



Implementing Industrial Symbiosis Incentives: an Applied Assessment Framework for Risk Mitigation

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Abstract

Industrial symbiosis (IS) is a business model that proposes symbiotic exchanges, allowing the flow of resources, wastes, and utilities between companies. In recent years, IS initiatives have been exponentially growing around the world. This can be attributed to the increasing awareness on the possibility of obtaining economic, environmental, and social benefits through the implementation of this model. Despite the exponential growth of IS initiatives, the companies are still facing problems in the achievement of reliable and permanent synergies. Over the years the literature has identified several factors in the IS emerging process. Incentives are among these factors, being defined as unlocking tools or mechanisms related to diverse dimensions such as economic, political, social, intermediaries, process, and technology. Authors believe that the large-scale implementation of IS incentives has not been properly addressed. In order to promote facilitated IS implementation and achieve a replicator effect, incentives should be fully addressed. In many case studies, it has been observed that the incentives for IS can be threatened by risks, compromising the implementation, and hindering the emerging process. This study developed a dedicated framework that is composed of incentive identification from best practices of IS and expert consultation; a risk assessment model based on risk factors identification and clustering; and finally, the mitigation actions based on the assessment outputs. The main result of this study is one set of mitigations actions that correlate the implementation levels (clusters) and the potential stakeholders involved.

Keywords Circular economy · Industrial symbiosis · Incentives · Assessment framework · Risk mitigation

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Introduction

Industrial Symbiosis and Its Emerging Process

The concept of Industrial Symbiosis (IS) was introduced in the early 70s [1] and is considered a subfield of Industrial Ecology. Inspired by the biological mutualistic relationships [2], IS makes reference to an environmental metaphor, in practical terms, this business model aims to create an ecosystem represented by a group of industrial actors sharing waste, resources, and utilities [2]. The principle behind IS is quite simple, instead of being thrown away or destroyed, surplus resources generated by an industrial process are captured and redirected for use as a ‘new’ input into another process by other industries providing a mutual benefit or symbiosis [3]. The firms involved through these synergies can obtain economic, environmental, and social benefits by sharing resources, wastes, information, knowledge, expertise, political support, supply networks, and distribution markets [4]. In most cases, these benefits might translate into a reduction in the operational costs [5], reduction of greenhouse gas emissions [6], increases in knowledge and skills [7], job creation [8], tax benefits [9], and economic profit [10].

In the last 20 years, IS has been gaining greater importance in the industrial context around the world [11]. This increase in IS implementation is mainly due to the concerns about climate change [11] and the growing awareness of the possibility of obtaining diverse benefits through the implementation of this model [12]. This fact has been especially verified in regions with intense industrial activities like the European Union [12, 13], United States [14–18], and China [8, 19–26]. As a consequence, those regions have promoted frameworks, programs, and plans that support the facilitated implementation of circular economy and its business models [27, 28]. One of the examples that can be highlighted is the European Circular Economy Action Plan and the European Green Deal [29, 30], these two initiatives are aligned with the purposes of scaling up the circular economy. Regardless of the significant potential for the application of IS, it seems that the effective application of IS is not entirely exploited and there is a range of opportunities for its large-scale implementation [31]. To achieve a large-scale implementation of IS (Implementation across industrial sectors in a national or regional perspective) it will be necessary to overcome the main challenges and barriers, such as social issues (trust environment and social inertia) [32, 33], lack of appropriate investment for synergies development [34–37], lack of regulation and framework for IS [31, 38, 39], amongst others.

Several authors have identified and characterized the IS emerging process [12, 31, 40], having a special focus on understanding the early stages and promotion of synergies. These studies have also recognized the existence of a group of factors that appear and end up being crucial for the synergies promotion [12, 41], they are normally called key or intervening factors. Those factors are defined as determinants for the emerging process of synergies [42], cross-cutting different dimensions, namely, policy, social, economic, intermediaries, geographical, and technological [4, 12, 40, 42–48]. Over the years, literature categorizes these key factors into different groups: enablers, drivers, challenges, barriers, etc. Regardless of which classification and denomination literature suggest, that they can intervene in three perspectives: factors that promote and facilitate the development of IS supporting or unlocking (enablers, drivers) [40, 47]; factors that hinder or constrain the implementation of this practice (barriers, challenges) [47, 49], and factors that ignite the implementation (triggers) [39].

Recently, several studies have also mentioned the importance of incentives for industrial symbiosis [50–52], especially incentives associated with fiscal/ process [53, 54], policy [55,

56], and economic domains [54, 56–58]. Nevertheless, it was also observed that most of the studies do not discern between incentives and enablers, and therefore, are constantly confused and several times allocated in the same category. This approach is doubtful since the incentives and enablers for IS are in different categories due to their different scopes and contexts. Enablers are factors that support the emerging process of industrial symbiosis while incentives, are instruments or mechanisms supporting the consolidation of the enablers [59]. These incentives must have a principle of replicability, meaning that they can be applied under different conditions and different national realities. For instance, the existence of regulations and policies that allow symbiotic exchanges has been identified in various studies as a fundamental enabler for the promotion of IS [31, 40, 60]. This kind of policies are typically supported by instruments, such as landfill taxes [12], environmental taxes [6, 61], and Industrial Symbiosis plans [28]. All these instruments are incentives for IS.

Gap Knowledge and Research Question

The purpose of this paper is to advance the understanding of IS emerging process through the comprehensive identification and characterization of IS incentives. Therefore, it is necessary to analyse and correlate the incentives with their implementation risks and contribute to the promotion of mitigation actions that encourage the risk avoidance.

The research was developed and structured in order to answer the following questions:

- What are the main incentives for IS implementation on large-scale?
- What are the common risk factors and implementation risks related to the incentives?
- What are the actions that could be promoted in order to mitigate the risk associated with the incentives?

