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# Insights of Digital Transformation Processes in Industrial Symbiosis from the Viable Systems Approach (vSa)

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**Abstract:** The main purpose of this contribution is twofold: from a scientific point of view, to interpret the symbiotic logic through the framework of the Viable Systems approach (vSa), and from a managerial viewpoint, to provide the actors of industrial symbiosis initiatives, at any stage of their life cycle, with a guide to the most promising web-based solutions in terms of defining the best configuration for the symbiotic network. The article, therefore, aims to provide an in-depth study of the existing literature, which is still not exhaustive, and to consider synoptically and comparatively the modern platforms capable of supporting industrial symbiosis initiatives. The objective was pursued by examining 10 existing and functioning Web-based platforms, of which only a few were previously explored in the previous literature, while the recognition of the latter was carried out on a bibliometric basis to articulate in more detail the existing gap based on a panel of contributions as large as possible. The joint consideration of the literature review and the examination of the existing and functioning platforms shows an articulated framework of approaches, proposed models, and classification schemes of their functions, which allows us to conclude that given the sectoral, territorial, and specific characteristics of the materials addressed by each platform and considering the different cycles existing in eco-industrial parks (water, energy, by-products, etc.), the most promising way for their implementation is to consider multiple platforms to fully exploit the contribution of each of them. As for the management implications, the suggestion is to integrate the results obtained from the different platforms and to evaluate the configurational alternatives with multi-criteria procedures.

**Keywords:** industrial symbiosis; viable systems approach; web-based platforms; digital transformation



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## 1. Introduction

Under the pressure of government policies and public opinion towards green transitions and the digitalization of industrial activities, increasing attention is being paid, both in practice and in the scientific literature, to industrial symbiosis [1]. The exchanges of energy, information, raw materials or residues among firms, institutions, and local communities through networking, the location of production units in proximity of one another, and the shared management of sites all embody the "industrial symbiosis" (IS), first introduced by Renner [2] in his geographic studies on the location of industrial activities, and later defined by Christensen [3] based on his managerial experience in the Kalundborg eco-industrial park in Denmark. Subsequently, many other definitions have been proposed both in the scientific area of industrial ecology and in that of the circular economy, the most cited of which are from Chertow [4], Chertow and Lombardi [5], and Mirata and Pearce [6].

The attention to symbiotic initiatives, which has recently become more intense due to the global crisis caused by the COVID-19 pandemic and the pressing need to close production cycles as much as possible to limit resource withdrawals and waste, is materialized in the operational and scientific perspective through the overlapping and convergence of information and production technologies related, in particular, to businesses connected in clusters operating within the framework of the circular economy.

Recently, conviction is gaining ground, both operationally and academically, that IS processes can be enhanced, both in abundance and in economic, social, and environmental performance, through Web-based platforms (Wb-platforms) expressly aimed at supporting the transition of industrial processes towards industrial symbiosis and, in general, towards sustainability and circular economy [7–9].

The potential of Wb-platforms in supporting IS is expressed, in particular, at the level of social relations among networked actors. Social relations constitute the substrate for industrial symbiosis, as reflected in the definition of Jensen et al. [10], for which "close working agreements underlying the innovative reuse, recycling, or sharing of resources leads to resource efficiency"; by Alkaya et al. [11], which highlights "long term partnership and work in solidarity"; and by Lombardi and Laybourn [12], which emphasizes the importance of "sharing knowledge".

As the success of any kind of synergy relies on trust, consonance, direct or facilitated knowledge, and information sharing [13–15], in the specific case of industrial symbiosis, these conditions are essential for discovering and exploiting industrial synergy opportunities [16,17].

The Wb-platforms of the most recent conception complement the traditional functions of opportunity identification by the means of databases aimed to facilitate the meeting of supply and demand, particularly of waste, with tools able to simulate network configurations and simultaneously assess the environmental, economic, and efficiency performance of complex, digitalized production systems aligned with the Industry 4.0 paradigm. In this regard, Grant et al. [18] articulate the complex of modern Wb-platform functions in opportunity identification, opportunity assessment, barrier removal, commercialization, and adaptive management, documentation, review, and publication. In the vast literature on industrial symbiosis, however, limited attention is paid to the applicability of existing platforms to the transition of industrial parks towards sustainability.

