

# Web-Based Platforms in Support of Industrial Symbiosis Initiatives: A Bibliometric Review

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The main purpose of this contribution is to depict most promising web-based solutions in terms of best configuration for symbiotic network. By examining 10 existing and functioning Wb-platforms of which only some have been previously explored in the previous literature, the paper aims at underling main contributions that platforms can provide to industrial symbiosis. Thanks to a mixed research method, the paper shows that the most promising way for enhancing Wb-platforms within industrial symbiosis framework is to consider multiple platforms for integrating the results obtained from the different platforms and for assessing multi-criteria procedures.

*Keywords:* industrial symbiosis, web-based platforms, bibliometric review

## Introduction

Under the pressure of government policies and public opinion towards the green transition and the digitalization of industrial activities, increasing attention is being paid, both in practice and in literature, to IS (industrial symbiosis) (Domenech et al., 2019; Afshari, Tosarkani, Jaber, & Searcy, 2020). The exchanges of energy, information, raw materials, and residues among firms, institutions, and local communities through networking, the proximity of production units, and the shared management of sites all embody the phenomenon of “industrial symbiosis” (IS), introduced by Renner (1947) in his geographic studies on the location of industrial activities and defined by Christensen (1992) on the basis of his managerial experience in the Kalundborg eco-industrial park in Denmark. Subsequently, many other definitions have been proposed within industrial ecology and circular economy frameworks (Chertow, 2000; Chertow & Lombardi, 2005; Mirata & Pearce, 2006).

The attention to symbiotic initiatives, which has recently become more intense due to the global crisis caused by the Covid-19 pandemic, has generated an operational and scientific area interested in businesses connected in clusters operating within the framework of circular economy (Iandolo, Loia, Fulco, Nespoli, & Caputo, 2021; Wuyts, Marin, Brusselsaers, & Vrancken, 2020).

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Recently, an increasing number of contributions have underlined that IS processes can be enhanced through Web-based platforms (Wb-platforms) as configurations aimed at supporting the transition of industrial processes towards industrial symbiosis and, in general, towards sustainability and circular economy (Benedict, 2018; Song, Geng, Dong, & Chen, 2018; Velenturf & Jensen, 2016).

As the success of any kind of synergy relies on trust, consonance, knowledge, and information sharing (Barile, Saviano, Iandolo, & Calabrese, 2014; Saviano, Barile, Farioli, & Orecchini, 2019; Simone, Barile, & Calabrese, 2018), in the specific case of industrial symbiosis, these conditions are essential for discovering and exploiting industrial synergy opportunities (Ghali & Frayret, 2019; Dounavis, Kafasis, & Ntavos, 2019).

The Wb-platforms complement the traditional functions of opportunity identification by the means of data-bases and—simultaneously—they assess the environmental, economic, and efficiency performance of complex, digitalized production systems aligned with the Industry 4.0 paradigm. Nevertheless, the chance to support new symbiotic projects and ongoing innovation processes in EIPs (eco-industrial parks) taking advantage of Wb-platforms seems to be little exploited. This circumstance is witnessed, in operational practice, by the termination, in the last decade, of some platforms [e.g. SMILE, the Ireland Industrial Symbiosis programme that provided a free platform for businesses to connect and identify synergies where a waste in one business can be a resource in another («(1) SMILE»)] and, in literature, by several proposals of new methodologies and tools aimed at better meeting the needs of users through ICTs (Information and Communication Technologies) (Yazan, Yazdanpanah, & Fraccascia, 2020; Raimbault et al., 2020; Meng et al., 2018; Fraccascia, 2020; Iandolo et al., 2021). Recognizing the existence of a wide gap in knowledge with reference to the role of Wb-platforms in promoting IS, the rest of the paper aims at investigating *how Wb-platforms can support IS*. With the aim to provide a possible answer to this research question the paper focuses the attention on the industrial park and on their transition to EIP. In such a line, the rest of the paper is structured as follows: Section 2 provides a literature review about IS; Sections 3 reviews a few cases of existing and operating Wb-platforms, and Section 4 links and discusses results from literature and Wb-platforms review. Finally, Section 5 provides conclusive remarks, argues the managerial and academic implications, outlines future research areas, and critically discusses the limitations of the work.

### **IS and Wb-Platforms: An Explorative Literature Review**

The literature review was conducted with a mixed procedure: in the first phase (bibliometric), contributions specifically devoted to ICT platforms were identified in Web of Science Core Collection within the scientific production on industrial symbiosis existing in the two macro-scientific areas of circular economy and industrial ecology. The query was: 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. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC.

The query returned 79 documents, represented in the following Figure 1.

In the second phase, the contributions were catalogued in Clarivate Analytics’ EndNote and the content analysis of the full-texts was carried out in order to obtain a picture of the evolution of the literature.