This study is based on an integrated approach that is supported by a literature review, best practices experiences, expert consultation, and external observation. This paper is structured as follows: the “Introduction” section above, is an introductory section discussing the paper motivations and research questions. The “Research Methodology Definition” section describes the research methodology performed in this study. The “Promoting an Assessment Framework for Risk Mitigation” section performs the incentive assessment and proposes the mitigation actions and the “Result Discussions” section promotes a critical discussion of the results. The conclusions are drawn in the last section.

This research arises in the sequence of an extensive study developed in the context of the project SCALER [62], which envisages the promotion of IS practices in the European process industry.

Research Methodology Definition

The first step of this study was to define the methodology research that would allow the achievement of the proposed objectives. This research methodology consists of two main phases. The first one dedicated to the identification of incentives by literature review and expert consultation. The second one is dedicated to the incentive analysis in a detailed perspective by the development of an applied assessment framework for risk evaluation,

finally resulting in a set of mitigation actions from different perspectives. Figure 1 represents the proposed research methodology model.

Phase 1: Incentive Identification

Literature Review

The IS incentives identification was initially conducted through a literature review and complemented by expert consultation. The main objective of this review was to identify IS implementation best practices and their associated intervening factors and incentives [39]. The identification was developed through searches in the database of Science Direct, Scopus, and the internet search engine machine Web of Science, with the keyword ‘Industrial Symbiosis’ in the title, abstract, or keywords. This search allowed the identification of 210 scientific journal papers (Initial sample). The main criteria used in the final reference selection phase were related to the existence of implementation case studies (Directly or indirectly). Theoretical studies and conceptual approaches were not considered for this study. After the analyses, 85 key publications were identified (Final sample).

It is important to highlight that this characterization was mainly based on scientific peer-reviewed journal articles. Nevertheless, other publications (non-scientific publications) were also considered, such as technical reports of EU countries, EU official documents, statistics, and case studies. Figure 2 represents the systematic approach followed in the development of the literature review.

After selecting the final sample of references, a thematic analysis of the papers’ content to identify emerging themes, common threads, and best practices was performed. The main outputs of the literature review are derived from two perspectives: At the macro level, the literature review offered an overview of the different dimensions of incentives in implementation cases. In this sense, six fundamental dimensions of incentives (Economic, policy, technical, social, information, and process) were suggested for this study and subsequently validated in the expert consultation. From a more specific perspective, the literature review allowed us to characterize the various incentives and instruments that have been promoted. Both results are presented and discussed in the “Promoting an Assessment Framework for Risk Mitigation” section.

Expert Consultation

The second method used for the incentives identification was based on expert consultation through a dedicated inquiry. This inquiry aimed to obtain the opinion of IS experts about their perspective on the role of incentives and validate their critical dimensions. More than 40

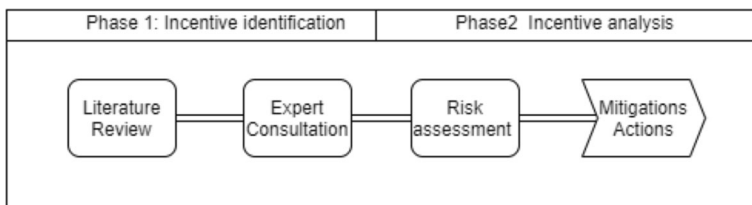


Fig. 1 Research methodology model

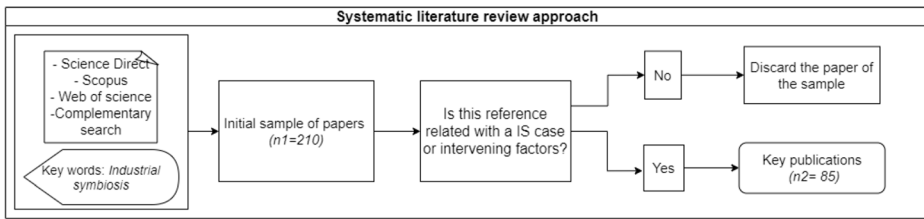


Fig. 2 Systematic literature review approach

international IS experts were invited to share their experience in the inquiry, including businesses and practitioners that are involved in various stages of IS implementation, from emergent to fully implemented, in all sectors. Most of the respondents were contacted by email, where the scope of the study and the methodology used was introduced.

In terms of design, the inquiry was built up with an exploratory character rather than test or generate statistical significance for any of the themes included. It incorporated 24 open-ended and multiple-choice questions in a qualitative, online, and anonymous survey [39]. The survey was based on the literature, best practices analysis, and embedded the following key themes and dimensions: triggers, stakeholders, benefits, enablers, barriers, incentives, challenges, intermediaries, and tools and technologies. Nevertheless, for this study, only questions related to the main incentives for developing and implementing resource synergies were considered.

After the initial contact and dissemination process, a total of 17 responses were received, corresponding to companies and industrial actors from diverse sectors. The responders totalize 8 different countries. Figure 2, shows the total number of respondents, their sectors, countries, and maturity level. The triangulation of the main findings from the literature review and the expert inquiry resulted in a final incentive identification (Presented in the “Promoting an Assessment Framework for Risk Mitigation”).

Concerning the sample of participants that were involved in the expert inquiry, most of the agents were companies associated with diverse industrial sectors such as chemical, manufacturing, plastic productions, water treatment, and cork. Nevertheless, there are also a considerable number of participants associated with non-industrial activities such as consultancy and Research & Development.

In terms of the maturity level in IS, most participants have more than three years of experience regarding IS implementation, therefore a medium-high maturity level was predominant in the sample. The maturity level is defined by the level of knowledge (specific and generic) in IS implementation that the responders have, this level is derived from the responder experience in resource synergy initiatives. Approximately 56% have a high level of maturity, 38% have a medium level and only 6% have an early maturity level.