The chance to support new symbiotic projects and ongoing innovation processes in eco-industrial parks taking advantage of the potential of Wb-platforms is little exploited despite the growing awareness of managers about the importance of gaining more information than in the recent past. This circumstance is witnessed, in operational practice, by the termination, in the last decade, of some platforms, e.g., SMILE, the Ireland Industrial Symbiosis program that provided a free platform for businesses to connect and identify synergies where waste in one business can be a resource in another and, in literature, by many proposals of new methodologies and tools able to better meet the needs of users exploiting the enormous progress of Information and Communication Technologies (ICTs) [19–22].

From Wb-based platforms limited to supply and demand to databases that present best practice examples, ideas, and projects, new projects have therefore gone in the direction of interactive online platforms aimed at diagnosing and designing the alternative network configurations resulting from the possible interdependences of technical and social systems.

Industrial parks are no exception: Massard and Jacquat [23] detect the innovative ferments in 168 eco-innovation parks detailed for 27 countries, analyzing their best practices and success factors. In this context, Wb-platforms can express their potential, in particular the modern ones based on simulation and assessment functions.

The previous observations and a summary consideration of the existing literature lead to the following research questions: What improvements can the online digital platforms convey to IS? What improvements can the online digital platforms convey to industrial parks in their transition to EIP?

This paper is structured as follows: successive to this introduction, Sections 2 and 3 provide the methodological framework, while Section 4 provides the literature review to articulate the research gap in more detail. Section 5 reviews existing and operating Wb-platforms having the character of "synergy exploitation systems", and Section 6 deals with the results of the joint consideration of the literature and the Wb-platforms review. Section 7 provides conclusive remarks, argues the managerial and academic implications, outlines future research areas, and critically discusses the limitations of the work.

## 2. Methodological Framework

The evident nature of open systems of the industrial symbiotic networks is denoted by the presence and contextual interactions of the companies directly involved as the main players in the exchanges and by the observable ecosystem made up of suppliers, customers, research centers, public authorities, and others; in such systems, each of the actors plays a specific role based on the inter-organizational relationships in which it participates with different sensitivity, therefore determining its complexity. Despite the evident systemic character, the use of interpretative keys provided by systems theories for the analysis of the industrial symbiosis phenomena is, in the existing scientific literature, still underdeveloped. The concept of "viability" of symbiotic systems, which originally appears in Christensen's definition, is also present only sporadically in subsequent literature. Among the exceptions, Ashton [24] develops, concerning the concrete case of an eco-industrial park, an interpretative scheme of the functions, economic transactions, political and regulatory context, and social interactions in which collaboration between companies evolves by making use of the tools of the Complex Adaptive Systems. More recently, Wang et al. [25] implicitly recall the founding principles of cybernetics and systems theories in a contribution that indicates the use of automatic control methods, concluding that these can play a key role in limiting vulnerability as a remedy to contain the fluctuations in the equilibrium of industrial symbiotic networks due to environmental stresses, which can compromise the functioning of the network or even its survival due to unexpected perturbations such as the sudden abandonment of a company or variations in the quality of the residues exchanged, increasing its resilience. More directly, Cui et al. [26] use the methods of System Dynamics to formalize a model of the evolution of symbiotic networks. The interpretations of symbiotic networks through the Viable System Model (VSM) [27–29] and the Viable Systems Approach (vSA) [30,31] are almost absent in the existing literature, although significant traces of some perspectives and concepts belonging to them are scattered in various contributions. Hewes and Lyons [32], for example, based on an empirical analysis of a sample of eco-industrial parks, find that social relations based on rootedness in the local socio-economic fabric and on trust are considered more relevant for the viability of the system for technical and technological connections: the parallelism with proposition 2 (Eidos) of the (vSA), relating to the distinction between structure and system, is clear, although implicit. Behera et al. [33], referring to the design phase of the evolution process of conventional industrial complexes into eco-industrial parks, emphasize the role of communication channels between the actors, the absence of which could make the efforts aimed at transformation unproductive for the viability of the system: with the lens of the VSM "the necessary and sufficient condition for the viability of the system is violated". One of the obstacles to the implementation of viable systems models for the interpretation of symbiotic networks, and perhaps the explanation for their absence in the literature, is probably constituted by the many forms that these networks can assume (each of which represents a unique case) and for which reason it is not easy to refer to them as vital systems; the importance of referring to homogeneous classes of experiences of industrial symbiosis stands out, in the viable systems approach, for the purpose of identifying the organ (or organs) governing the system [30,31], the level of management of it, and their responsibilities. In Beer's Viable System Model [27–29] the availability of homogeneous classes of industrial symbiotic experiences is central to identifying the actors and their role within the five subsystems identified in the model. The Viable Systems Approach (vSA) framework begins with an analysis of the viable systems in a real-world problem situation [30]. (vSA) is an approach to study the viability of systems in a complex environment. Viability is both objective survival and a subjective ability to respond to environmental change, where environmental change is mostly generated by other viable systems. Viability depends first and foremost on a government capability, for both internal self-governance and external relationship governance that creates value for the stakeholders or suprasystems. Each system has to attain consonance (a potential for value creation) and resonance (the realization of value creation) with its environment to be viable. In other words, the survival of a system depends on the coherence of its decision-making and problem-solving processes (consonance and resonance) with the complexity and change in the environment, known as the context in the (VSA) view that is the subjective representation of the reality created by the government. The innovative concepts of consonance and resonance are fundamental to all (VSA) analyses of problem situations. Consonance means the structural compatibility or adequacy between different entities, while resonance is the outcome of the interaction between these consonant entities. In other words, the consonance measures the capability of the system to achieve mutual benefits (value cocreation) based on their structure (accessible resources) and the limits to sharing and coordinating information between different entities (viable systems); the resonance measures the results of interactions in context, producing and sharing value for and with stakeholders or suprasystems. If consonance (potential) increases with time, then so can the resonance (performance). In the (VSA) perspective, the researcher looking at complex phenomena has to realize that he can never achieve complete and fully objective, but only approximate, knowledge [34–36]. In complex environments of other entities, the search for viability means the capability of the government component of a viable system entity to make decisions based on approximate knowledge. The government component of an entity has two main types of knowledge that we refer to as Decision-Making (D-M) and Problem-Solving (P-S) knowledge. D-M provides guidance about which ends (know what) to achieve, and P-S provides means (know how) to those ends. Both types of knowledge are the fundamental capabilities (cognitive assets) required to attain and maintain viability [37]. Because viable system entities change and learn, the resource allocation problem is the fundamental decision that repeatedly must be made to remain viable [38]. Dealing with new levels of complexity requires new types of decision-making in which we cannot necessarily use fixed models or stochastic methods to find a solution, but we need a pattern or schema suitable to a particular problem's complexity level [31].