From the conducted literature review, it emerges that—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 developed. Beyond the preliminary studies reported by Chertow and Portlock (2002) and in particular in the contribution of Brown, Gross, and Wiggs (1997) which refers to Matchmaker! (one of the first portals for matching demand and supply of waste), the interest about IS has grown up in the last decade.

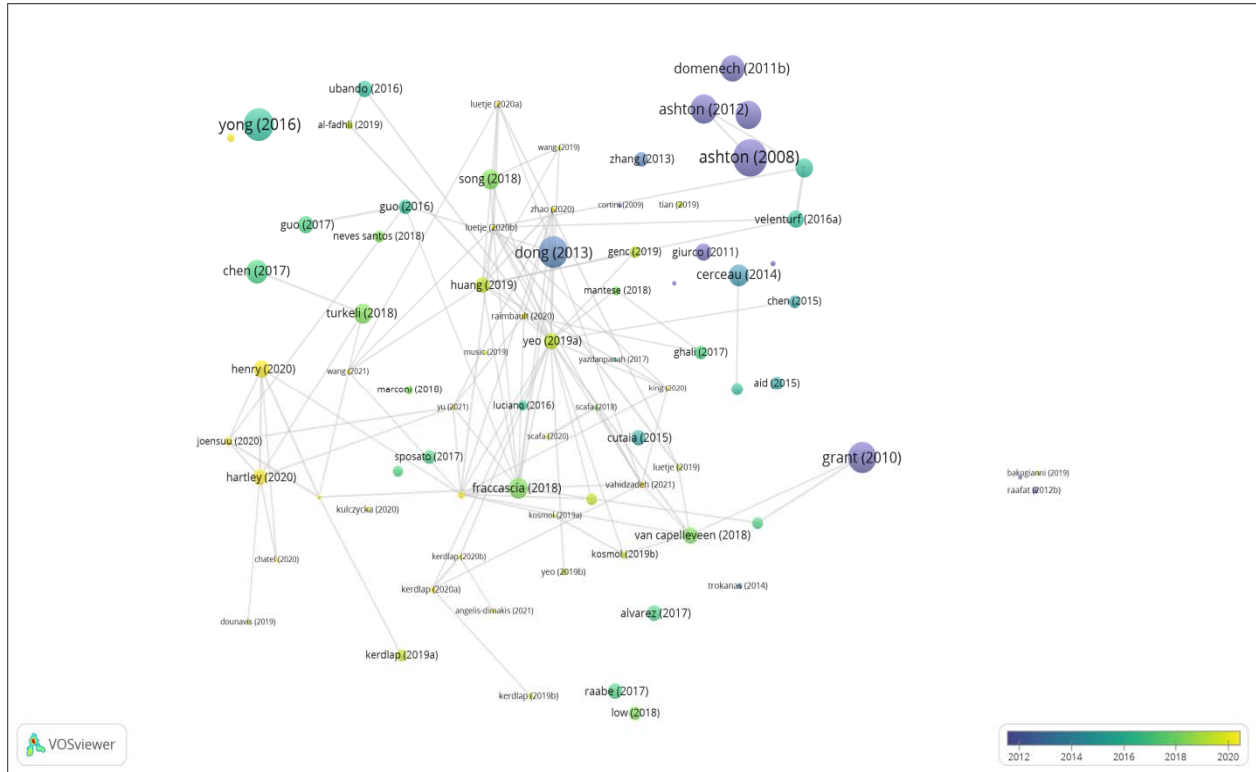


Figure 1. Bibliographic coupling of the references, overlay visualization. Source: Authors' elaboration (The map has been built with Vosviewer of van Eck and Waltman (2010; 2014). It is downloadable at the link <https://bit.ly/2RLNGbt>).

The expression “Industrial Symbiosis Platforms” is first used by Benedict (2018) who observes how information and communication technologies increasingly take the form of online platforms for helping to mitigate information and social barriers in IS. More recently, 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 (van Capelleveen, Amrit, & Yazan, 2018), of the simulation of transformations that take place in symbiotic networks (Lutje and Wohlgemuth, 2020), and of their design (Benedict, 2018). Despite this, from the literature, it emerges a fragmented picture in which there are few attempts of systematization of the potential of Wb-platforms, among which we have:

Grant, Seager, Massard, and Nies (2010) assess the opportunities granted within the phases of sprouting, uncovering, embeddedness of IS and systematizes the functionality of existing platforms in the stages previously disclosed. Maqbool, Alva, and Van Eetvelde (2019) advance a classification of 20 platforms among operational, discontinued, and in development on the basis of a scale relating to the prevalent focus on one or more of the Grant phases while van Capelleveen et al. (2018) propose a taxonomy declined along the dimensions of different information systems characteristics, role of support the systems provide, and technologies used to enable IS.

