In a packaging center, citrus fruits are selected according to the quality standards required for fresh table fruit; those that do not meet these requirements are used to produce juices, jams, creams. Essential oils are extracted from a by-product of citrus juices production (i.e. peels). Another by-product of citrus processing, the so-called pastazzo, is used to produce compost. Organic citrus essential oil is combined with extra virgin olive oil with higher acidity to produce cosmetic products

(continued)

Id	Involved companies [#]	Involved sectors [#]	Involved sectors – classification[1]	Geographical area	Public actors involvement	Facilitators involvement	Governmental support	Geographical proximity	Development strategy	Brief description
31	4	3	Manufacturing; Water supply, sewerage, waste management and remediation activities; Agriculture, fishing and forestry	Central Italy	X	X	✓	✓	Bottom-Up	A local farmer breeds soldier fly larvae, which feed on a large variety of organic material, including decomposing ones, such as agricultural or agri-food industry waste. The larvae are used as raw material for pet food. The larvae breeding residues can be used as fertilizer or as input to anaerobic digestion
32	10+	1	Manufacturing	Central Italy	X	X	✓	✓	Bottom-Up	A by-product of olive oil production, typically disposed of, is used to produce a concentrate with up to 20% of polyphenols, i.e. organic molecules with antioxidant, anti-inflammatory properties, etc

(*continued*)

Table A1.

Table A1.

Id	Involved companies [#]	Involved sectors [#]	Involved sectors – classification[1]	Geographical area	Public actors involvement	Facilitators involvement	Governmental support	Geographical proximity	Development strategy	Brief description
33	3	3	Manufacturing; Water supply, sewerage, waste management and remediation activities; Construction	Southern Italy	X	X	X	✓	Bottom-Up	The residual waste heat produced as output of the steel production process is used to produce energy. By-products of the steel production process, such as slag, is reintroduced as input of the cement production process
34	350+	3	Manufacturing; Water supply, sewerage, waste management and remediation activities; Electricity	Central Italy	X	✓	X	✓	Top-down	The wastewater management is optimized through the implementation of circular principles in the textile industry
35	150+	2	Manufacturing; Water supply, sewerage, waste management and remediation activities	Central Italy	✓	X	X	✓	Top-down	Leather processing by-products and wastes are used to produce fertilizers. The leather processing wastewater is treated in order to purify it and recover metals, such as chromium

(*continued*)

Id	Involved companies [#]	Involved sectors [#]	Involved sectors – classification[1]	Geographical area	Public actors involvement	Facilitators involvement	Governmental support	Geographical proximity	Development strategy	Brief description
36	10+	3	Manufacturing; Water supply, sewerage, waste management and remediation activities; Agriculture, fishing and forestry	Southern Italy	X	X	X	X	Bottom-Up	The by-products of the agro-food (fruit and vegetables, cereals and dairy products) production process are used to produce energy and fertilizers
37	2	1	Manufacturing	Southern Italy	X	X	X	✓	Bottom-Up	The wastewater of the production process of a local company producing gluten-free products is collected and treated by another company. This company uses the treated water as an input to produce the spirulina microalgae

(*continued*)

Table A1.

Table A1.

Id	Involved companies [#]	Involved sectors [#]	Involved sectors – classification[1]	Geographical area	Public actors involvement	Facilitators involvement	Governmental support	Geographical proximity	Development strategy	Brief description
38	3	2	Manufacturing; Water supply, sewerage, waste management and remediation activities	Southern Italy	X	X	X	✓	Bottom-Up	A by-product of a dairy company (i.e. the whey) is concentrated. Water in excess from the concentration process is used for industrial washing and it is used as input in the fertilizer industry and in the food supplement industry
39	3	1	Manufacturing	Central Italy	X	X	X	X	Bottom-Up	Two by-products of the production process of a company producing high quality pillows and mattresses are valued. First, fabric production scraps are processed and offered to consumer retailers. Second, elastic disc shavings are used to produce lower quality pillows

(*continued*)

Table A1.

Id	Involved companies [#]	Involved sectors [#]	Involved sectors – classification[1]	Geographical area	Public actors involvement	Facilitators involvement	Governmental support	Geographical proximity	Development strategy	Brief description
40	5	4	Manufacturing; Water supply, sewerage, waste management and remediation activities; Education; Professional, scientific and technical activities	Northern Italy	✓	✓	✓	✓	Top-down	Innovative technologies, such as ultrasound, are used to extract the CO_2 from industrial wastewater and gaseous wastes. The extracted CO_2 is reused to produce biomethane, through an upgrading process
41	3	3	Manufacturing; Professional, scientific and technical activities; Electricity	Southern Italy	X	✓	X	✓	Top-down	Industrial Symbiosis involving a chemical company and a hydroelectric plant, in which the energy produced by the hydroelectric plant is used for the industrial activities of the local chemical company
42	3	3	Manufacturing; Water supply, sewerage, waste management and remediation activities; Agriculture, fishing and forestry	Northern Italy	X	X	X	✓	Bottom-Up	Wood processing by-products and wastes are valorized and used to: essential oils, hydrolat and ultimately, energy

(*continued*)

Table A1.