## 3. The Nature of Symbiotic Service Systems

Based on the assumed methodological framework (VSA), the web-based symbiotic networks can be read as complex holistic service systems, or dynamic systems structurally composed of interacting sub-systems, whose functioning—overall systemic vitality—cannot be understood "simply" by breaking down its structure and analyzing its constituent components, nor can they be explained and described by analyzing all the components with their interactions. Instead, it is necessary to evaluate and read the dynamic behavior of each component, as well as the reciprocal interactions, linear and non-linear, in a computational way and grasp their complex nature in terms of emerging behaviors, self-organization, and survival skills in dynamic contexts.

Precisely because of this assumption, artificial symbiotic systems—such as industrial symbiotic platforms—can be interpreted as a cluster derived from natural "ecological networks". In particular, we can refer to the biological example that can be found in nature of the so-called "mycorrhizal networks", otherwise called Common Mycorrhizal Network (CMN): root systems of at least two plants (sub-systemic components) that are colonized (managed, fed) by the same fungus mycorrhizal (a governing component of the complex system), which represents the communication/feeding channel between the interacting plant entities, allowing for the transit of nutrients and chemical mediators capable of guaranteeing life to the entire complex system generated (systemic viability). By analyzing the interaction between these natural sub-components mediated and fed by the third fungal component, we find the emergence of the ecological network that more than a few biologists assume in an analogy of structure and functioning to the world wide web.

Just as the natural phenomenon of the mycorrhizal network has a significant influence on the survival chances of interconnected plants in a given ecosystem and since the communicative connections favor the growth and development of the plants themselves, so the industrial symbiotic networks represent composite structures of sub-industrial systems which, as a result of mutual interaction, dynamically evolve in complex contexts, optimizing the exchange of resources—tangible and intangible—and guaranteeing the dynamic survival and resilience of the constituent components and the overall system/network.

If this vision is shared, then the conditions of the vitality of a mycorrhizal network (natural-biological ecosystem) can analogously be transferred to the symbiotic industrial network (artificial-socioeconomic ecosystem) as shown in Table 1.