Eight countries participated in the survey. Most are located on the European continent (Portugal, Italy, Germany, France, and the Netherlands). The rest of the participants are distributed in various regions of the Asian continent (China, Singapore, and Israel).

Concerning the responder's opinion on the incentives, most of the responders considered that the economic benefits, the availability of willing partners to develop synergies, and policies supporting IS are the most relevant incentives. Those incentives have been represented transversally in some studies [54–58], reinforcing the importance of these factors in the emerging process. Respondents have also identified other incentives that they consider relevant for IS implementation, namely, local/ regional regulation for IS / EC, technical motivation, and co-financing funds. However, they have been represented with less relevance.

Phase 2: Incentive Analysis

Risk Assessment

Once the incentives were clearly identified, it was necessary to assess their implementation risks. This evaluation was promoted by a risk assessment model. This assessment is based on the basic principles of risk management, consisting of 3 main steps, risk identification, risk analysis/ evaluation, and risk treatment, which are promoted by the ISO 31000 [63]. This normative provides guidelines, principles, a framework, and a process for managing risk. The main reason to select the model proposed by this normative was the standardization character and the methodology that can be adapted for this study. Figure 3 represents the applied assessment framework proposed for this study.

The applied assessment framework is structured in three sequential steps: (a) the first step, risk identification, allows the identification of implementation risks through the analysis of external and internal factors by documentation review techniques [64]; (b) the second step focus on the analysis of their common factors associated allowing to identify and evaluate the implementation risks, in order to propose measures for the risk treatment; (c) the third step defines the mitigation actions associated with risk treatment. It should be noted that the risk assessment is mostly based on a mixed approach that is supported by implementation case experiences, expert consultation, and external observation. Figure 4

Mitigations Actions

The last step of phase 2 is the promotion of mitigation actions. The mitigation actions are based on the risk factors and implementation risks that were previously identified. The approach used was developed in the perspective of avoiding and reducing the implementation

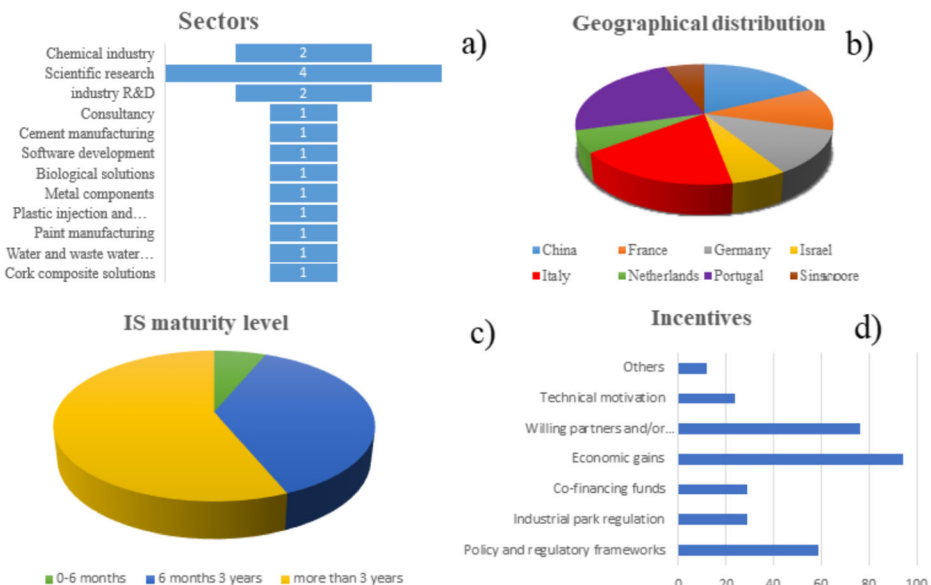


Fig. 3 Sectors (a), geographical distribution (b), IS maturity Level (c) and incentives (d)

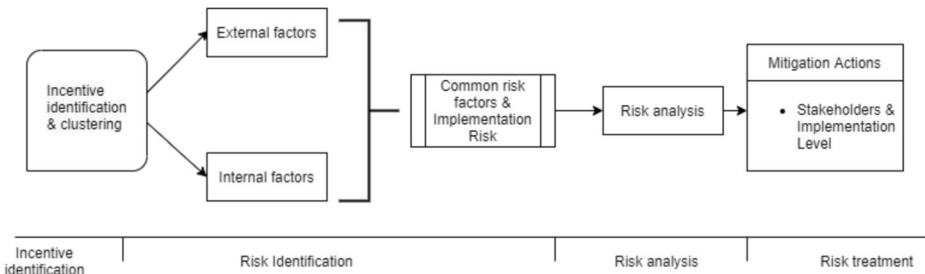


Fig. 4 Applied assessment framework for risk mitigation definition

risks. Mitigation action implementation is highly dependent on case study specificities and slight adaptations based on empirical practices are advised. In this sense, a dedicated structure of mitigation actions was designed to promote the correlation between the implementation levels (clusters) and the potential stakeholders involved. The proposed set of mitigation actions can be a useful insight for companies aiming to start symbiotic exchanges.

Promoting an Assessment Framework for Risk Mitigation

IS Incentives Identification

Based on the literature review and the expert consultation process, core incentives for IS in their different dimensions were identified. Due to their diversity, and in order to present a comprehensive and simplified organizational structure, they were grouped into three different clusters. The clustering process was based on thematic affinity criteria of the incentives finally compiled as:

1. Law and Politics
2. Material / technical management
3. Company / networks management

These clusters involve the six pre-identified dimensions of incentives: economic, policy, technical, social, information, and process. Table 1 presents the final incentive identification framework, integrating the identified clusters, dimensions, and incentives.