Id	Involved companies [#]	Involved sectors [#]	Involved sectors – classification[1]	Geographical area	Public actors involvement	Facilitators involvement	Governmental support	Geographical proximity	Development strategy	Brief description
43	13	2	Manufacturing; Professional, scientific and technical activities	Northern Italy	✓	✓	X	X	Top-down	Top-down Industrial Symbiosis with the involvement of a facilitator and a public actor which coordinate different manufacturing companies to value their production processes' by-products and wastes through symbiotic exchanges
44	3	2	Manufacturing; Water supply, sewerage, waste management and remediation activities	Central Italy	X	X	X	✓	Bottom-Up	Local paper companies produce paper products from recycled raw material coming from pulping and separate collection

(*continued*)

Id	Involved companies [#]	Involved sectors [#]	Involved sectors – classification[1]	Geographical area	Public actors involvement	Facilitators involvement	Governmental support	Geographical proximity	Development strategy	Brief description
45	19	1	Manufacturing	Southern Italy	X	X	X	✓	Bottom-Up	The by-products, i.e. metal scraps, produced by companies operating in the motorcycle sector are treated and reintroduced as input of industrial processes instead of virgin metal
46	200+	3	Manufacturing; Water supply, sewerage, waste management and remediation activities; Construction	Northern Italy	✓	✓	X	✓	Top-down	Industrial network involving many companies which collectively share services and infrastructures, such as a dedicated railway line connected with the national railway line. Industrial wastes and by-products are valued, such as waste heat which is used to produce energy

(*continued*)

Table A1.

Table A1.

Id	Involved companies [#]	Involved sectors [#]	Involved sectors – classification[1]	Geographical area	Public actors involvement	Facilitators involvement	Governmental support	Geographical proximity	Development strategy	Brief description
47	8	3	Manufacturing; Water supply, sewerage, waste management and remediation activities; Professional, scientific and technical activities	Central Italy	✓	✓	X	✓	Bottom-Up	Companies belonging to different sectors (e.g. ceramics, carpentry, engineering services) have established a partnership to share wastes, plants, know-how and knowledge to recover and value industrial wastes and by-products
48	5	5	Manufacturing; Water supply, sewerage, waste management and remediation activities; Education; Professional, scientific and technical activities; Construction	Northern Italy	✓	✓	✓	✓	Top-down	The waste heat produced by the steel plant is reused for district heating. Furthermore, the slag produced during the metal melting in the electric furnace constitutes the raw material of the granulate, which can be used for civil engineering and road construction works

(continued)

Id	Involved companies [#]	Involved sectors [#]	Involved sectors – classification[1]	Geographical area	Public actors involvement	Facilitators involvement	Governmental support	Geographical proximity	Development strategy	Brief description
49	150+	2	Manufacturing; Water supply, sewerage, waste management and remediation activities	Northern Italy	✓	✓	X	✓	Top-down	Industrial network involving several companies which collectively share services and infrastructures, such as a dedicated railway line, two dedicated motorway toll booths, different business services and a fiber optic ring. line. Industrial wastes and by-products are valued, such as waste heat which is used to produce energy

(*continued*)

Table A1.

Table A1.

Id	Involved companies [#]	Involved sectors [#]	Involved sectors – classification[1]	Geographical area	Public actors involvement	Facilitators involvement	Governmental support	Geographical proximity	Development strategy	Brief description
50	90	2	Manufacturing; Water supply, sewerage, waste management and remediation activities	Central Italy	X	✓	X	✓	Top-down	Industrial network involving many companies operating in maritime activities such as shipbuilding, mechanical and repair activities, marine furnishings, food supplies, logistics, shipping agencies and fish processing. The industrial network shares services which offer training, consultancy and business support to value wastes and by-products

Note(s): [1]Industrial sectors are classified according to the Italian ATECO classification (ISTAT, 2009)
Source(s): Authors' own creation

About the authors

Lucrezia Sgambaro is a Ph.D. Candidate at Politecnico di Milano. She got her Bachelor and Master of Science degrees at Politecnico di Milano in Management Engineering, with major in Energy and Environmental Management. Her research interest is in the interplay between management and sustainability topics with a particular emphasis on circular economy, sustainable mobility and decarbonization. Lucrezia Sgambaro is the corresponding author and can be contacted at: lucrezia.sgambaro@polimi.it

Davide Chiaroni is a Professor of Strategy and Marketing at Politecnico di Milano, where he obtained his PhD in Management, Economics and Industrial Engineering. His research interest is in the management of innovation, with a particular focus on circular economy, sustainability, energy management and smart ecosystems (grid, buildings, communities, cities). He is among the most cited author in the field of Circular Economy, where he studies the implications of the adoption of circular business models.

Emanuele Lettieri (Ph.D.) is Professor of Accounting, Finance and Control at Politecnico di Milano (Italy). His research interests are at the intersection of technology, management and policy in professional and knowledge-intensive industries such as life science, medtech and healthcare. He has developed a distinctive expertise in impact assessment of innovation, foresight and future thinking, sustainability and sustainable future, with a focus on digital technology and digital transformation. He has contributed to many European projects.

Francesco Paolone holds a degree in Business Administration and Management at Bocconi University. He obtained his Ph.D. at Università degli studi di Teramo (Italy). He is currently Full Professor of Business Economics and Accounting at Universitas Mercatorum (Rome, Italy). His research interests are in the field of financial economics, business administration, accounting and business models innovation. He is author of several scientific contributions in important national and international conferences, journals and books.