**Table 1.** Networks in natural-biological ecosystems and artificial-socio-economic ecosystems.

| Natural-Biological Ecosystem Mycorrhizal Network | Artificial-Socioeconomic Ecosystem Socioeconomic Network |
|---|---|
| • existence of mycorrhizal networks within a natural ecosystem | • existence of interacting systems within the socioeconomic ecosystem |
| • transfer of resources between the different natural components (plants) | • transfer of resources between the different natural components (socioeconomic sub-systems) |
| • morphological (spatial arrangement of plant components) and topological (nodes and communication links) characteristics of mycorrhizal networks | • morphological (spatial arrangement of industrial components) and topological (nodes and communication links) characteristics of socioeconomic networks |
| • degree of resilience and influence in the ecological ecosystem | • degree of resilience and influence in the socioeconomic ecosystem |
| • biological sustainability | • industrial sustainability |

Source: Authors' elaboration.

Undoubtedly, both natural networks and artificial networks "live" by virtue of intelligent (smart) evolutionary mechanisms.

Service systems are a "value co-creation configuration of people, technology, value propositions connecting internal and external service systems, and shared information" [39,40]. In service systems, value cannot be realized by one entity. There are at least two entities: the one that proposes the value and the other that realizes the value. This is why the value creation process is called the 'co-creation of value'.

As shown in Figure 1, such systems can assume two configurations depending on whether the evolutionary processes follow a vicious or virtuous trust logic. In this sense, there are two types:

- smart systems, characterized by vicious circuits of interaction and trust, focused on individualistic, speculative interest with a dominant top-down, despotic powership matrix;
- wise systems, characterized by virtuous circuits of interaction and trust, focused on collective, sustainable, and participatory interest with a matrix of collaborative and cooperative bottom-up partnerships.

The "Smart" term is a necessary but not sufficient condition for the viability of the systems and to develop resonance and viability in the context [41,42]. So, a smart service system creates value mediating and integrating the interactions between (human) actors and efficient use of resources [43,44], but it is not able to ensure the complete exploration of opportunities for a better co-creation of value for future generations.

A smart system represents a potential efficiency degree for creating social and economic systems—such as wise systems—in which the potential efficiency becomes a high efficacy degree of value co-creation. Smart is the potential capacity of a system to survive and produce value (condition of potential consonance). On the other hand, Wise is the ability to determine the best possible solution for the wider and common good (resonance effect). For these reasons, the viability of systems depends on wise system governance for developing the whole social-economic context.

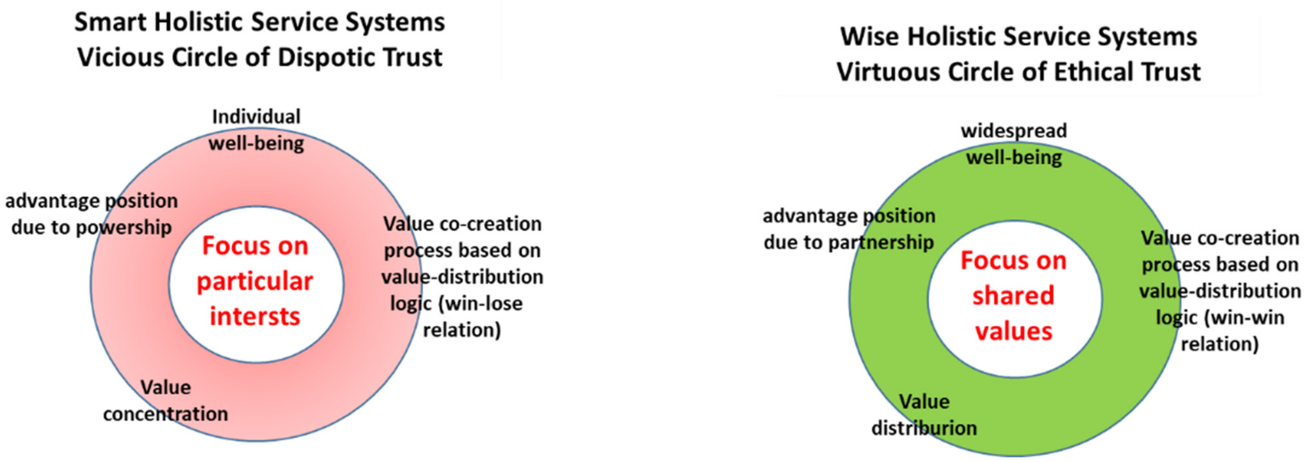


**Figure 1.** Smart and wise holistic service systems.

In light of this conceptual framework, we can affirm that, although smart and wise service systems respond to the logic of value co-creation and dynamic vitality in complex scenarios, the latter (wise configuration) better interprets the symbiotic configurations of natural networks, and therefore, artificial ones such as symbiotic reticular structures are integrated into web-based industrial platforms, in a way linking business ecosystem and natural ecosystem [45]. Wise symbiotic networks represent optimizing configurations of the processes of co-creation and win-win distributions of the value generated and produced by symbiotic relational synergies.