The first cluster, law & politics, is constituted by two dimensions of incentives: economic and policy. In the economic dimension, two types of financial incentives were identified, those that help attract funds to promote synergies and those that help to reduce associated costs. Among the main instruments that allow fundraising, financing programmes such as co-funding investment or R&D projects can be highlighted. The SPIRE calls of the H2020 programme addressing resource efficiency is a good example of this kind of incentive [66]. Complementary, there are initiatives that allow reducing operational costs through tariffs or special regimes that reward companies that pursue the incorporation of renewable energies. This kind of incentive has proven to be an important incentive in Nordic countries [6]. In this dimension, other incentives were also identified that promote the purchase and sale of waste in a centralized, digital, and legal manner, therefore generating economic advantages in the purchase of surpluses. The MOR (Organized Waste Market) promoted by the Portuguese Environment Agency is an example of the negotiation of waste through digital platforms [67].

Table 1 Incentive identification framework (Adapted from [65])

Clusters	Dimension	Incentive identification
Law and Politics	Economic	Co-funding investment Programs Common Waste Market Premium Tariff Energy Bio fuels Tariff
	Policy	Landfill Tax Desegregated industrial waste policy framework Environmental and Energy Taxes Green criteria as key element for public procurement Improving Energy and Resource Efficiencies through policy
Material/ technical management	Technical	Transition to Industry 4.0 programs Integrated method to calculated benefits Share data bases and tools
Company/ networks management	Social	Training programs (Build awareness) Collaborative networks Sectorial clustering Social Corporate Responsibility programs
		Information
	Process	Promotion of protocols

Two types of incentives were identified in the policy dimension: fiscal instruments and policy instruments that support companies to include environmental concepts in their activities. Concerning fiscal instruments, they can be separated into two main approaches; those that penalize environmental pollution or excessive and inefficient use of resources, such as the Norwegian CO₂ tax [61], and those taxes that promote the use of alternative methods with less environmental impact, such as the Finnish reduced taxation [6]. Regarding policy instruments, the most effective and predominant instrument has been the industrial waste policy framework. Specifically disaggregated policies for industrial waste valorisation (National, regional, and local) allows the synergies implementation between industries, through the simplification of industrial waste declassification procedure. In this same dimension, other political incentives that have great relevance were identified, namely the strategies for green growth, such as the Green Public Procurement [68], resource/ energy efficiency programs [69], and circular economy plans [30].

The second cluster is completely focused on technical incentives. This kind of incentive complements the other dimensions as they play a fundamental role in the implementation of IS on large-scale [40, 70]. For instance, programs for the transition to Industry 4.0 allow the automation of the industry and consequently the control and monitoring of the production processes in an optimized manner [71–73]. Also, tools such as cyber-physical systems, cloud manufacturing, and the Internet of Things (IoT) have proven to be useful in this process [70, 74]. The shared databases and ICT tools are also important incentives [75], since the integration of datasets and geolocation data are crucial for matchmaking and mimicking methodologies [76, 77].

The third cluster, ‘company/networks management’, is divided in three dimensions: social, information, and process. Social and information-related incentives are relevant for the IS promotion, especially those instruments and programs that support the creation of awareness at the community and institutional level. Some of the most popular instruments are collaborative

networks [78], clusters [4], training initiatives, dissemination programs, green marketing [79], and action plans [12]. These instruments help to overcome barriers such as lack of trust and social inertia through the creation of awareness. Other important instruments in this cluster are the process incentives since they encourage companies to join and formalize the synergies process. Among those incentives can be mentioned the protocols, partnerships, and formal contracts [39].

Assessing Implementation Risk

In a risk management process, it is important to consider and contextualize the associated factors to the risk, including those who occur internally (social, cultural, legal, and regulatory) or externally (strategy, capacities, norms, and relationships) [63]. The purpose of any risk analysis is so to understand the nature of the risk and its characteristics. In this phase of the assessment, the common risk factors were identified in each cluster. This identification was based on general risk factors (Appendix 1) and their incidence principle. The main objective was to unveil the common factors, and eliminate overlaps between them, selecting those of the highest priority for mitigation (higher prevalence). Tables 2, 3, and 4 presents the common risk factors and implementation risks obtained for each cluster. Appendix 1 presents all the general risk factors identified in the first part of the assessment.

The internal common risk factors listed in the first cluster are mostly associated with financial risks such as dependency and lack of funds to promote IS [39, 44, 80]. Social factors such as lack of motivation [47] and lack of knowledge [42] were also identified. From an external perspective, lack of policy that allows symbiotic exchanges [31, 38], the complexity of the regulations for waste recovery, and limitations of national financing in terms of industrial sustainability were the main risk factors identified. The implementation risks derived from the factors analysis of this cluster indicate that there are two perspectives of implementation risks, macro, and meso. In the macro perspective, the loss of financing and continuity of incentives, stagnation of policies that do not allow the effective promotion of IS, and alteration of national policies to less favourable regimes were identified as relevant risks. Concerning the meso perspective, the risks are mainly associated to the low adherence of the business actors to incentives.

From an internal perspective, the risk factors identified in the second cluster are directly associated with the lack of resources (technical and economic) that generates a lack of capacity (on the part of the companies) to face new challenges [31]. There are also risk factors related to confidentiality issues that might involve the implementation of tools and platforms for Industrial Symbiosis [81]. From an external perspective, some risks were identified such as the lack of financing or lack of political conditions to support this type of incentive [31, 38, 39, 44, 80]. These common risk factors are translated mainly into risk implementation such as lack of effective implementation of technological incentives and loss of financing.

In the third cluster, common risk factors of a meso nature are dominant regarding the internal and external perspectives. These risk factors are mainly linked with social factors at the business and community level, such as lack of receptivity, business scepticism [20], lack of community awareness [47], and lack of motivation [47]. Nevertheless, there was also the presence of a risk factor from a macro perspective, mainly associated with political and financial domains such as the lack of financing and the lack of presence of policymakers. These common risk factors can be translated into implementation risks such as low application of this type of incentive due to low participation or interest.