### Synergies Exploitation Systems: A Review of Existing Wb-Platforms

Several Wb-platforms—inspired to the principles of circular economy and industrial symbiosis—have recently been developed to support collaborative initiatives between single firms or firms operating in industrial clusters. This Section focuses on such Wb-platforms in terms of synergy exploitation systems as package of services that goes from the identification of symbiotic opportunities to the monitoring of processes, passing through the definition of alternatives symbiotic network configurations and the assessment of their effects in economy, environmental, and social terms for all the involved stakeholders.

Following the taxonomy of van Capelleveen et al. (2018), 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, resulting in very scarce information and data available (Ghali, Frayret, & Robert, 2016).

The main characteristics of few cases of Wb-platforms currently accessible and usable are summarized and analysed in the following Table 1.

Table 1

#### 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». <a href="https://maestri-spire.eu/">https://maestri-spire.eu/</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”.
SWAN «SWAN—Home Page». <a href="http://swanplatform.eu/">http://swanplatform.eu/</a> .	The SWAN platform, previously discussed by Angelis-Dimakis et al. (2021), 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». <a href="http://platform.fissacproject.eu/">http://platform.fissacproject.eu/</a> .	FISSAC Industrial Symbiosis Management Software Tool (FISSAC ICT Platform) is able to 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»).
CIRCULATOR «Home-Circulator». <a href="http://circulator.eu/">http://circulator.eu/</a> .	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.
PERCORSO CIRCOLARE «Percorso Circolare», 2019. Circularity (blog). Updated to April 10, 2019. <a href="https://circularity.com/servizi/percorso-circolare/">https://circularity.com/servizi/percorso-circolare/</a> .	Circularity.com, previously treated by Pizzi, Leopizzi, and Caputo (2021), platform aimed to develop to foster the industrial symbiosis of different types of organizations, advertises itself as the first and only circular economy industrial symbiosis platform in Italy.
WSX BM «Welcome to WSX-BM—WSX BM—European Waste Services Exchange Business Model», 2021. <a href="https://www.wsxbm.eu/en/">https://www.wsxbm.eu/en/</a> .	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 «INex Circular—Le Leader de La Détection de Gisements de Déchets». <a href="https://sourcing.inex-circular.com/">https://sourcing.inex-circular.com/</a> .	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 «REACT». <a href="https://react.biseps.eu/en/business-parks">https://react.biseps.eu/en/business-parks</a> .	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»).

Table 1 to be continued

ZBP «ZBP». <a href="https://www.inex-circular.com/eng/1/home">https://www.inex-circular.com/eng/1/home</a> .	The Zero Brine Platform, previously treated by Bakogianni, Skourtanioti, Meimaris, Xevgenos, and Loizidou (2019), allows 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.
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Source: Authors' elaboration.

## Discussions

The review of the literature and the examination of the platforms interested in the promotion and support of industrial symbiosis initiatives show an articulated framework of approaches and functions. With reference to the identification of possible synergies, the promotion of relationships between stakeholders, the simulation and evaluation of alternative network configurations, they differ for the economy sectors which they are mainly addressed to, for the territorial scales provided and for the types of exchanges (energy, waste, water, by-products). Accordingly, the improvements that the online digital platforms can convey to IS 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. Such results are possible only through the establishment of consonant social relationships among all the stakeholders involved in the projects made possible by platforms as instruments through which to reduce information asymmetries and generated coded communication formats.

## Implications, Limits, and Future Research

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 of the information available in real time thanks to Wb-platforms allows overcoming traditional barriers that hinder the degree of openness of industrial systems. Given the sectoral, territorial, and specific character of the materials considered of the different existing and functioning platforms the most promising way for their use is to consider multiple platforms in order to take full advantage of the contribution of each of them.

This contribution summarizes main characteristics of platforms in supporting industrial symbiosis. It also suggests the opportunity to use multiple platforms in order to integrate the results related to the different cycles (existing or planned) and evaluate the configurational alternatives with multi-criteria procedures.

The paper contributes to current literature by carrying out a first review of the functionalities of few platforms interested in supporting industrial symbiosis, drawing the attention on the need for a systematization of their potential contributions for improving technical, economy, and environmental efficiency of IS. Given the tumultuous evolution of ICT solutions and the rapid spread of their use by operators, future research lines require to improve a multi- and trans-disciplinary approach to in depth investigate challenges and opportunities of Wb-platforms in the domain of IS.

Main limitations of this contribution consist in the moderate number of analysed cases that have a range of action limited to European countries. Accordingly, future research will extend the observation in order to catch similitudes and divergences among Wb-platforms and IS processes in different geographical and cultural areas.

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