From a governance perspective—which we frame in Faucoult's sense of intelligent, collaborative, and participatory governance—symbiotic networks imply:

1. strong specialization in sub-systemic components;
2. functional integration and complementarity;
3. degrees of relational trust oriented towards the sharing of values, strategic collaboration, and operational cooperation;
4. processes of syntropy.

Such conditions allow for vital holistic service systems to activate widespread virtuous relational mechanisms, aimed at the production of shared well-being.

## 4. Literature Review

### 4.1. Data Collection

The literature review was conducted with a mixed procedure: in the first phase (bibliometric phase), the contributions specifically devoted to ICT platforms were identified in the Web of Science Core Collection within the vast scientific production on industrial symbiosis existing in the two macro-scientific areas of circular economy and industrial ecology. The query used was as follows: TOPIC: ("industrial symbiosis") AND TOPIC: (platform * OR "information system *" OR ict OR "social network")—Refined by: [excluding] DOCUMENT TYPES: (EARLY ACCESS OR EDITORIAL MATERIAL OR BOOK CHAPTER)—Timespan: All years. Indices: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC.

### 4.2. Methodological Approach

The query returned 79 documents, represented in static form in Figure 2. The map, built with Vosviewer of van Eck and Waltman [46,47], is downloadable at the link https://bit.ly/2RLNGbt (accessed on 21 August 2021) in its explorable form through the zooming and scrolling functionalities of the software, also allowing access to the single contributions as each item is linked to the full text.

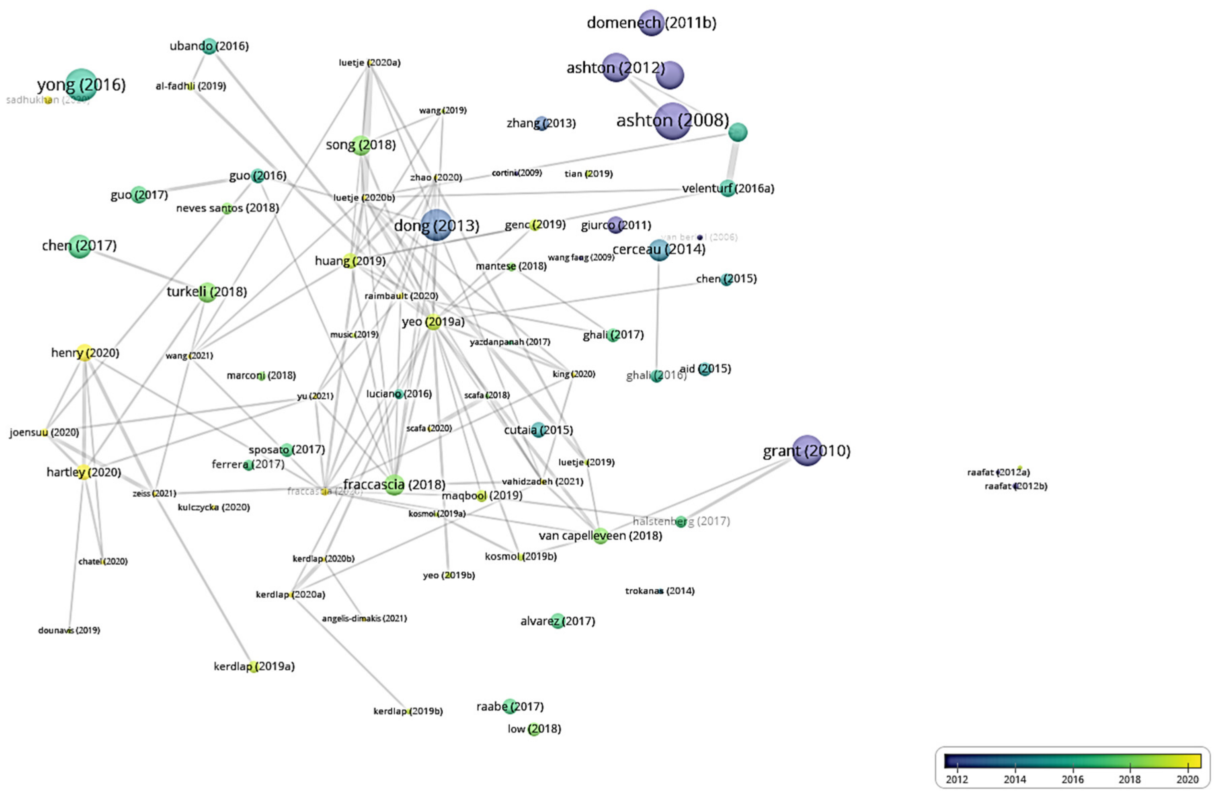


**Figure 2.** Bibliographic coupling of the references, overlay visualization.

In the second phase, the contributions were cataloged in Clarivate Analytics' EndNote, and the content analyses of the full texts were carried out to obtain a picture of the evolution of the literature on the topic.