Table 2 Cluster 1 common risk factors and implementation risks

Cluster #1	Incentive identification	Common risk factors		Implementation risks
		Internal	External	
Law and Politics (theoretical approach)	<p>Co-funding investment Programs</p> <p>Common Waste Market</p> <p>Premium Tariff Energy</p> <p>Bio fuels Tariff</p> <p>Landfill Tax</p> <p>Desegregated industrial waste policy framework</p> <p>Environmental and Energy Taxes</p> <p>Green criteria as key element for public procurement</p> <p>Improving the Energy Efficiency and Resource Efficiency through policy</p>	<ul style="list-style-type: none"> • Dependence on state funds for the implementation of the different incentives • Lack of initial investment to adapt the industrial process (Technology, materials, equipment) • Lack or insufficient knowledge regarding IS implementation (technical and strategic) • Business scepticism regarding industrial ecology concepts • Lack of motivation and resistance of companies to initiatives/ projects (Resistance to change) 	<ul style="list-style-type: none"> • Lack of national funding to promote and maintain diverse initiatives (tariffs, projects, co-funding, etc.) • Lack of standardized environmental regulation to support special regimes (tariffs and taxes) • The bureaucratic complexity associated with transition and adaptation to new policies and implementation of incentives (Tariffs and taxes) • Low receptivity of large companies 	<ul style="list-style-type: none"> • Low adherence rate for the initiatives (funding, tariff, markets, taxes special regime) • Loss of financing due to poor receptivity or hinder the development of IS initiatives • Stagnation of policies that do not allow Alteration of policies for a less favourable approach for the IS promotion

Table 3 Cluster 2 common risk factors and implementation risks

Cluster #2	Common risk factors		Implementation risks
	Incentive identification	<div style="display: flex; justify-content: space-between;"> Internal External </div>	
Material/ technical management (Technical approach)	<p>Transition to Industry 4.0 programs</p> <p>Integrated method to calculated benefits</p> <p>Share data bases and tools</p>	<ul style="list-style-type: none"> • Confidentiality issues (Data management and sensitive data) • Lack of technical knowledge and IT skills necessary to join the kind of initiatives • Inability of the company to face new technological challenges that this type of initiatives implies 	<ul style="list-style-type: none"> • Lack of financing to promote and maintain programs, platforms, and tools • Lack of trust from companies to share their data (sensitive data, industrial data, etc.) • Lack of regulation that supports and implement this kind of incentives <p>Low application/use and participation by the companies and the end-users (industrial actors)</p> <p>Loss, discontinuation or cancellation of financing programs</p> <p>Lack of data</p>

Table 4 Cluster 3 Common risk factors and Implementation risks

Cluster #3	Incentive identification	Common risk factors		Implementation risks
		Internal	External	
Company/ networks management (Business approach)	<p>Training programs (Build awareness)</p> <p>Collaborative networks</p> <p>Sectorial clustering</p> <p>Social Corporate Responsibility programs</p> <p>Networking initiatives</p> <p>Knowledge and training</p> <p>Dissemination initiatives</p> <p>Promotion of protocols</p>	<ul style="list-style-type: none"> • Lack of receptivity and trust among employees to join initiatives that eventually could change the business as usual • Business scepticism about new environmental challenges and social barriers (resistance to change) • Lack of motivation and collaborative approach to join the initiatives (networks, cluster, programs, etc.) 	<ul style="list-style-type: none"> • Lack of funding to promote and maintain diverse initiatives (training program, dissemination plans, networks, etc.) • Reduced government presence as a driving agent in the clusters, programs, and networks • Lack of community and business actors' interest 	<p>Low attendance and participation by the business actors, scientific community</p> <p>Low implementation and application for the incentives (Agreements, protocols, Social Corporate Responsibility plans, transfer knowledge activities, training course, etc.)</p>

Table 5 Set of mitigation actions

Cluster	Stakeholders	Mitigation actions
Law and Politics (theoretical approach)	National Entities	<ul style="list-style-type: none"> Promote new policies and legal frameworks that support the transition to a more sustainable industry Reinforce the participation in IS initiatives and programs Reinforce the allocation of sufficient national funds for IS/EC Promote and prioritize supranational initiatives to tackle climate change
	Regional/ local government	<ul style="list-style-type: none"> Reinforce the commitment in the dissemination of IS and its benefits, greater participation and involvement in the promotion of CE Increase engagement through actively participating in IS programs, clusters, initiatives in progress Increase community awareness in environmental problems and sustainable development through the knowledge transfer
Material/ technical management (Technical approach)	Intermediaries	<ul style="list-style-type: none"> Development and promotion of mechanisms (methodologies, tools, etc.) that allow to measure Industrial Symbiosis benefits
	Business	<ul style="list-style-type: none"> Reinforce the technological investment areas, such as the purchase of utilities, IT skills improvement, and training among employees
Company/ networks management (Business approach)	Knowledge Agents	<ul style="list-style-type: none"> Reinforce the participation in clustering and networking initiatives Encourage a close relationship with the industry, developing applied research linked with real industry needs and practical problems
	Intermediaries	<ul style="list-style-type: none"> Reinforce the negotiation process (Promotion of protocols, agreement of timing formal partnership, etc.)
	Businesses	<ul style="list-style-type: none"> Boosting the internal training & dissemination initiatives in topics such as the circular economy and their business models, green thinking, and green growth. Boosting the participation in initiatives such as clustering/ networking and really engage with partners and initiatives Build trust environment and promote open mindedness to receive anchor companies, knowledge agencies, local authorities' representatives, and other intermediaries Reinforce the transfer of knowledge and the participation in associations and industrial clusters, due to its supportive role in the IS emerging process

Mitigating Implementation Risks for Facilitated Implementation

The last step of the presented risk assessment methodology envisages the formulation of mitigation actions that can minimize the implementation risks associated with the application of those incentives. The aim of this set of actions is to reduce the frequency, magnitude, and severity of the risk impact. In this sense, this study promotes a set of mitigation actions that correlate each one of the three clusters and the involved stakeholders. For this purpose, six different groups of stakeholders were considered: national entities (ministries, agencies, authorities, etc.); regional/local government (Chambers, regional agencies, business councils, associations, etc.); intermediaries (clusters, consultancies, etc.); knowledge agents (R&D organizations, universities, etc.), and businesses (companies, industries, etc.). Table 5 shows the associated mitigation actions proposed to each group regarding each cluster.

In the first cluster, the mitigation actions are directed to national entities and regional governments. From a national perspective, the main actions refer to ensure the conditions for the development of IS through the promotion of policies and funds that facilitate the creation of a favourable environment to create synergies [31, 40, 60]. The promotion of new policies and legal frameworks that support the transition to a more sustainable industry, aligned with clear European legislation (standardized) [39] is one example. The allocation of sufficient national funds for IS incentives, which must necessarily have a character of continuity to overcome the barriers associated with uncertainty, is an important action in this perspective. The promotion and prioritization of supranational initiatives that are aligned with the collective efforts to tackle climate change (e.g. European Green Deal [29, 30]) has also been identified as an important action in this cluster. At the regional level, mitigation actions are mainly focused on increasing awareness at the community and company level. Among the various actions that can be mentioned the increase of engagement through actively participating in IS programs, clusters, initiatives have been an important measure in this first cluster. It is fundamental that the industrial sector feels the support of the local/regional authorities. Government entities cannot limit themselves as a funding entity but should also act as promoters. Also, the increase of community awareness in environmental problems and sustainable development [47], through knowledge transfer, will also play an important role to overcome issues like lack of interest and knowledge [42]. Lastly, the reinforcement and commitment in the dissemination of IS and its benefits [82, 83], and greater participation/ involvement in the promotion of the Circular Economy and its business models (through conferences, workshops, action groups, or regional communication plans) are important mitigation measures in this cluster.

The material / technical management cluster, involves actions that are directed to the businesses and intermediaries. Regarding intermediaries, the actions are linked to the development of methodologies, tools, frameworks, and platforms that facilitate the integration of IS at the company level, and also helps to measure which benefits involve the incorporation of symbiotic synergies [13, 84]. Complementarily, businesses' actions are associated with the greatest investment (Internal) in the technological area, in order to purchase infrastructure, utilities, and services required for developing synergies, for instance, the purchase of utilities, IT skills improvement, and training among employees.

The mitigation actions identified in the third cluster, Company/ networks management, are mainly related to knowledge agents, intermediaries, and businesses. Most of the actions related to businesses intent to create awareness at the intra-company level and promote cooperation with other stakeholders, with the main objective of facilitating the IS emerging process. For instance, boosting the internal training & dissemination initiatives and the participation in initiatives such as clustering/ networking [4, 85, 86], build a trust environment, and invest in transfer knowledge, all those actions that will help overcoming social barriers. Intermediaries must reinforce the negotiation process between companies and the creation of synergies through instruments such as protocols, partnerships, and formal contracts. Lastly, knowledge agents should promote close relationships with the industry, developing applied research linked with real industry needs and practical problems. It will also be necessary to reinforce the participation in clustering and networking initiatives, which will help to overcome the social barriers related to the different approaches of the two sectors (Industries actors and the scientific community).

Result Discussions

Considering the first research question about the main incentives for IS implementation on large-scale, the outputs were obtained by extensive characterization of the incentives by a new framework that relates a clustering process and the different dimensions of the incentives.

Most of the incentives identified in this study are related to the economic, policy, and social dimensions. This study suggests that companies are strongly encouraged to develop synergies mostly due to economic reasons. As a consequence, it was observed that financial incentives prevail in the podium as the most relevant, not only for direct gains, such as reduced operational costs [5] or revenues from the incorporation of new business models, but also for indirect gains such as governmental funds, tax benefits, credits, and projects. [87–89]. It should be noted that companies are especially attracted by the economic incentives supporting the purchase of infrastructure, utilities, and services [90], which help overcoming barriers such as financial limitations of the companies to develop the initiatives by themselves.

Policy incentives are mostly associated with actions or initiatives that can modify the current political conditions by overcoming the addressed barriers. Most of the incentives identified in this dimension are focused on two key points to support the political transition: (1) allow the implementation of symbiotic exchanges, and (2) facilitate the emerging process of industrial symbiosis.

Diverse authors have identified and typified that social factors can limit the spread of symbiotic exchanges [38, 78]. In this dimension, government and local authorities play a fundamental role as a driver of green growth and circular economy [91]. In order to reach the synergies propagation aspects like dissemination, involvement, and commitment are considered key elements to success [6]. Other incentives dimensions such as technical, information, and process were also identified in this study. Nevertheless, most of the initiatives identified in these dimensions, although of great importance, work as complementary dimensions to the three main ones (economic, policy, and social).

The risk assessment developed in this study, indicates that most of the identified common risks are related to economic and social factors. The origin of these factors is varied but in general terms, financial factors are directly related to economic barriers such as the lack of national financing [91], lack of internal funding, and the dependence on state funds to develop synergies [59, 80]. Regarding the social factors, those are directly related to barriers such as lack of trust between partners [32, 33], resistance to new concepts [59], uncertainties, lack of interest/motivation [47], and confidentiality issues [81]. Complementarily and without disregarding their importance, common risk factors such as political and institutional capacity were identified in a secondary position when compared to economic and social risk factors.