### *4.3. Analysis*

Concurrent with the intensification of the development of ICT solutions devoted to companies operating in symbiosis, the interest of scholars to the theme of ICTs' contribution to IS has matured as well. Beyond the preliminary studies reported in Chertow and Portlock [48], and in particular, in the contribution of Brown et al. [49], which refers to Matchmaker!, one of the first portals for matching demand and supply of waste, the interest has intensified over the last decade.

In this period, the focus has been on the deepening of the characteristics of ICT solutions suitable for IS declined along the guidelines of the identification of opportunities for exchanges [50], of the simulation of transformations that take place in the symbiotic networks [51], and of their design [7]. The expression "Industrial Symbiosis Platforms" is first used by Benedict et al. [52], who observe how information and communication technologies increasingly take the form of online platforms to help mitigate information and social barriers in IS.

It results nonetheless in a fragmented picture in which only a few attempts of systematization of the potential of Wb-platforms can be observed, while most of the contributions are dedicated to a specific IT solution or to a few of them. While many Scholars propose models of decision support tool or systems architecture able to assess the social-environmental, economic viability of industrial symbiosis, most of them have been not translated into Wb-platforms yet [53–55].

Among the contributions aimed to a systematization and/or taxonomy of the existing Wb-platforms, Grant et al. [18] assess the opportunities granted within the phases of sprouting, uncovering, and embeddedness of IS and systematizes the functionalities of existing platforms in the stages previously disclosed. Based on this taxonomy, taken up several times in subsequent literature, Maqbool et al. [56] advance a classification of 20 platforms that are operational, discontinued, and in development based on a scale related to the prevalent focus on one or more of the Grant phases previously discussed.

Van Capelleveen et al. [46], based on a review of the literature, create a taxonomy declined along the dimensions of the different information systems' characteristics, the type of support role the systems provide, and the technologies used to enable IS; the Authors propose the following types: passive facilitation of waste transactions; active facilitation of waste transactions; profiling of waste production and use for industry; and mixed: (a) Building social relations and (b) Knowledge exchange, urban planning, and policy making.

## 5. Synergies Exploitation Systems

Several Wb-platforms inspired by the principles of circular economy and industrial symbiosis have recently been developed to support collaboration initiatives between single firms or firms operating in industrial clusters. This Section focuses on such Wb-platforms, which perform the function of synergy exploitation systems. By this we mean that they supply an integrated package of services that goes from the identification of symbiotic opportunities to the monitoring of processes, passing through the definition of the alternatives of symbiotic network configurations and the assessment of their effects in the economic, environmental, and social term for all stakeholders involved.

Following the taxonomy of van Capelleveen et al. [46], we discuss these types of systems, excluding open online waste markets, IS knowledge repositories, and social network platforms which are still in an embryonic stage [57].

The main characteristics of some of the platforms currently accessible and usable are presented in Table 2.

**Table 2.** Main synergies exploitation systems.

| Wb-Platform | Main Characteristics of the Platform |
| --- | --- |
| MAESTRI «MAESTRI—Energy and Resource Management Systems for Improved Efficiency in the Process Industries—A H2020-Project under the SPIRE-PPP Initiative». Examined on 31 May 2021. https://maestri-spire.eu/ (accessed on 31 May 2021). | A database developed by the Center for Industrial Sustainability, University of Cambridge, within the MAESTRI project, "Energy and resource management systems for better efficiency in the process industries". The database, containing 46 case studies, consists of a narrative section organized along the dimensions "main challenge (trigger)", "main barriers", "approach", "discovery process", "prerequisites", and a section in which symbiont enterprises are qualified and the type of resources exchanged identified. MAESTRI Total Efficiency Framework (MTEF) aims to advance the sustainability of manufacturing and process industries by providing a management system in the form of a flexible and scalable platform and methodology («MAESTRI»). |
| SWAN «SWAN—Home Page». Examined on 31 May 2021. http://swanplatform.eu/ (accessed on 31 May 2021). | The SWAN platform, previously discussed by Angelis-Dimakis et al. [58], is an open-access tool able to map and match solid waste sources with potential waste re-users and propose waste reuse loops and value chains in the countries of Greece, Bulgaria, Albania, and Cyprus («SWAN»). |
| FISSAC «FISSAC Project platform». Examined on 1 June 2021. http://platform.fissacproject.eu/ (accessed on 1 June 2021). | FISSAC Industrial Symbiosis Management Software Tool (FISSAC ICT Platform) can support decision making in material flow analysis and industrial clustering. The fundamental aim of the Wb-platform developed under FISSAC is to demonstrate and maximize environmental, social, and financial benefits of IS networks to support circular economy structure in the construction value chain («FISSAC Project platform»). |