Concerning the third question, actions that should be promoted in order to mitigate the implementation risks, these mitigation actions are completely based on the main findings of the risk analysis. Most of the common risk factors identified in the previous step were categorized as economic, social, political, and institutional capacity. Therefore, a dedicated structure addressing these risks was proposed together with the actions that must be taken by the involved stakeholders. In general terms, the actions are directed for business practice, awareness-raising, and engagement reinforcement. Although all the proposed mitigation actions are relevant for the IS implementation process, the actions of the ‘Law and policies’ cluster might be the ones with the highest priority, since they respond to the risks associated with the political and economic domains. The ‘material/technical management’ cluster focuses its actions mainly on an operational perspective, specifically, the creation of internal technical

conditions for the development of synergies. The last cluster, ‘company, and management’, focus the actions in the reinforcement of social aspects to overcome barriers.

Conclusions

This study has systematically reviewed the incentives that contribute to the implementation of IS and promotes an applied assessment framework for risk mitigation based on the identification of common risk factors and implementation risks. The main output of this study is the set of mitigation actions that were proposed by correlating a multi stakeholders’ perspective and three incentives clusters: Law and Politics, Material/ technical management, and Company/ networks management.

The economic incentives for IS, for direct gains or reduction of costs, as well as the policy-related incentives, such as policy transition instruments, were found to be the most important at the company level. Regarding the common risks and implementation risks, they were mostly related to economic, social, political, and institutional capacity risk factors, mainly associated with barriers such as economic inability, lack of trust environment, uncertainties, and lack of interest/motivation.

The mitigation actions proposed aim to reinforce the business practice, policy transition, awareness-raising, and engagement. Regarding ‘Law and policies’, the introduction of supra-national strategic frameworks for IS, simplification of the status of secondary materials and by-products, and streamlining of existing fiscal policies are advised. From the technical approach, they were directed to promote methodologies, tools, and platforms and reinforce the digitalization of the industry with appropriate investment. At the companies’ level, the mitigation actions are directed to create an appropriate context for synergies, reinforcing aspects as negotiations, companies’ internal capacity and partnership for IS.

As the main contribution of the study, the authors consider that the methodology proposed in this paper and its results could contribute to researchers and practitioners of IS to avoid implementation risks, especially in the early stages of implementation, since the proposed structure can support the identification, characterization and clusterization of incentives, and their common risk factors. The methodology also allows to promote mitigation actions to avoid implementation risks during the following stages of the process.

Three main limitations were found in the methodological approach proposed. Firstly, the theoretical perspective of the assessment framework based on research methods such as observation, literature review, and expert consultation can compromise the full applicability of the proposed mitigation actions in real case studies scenarios at different levels. Another limitation refers to the information gathering process where the lack of previous research studies on the subject causes limited access to data, especially in the assessment of IS incentives mostly reduced to their contribution in the early stages of the process. Lastly, and regarding the sample size used for gathering information, although it provided important insights from the various experts IS, a larger sample would allow to diversify and provide more accurate results.

Further research and the validation in real case implementation scenarios, will strengthen the present mitigation actions and preliminary results. The authors consider that national and regional case studies could support the risk impact and the effectiveness of mitigation actions implementation and therefore recommend that such studies should be done in the future.

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Authors’ Contributions Juan Diego Henriques performed the literature review, selection of references, methodology and wrote the initial versions of the paper. João Azevedo, Rui Dias, Cristina Ascenço and Marco Estrela contributed to develop the paper structure, improvement of the research approach and the paper writing. Doroteya Vladimirova and Karen Miller designed and performed the methods for the expert consultation.

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Data Availability Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

Declarations

Conflict of Interest/Competing Interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Glossary

- CE Circular economy
- CO₂ Carbon dioxide
- EC European Commission
- EU European Union
- IS Industrial Symbiosis

Appendix 1

Incentive	Risk factors	
	Internal	External
Co-funding investment Programs	<ul style="list-style-type: none"> • Dependence on state funds for the implementation of IS initiatives • Lack of receptivity • Lack of knowledge regarding available funding programs and lack of technical competences to prepare /submit proposals 	<ul style="list-style-type: none"> • Lack of national funds to promote and maintain platforms that promote business links • High level of bureaucratic processes of co-financing programs and lack of standardized environmental regulation to support their implementation • Low receptivity of large companies
Common Waste Market	<ul style="list-style-type: none"> • Low waste quality in the residues, lack of controls and standards to guarantee the quality of the materials • Resistance of companies to initiatives/projects that necessarily change their operations • Lack of knowledge of possible uses of available waste 	<ul style="list-style-type: none"> • Waste price instability, compared to the virgin raw materials market • Vulnerability at the Supply Chain level regarding Waste / by-products, Partner location and logistics. Long distances and lack of transport might compromise the viability of synergies

Incentive	Risk factors	
	Internal	External
Integrated method to calculated benefits	<ul style="list-style-type: none"> Insufficient knowledge of technological capability and data management by companies 	<ul style="list-style-type: none"> Lack of funding to promote and maintain this initiative Different national realities regarding waste management, classification and recovery
	<ul style="list-style-type: none"> Insufficient knowledge and technological capacity Lack of interest and awareness in the principles of industrial sustainability Lack of data management by companies 	<ul style="list-style-type: none"> Different national realities regarding waste management, classification and recovery Lack of regulation at a national or European level that forces the companies to participate in the implementation of a shared waste database
Premium Tariff Energy	<ul style="list-style-type: none"> Inability to manage the responsibilities associate to adaptation process in order join this tariff Dependence on state funds to cover the initial investment Technological unviability 	<ul style="list-style-type: none"> Lack of national funding to promote and maintain this initiative Low development level of regulation and policies that promote this tariff High level of bureaucratic processes to acquire this tariff Lack of standardized environmental regulation to support the tariff implementation
Bio fuels Tariff	<ul style="list-style-type: none"> Inability to manage the responsibilities associate to adaptation process in order join this tariff Dependence on state funds to cover the initial investment Technological unviability 	<ul style="list-style-type: none"> Lack of national funding to promote and maintain this initiative Low development level of regulation and policies that promote this tariff High level of bureaucratic processes to acquire this tariff Lack of standardized environmental regulation to support the tariff implementation
Landfill Tax	<ul style="list-style-type: none"> Business scepticism about new environmental challenges and social barriers (resistance to change) Lack of interest due to the low prices of land fill gates (In some countries) 	<ul style="list-style-type: none"> Low development level of regulation and policies that promote this tariff High level of bureaucratic to effectively implement the land fill taxes Lack of standardized environmental regulation to support the tax implementation
Desegregated industrial waste policy framework	<ul style="list-style-type: none"> Problems in adapting to new policies approach Alteration of operations in order to achieve the new targets Lack of initial investment to adapt the industrial process 	<ul style="list-style-type: none"> Long distances and lack of transport might compromise the viability of synergies Lack of suitable partners for the synergies implementation Limited diversity of waste /by-product streams due to the high homogeneity of surroundings companies The bureaucratic complexity associated with transition and adaptation to new policies
Environmental and Energy Taxes	<ul style="list-style-type: none"> Business scepticism about new environmental challenges and social barriers (resistance to change) Lack of initial investment to improve the industrial process 	<ul style="list-style-type: none"> Lack of funding to promote and maintain this initiative Low development level of regulation and policies that promote energy and resource efficiency

Incentive	Risk factors	
	Internal	External
Green criteria as key element for public procurement	<ul style="list-style-type: none"> • Business scepticism about new environmental challenges and social barriers (resistance to change) • The resistance of companies to initiatives/projects that necessarily change the method they operate at different levels (Social inertia) 	<ul style="list-style-type: none"> • Low development level of regulation and policies that promote these taxes • Lack of regulation at national or European level that stimulates the companies to participate in this kind of initiative • Problems in the purchasing process due to insufficient or unstable product offer
Improving the Energy Efficiency and Resource Efficiency through policy	<ul style="list-style-type: none"> • Lack of technical competences to prepare /submit proposals • Financial limitations for initial investment • Lack of motivation to apply / participate in these initiatives 	<ul style="list-style-type: none"> • Lack of regulation at national or European level that stimulates the companies to participate in this kind of initiative • Lack of funding to promote and maintain the programs promoted for this policy • The bureaucratic complexity • Lack of funding to promote and maintain the training programs • Reduced government presence as a driving agent
Training programs (Build awareness)	<ul style="list-style-type: none"> • Lack of receptivity, trust and motivation among employees due to resistance to change • Business scepticism about new environmental challenges and social barriers (resistance to change) 	<ul style="list-style-type: none"> • Lack of funding to promote and maintain this initiative • Reduced government presence as a driving agent
Collaborative networks	<ul style="list-style-type: none"> • Business scepticism about new environmental challenges and social barriers (resistance to change) • Lack of motivation and collaborative approach to join the network 	<ul style="list-style-type: none"> • Lack of funding to promote and maintain this initiative • Reduced government presence as a driving agent
Sectorial clustering	<ul style="list-style-type: none"> • Mistrust due the fact that clusters normally are dominated by a few firms • Lack of receptivity due to resistance to change (complex cross-sector relationships) 	<ul style="list-style-type: none"> • Lack of funding to promote and maintain this initiative • Reduced government presence as a driving agent
SCR programs	<ul style="list-style-type: none"> • Lack of funds to develop an SCR plan • Lack of trust and social inertia at various levels of the institution 	<ul style="list-style-type: none"> • Lack of community interest • Lack of intermediaries to support this type of programs
Networking initiatives	<ul style="list-style-type: none"> • Business scepticism about new environmental challenges and social barriers (resistance to change) • Reduced “circular” company culture can affect the implementation of IS practices • Lack of receptivity, trust and motivation among employees due to resistance to change 	<ul style="list-style-type: none"> • Lack of cooperation between the scientific community and companies • Lack of receptivity of knowledge agents and business actors
Knowledge and training	<ul style="list-style-type: none"> • Reduced “circular” company culture can affect the implementation of IS practices • Lack of receptivity, trust and motivation among employees (Social inertia) 	<ul style="list-style-type: none"> • Lack of knowledge agents and entities trained to support and accompany this initiative
Dissemination initiatives	<ul style="list-style-type: none"> • Lack of receptivity, trust and motivation among employees • Reduced “circular” company culture can affect the implementation of IS practices 	<ul style="list-style-type: none"> • Lack of community and business actors’ interest • Lack of financing to disseminate IS appropriately

Incentive	Risk factors	
	Internal	External
Transition to Industry 4.0 programs	<ul style="list-style-type: none"> • Lack of employees with skills and knowledge to develop these initiatives • Inability of the company to face new technological challenges • Insufficient knowledge of technology capability and data management by companies • Inability to manage responsibilities associated to this initiative • Confidentiality issues 	<ul style="list-style-type: none"> • Lack of financing that generates dependence on state funds, such as, programs and projects • Low industry receptiveness or inability to make the necessary technology investments • Dependence on government participation as the main driver
Share data bases and tools	<ul style="list-style-type: none"> • Lack of confidence in the availability of data, confidentiality issues • Inability of the company to face new technological challenges • Lack of knowledge and equipment for data collection and treatment 	<ul style="list-style-type: none"> • Lack of financing to promote this initiative • Lack of trust from companies to share their data
Promotion of protocols and formal agreement	<ul style="list-style-type: none"> • Lack of personnel to take the responsibilities that the development of this type of documents implements • Lack of knowledge to develop protocols 	<ul style="list-style-type: none"> • Mistrust in accepting commitments that could have legal consequences • Conflicts of interest due to the competitive nature of the industrial sectors

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