**Table 2.** *Cont.*

| Wb-Platform | Main Characteristics of the Platform |
| --- | --- |
| CIRCULATOR<br>«Home—Circulator». Examined on 1 June 2021. http://circulator.eu/ (accessed on 1 June 2021). | Circulator is a Wb-platform aimed at supporting aspiring entrepreneurs to create a circular business model suitable for a particular company or start-up. The user can mix strategies from three main categories and use this mix to draw inspiration from existing companies. To provide further guidance to the user, Circulator identifies four archetypes, each representing a specific business focus, as the main entry point to develop a circular business model. Moreover, the user can browse the case database using individual strategies, country, industry, or maturity level as filters («Home—Circulator»). |
| PERCORSO CIRCOLARE<br>«Percorso Circolare», 2019. Circularity (blog). Updated on 10 April 2019. https://circularity.com/servizi/percorso-circolare/ (accessed on 1 June 2021). | Circularity.com, previously treated by Pizzi, Leopizzi, and Caputo [59], a platform developed to foster the industrial symbiosis of different types of organizations, advertises itself as the first and only circular economy industrial symbiosis platform in Italy. Based on geolocation algorithms, it identifies the actors that can be involved in a symbiotic process starting from the category (waste, second raw material, by-product) and provides the configuration of the resulting supply chain («Percorso Circolare»). |
| WSX BM<br>«Welcome to WSX-BM—WSX BM—European Waste Services Exchange Business Model». Examined on 31 May 2021. https://www.wsxbm.eu/en/ (accessed on 31 May 2021). | WSX BM—European Waste Services Exchange Business Model constitutes an expert system based on semantic engines and artificial intelligence that facilitates the meeting between the demand and the complex and articulated world of supply of services necessary for proper waste management («WSX-BM»). |
| INex Circular<br>«INex Circular—Le Leader de La Détection de Gisements de Déchets». Examined on 31 May 2021. https://sourcing.inex-circular.com/ (accessed on 31 May 2021). | iNex (Eco System Exchange) is a web platform designed to find practical solutions in a local area using big data techniques and knowledge on resources reusing. The platform instantly shows synergy potentials, simulates alternative network configurations, and for each of them assesses the effects in terms of environmental and economic benefits. («INex Circular»). |
| REACT<br>«REACT». Examined on 1 June 2021. https://react.biseps.eu/en/business-parks (accessed on 1 June 2021). | The Renewable Energy Area Collaboration Tool (REACT) is a user-friendly tool that identifies the best options for sustainable energy for companies and groups of companies and makes calculations for part of the businesses of a cluster or for a complete business cluster («REACT»). |
| ZBP<br>«ZBP». Examined on 31 May 2021. https://www.inex-circular.com/eng/1/home (accessed on 31 May 2021). | The Zero Brine Platform, previously treated by Bakogianni et al. [60], allows for the simulation of Water and Mineral Value and Supply Chain adopting a Circular Economy Approach to Reduce Industrial Salt Wastewater by Mineral Recovery and brine from other industries, thus "closing the loop" and improving the environmental impact of production. The service allows new entries to register according to their role and allows users to search for information and establish links with relevant parties («ZBP»). |

Source: Authors' elaboration.

## 6. Discussion

The review of the literature and the examination of the existing and functioning platforms for the promotion and support of industrial symbiosis initiatives carried out in the present work show an articulated framework of approaches and functions, representing a first attempt to consider synoptically and comparatively the modern platforms capable of supporting industrial symbiosis initiatives. In the context of basic functions, such as the identification of the possible synergies, the promotion of new relationships between stakeholders, and the simulation and evaluation of alternative network configurations, they differ for the sectors of economic activity to which they are mainly addressed, for the territorial scales provided, and for the types of exchanges considered (energy, waste, water, by-products). Therefore, the improvements that the online digital platforms can convey to IS, in general, consist in the dissemination among companies of the knowledge related to the existing symbiotic possibilities; this allows for a multiplication of initiatives, also due to the driving force of policies aimed at green transition and the design and implementation of more efficient network configurations in terms of resource withdrawals and emissions into the environment. Obtaining these technical effects is subordinated to the establishment of consonant social relationships among all the stakeholders involved in the projects or symbiotic processes. These are also facilitated by platforms, which have become one of the most important actors of the Fourth Industrial Revolution and the digital transformation, so that their use reduces information asymmetries and allows the creation of coded communication formats enhancing the clarity of the objectives of each actor and the transparency of the process as a whole [61].

The improvements that the online digital platforms can convey to industrial parks in their transition to eco-industrial parks essentially consist in promoting the extension of the network through the identification of new possible synergies and in the approach to initiatives through tools conceived to jointly optimize the network's technical, economic, environmental, and social efficiency with a view to sustainability and circular economy. For the innovative ferments that cross the eco-industrial parks in the different phases of their life cycle (from the incipient to the consolidated ones), the Wb-platforms, with their simulation and evaluation functions, constitute tools whose use creates the conditions for the success and viability of the initiative. In this regard, it is noted that in 17 of the 46 symbiotic initiatives registered in the MAESTRI database, including consolidated eco-industrial parks, network extensions are planned for over 130 more possible exchanges.

## 7. Concluding Remarks

As in many other fields, the future of industrial symbiosis and, in general, of projects pursuing sustainability and circular economy, depends on the ability of the actors to exploit the solutions offered by information technologies. The extension and depth of the information available in real-time by the means of Wb-platforms allows for the overcoming of the traditional barriers that hinder the degree of openness of industrial systems in terms of withdrawal of resources and emissions into the environment. Given the sectoral, territorial, and specific character of the materials considered in the different existing and functioning platforms and considering the different cycles existing in the eco-industrial parks (water, energy, by-products, etc.), the most promising way for their use is to consider multiple platforms to take full advantage of the contribution of each of them.

### *7.1. Managerial and Scientific Implications*

This contribution provides the web coordinates and outlines the main functional characteristics of some platforms supporting the industrial symbiosis initiatives that can help the companies interested in improving their activities at any stage of the life cycle of the symbiotic process. It also suggests the opportunity to use multiple platforms to integrate the results related to the different cycles (existing or planned) and evaluate the configurational alternatives with multi-criteria procedures. The principles and interpretative tools of the (vSA) provide general interpretations of symbiotic collaborations that allow managers to better adapt to the non-traditional role of managers of their businesses and components of a network. This requires managers to be able to successfully play the dual role of decision makers mainly aimed at the interest of the company to which they belong and of components of a broader governance system aimed at balancing the needs of all the stakeholders involved and those of the system as a whole, always inspired by the pursuit of not only economic but also social and environmental objectives, in one of sustainability. The conditions of success of the IS initiatives can essentially be declined along the lines of leadership style and cultural orientation towards sustainability; of the ability to develop relationships based on the principle of consonance with all the subjects belonging to the value chain, with sector associations, local and central authorities [62]; of predicting the opportunities for expansion of the symbiotic network through the analysis of potential flows of energy and materials of any type; of carrying out the related economic and environmental assessments; and of monitoring government policies and technological innovations regarding specific processes and waste management.

From this perspective, the first challenge of applying a systemic approach to the study of industrial symbiosis concerns the possibility of measuring the value created by sustainable practices in a broader perspective.

*7.2. Literature Implications, Limitations of the Current Study and Future Lines of Research*

Regarding the literature, this paper contributes by carrying out a first review of the functionalities of some platforms supporting industrial symbiosis, drawing attention to the incipient issue of their use in general and in eco-industrial parks in particular and highlighting the need for a systematization of their potential contribution in terms of improving the technical, economic, and environmental efficiency of the processes. Given the tumultuous evolution of ICT solutions and the rapid spread of their use by operators, future lines of research to be carried out with a view to continuous updating should be directed to an organic framework that could be achieved through the establishment of a network of scholars on the subject. Further research should be oriented to strengthening the systemic interpretations of industrial symbiosis through the modeling of the main social, economic, and environmental processes that can lead to viable symbiotic experiences intended as in the (VSA) framework, as well as to the entrepreneurial aspects [61,63–66]. In the same perspective, the main limitations of this contribution consist in the moderate number of cases considered and in the circumstance that it deals exclusively with platforms having a range of activities in the European countries, presenting yet another prospect of expansion of the present study.

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