Barriers to Industrial Symbiosis

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Industrial symbiosis (IS) can contribute to achieving a win-win situation between industry and environment for local and regional circular economies. Many authors have recognized that a variety of barriers can hinder the implementation of industrial symbiosis (IS). It is imperative to understand and prioritize the barriers which will provide guidance for the realization of IS projects and assist practitioners and stakeholders with more effective implementation. This, in turn, will contribute to development of circular economies.

industrial symbiosis | industrial ecology | barriers | circular economy

1. Introduction

Industrial symbiosis (IS) has been well-recognized as a key subfield of industrial ecology (IE) [1][2]. A widely cited definition of IS is presented by Chertow [1]:"engaging traditionally separate entities in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and by-products. The keys to IS are collaboration and the synergistic possibilities offered by geographic proximity" (p. 314). IS research is flourishing and has covered a broad range of topics and cases [3]. IS helps to increase the industrial system's circularity [4] and is considered to be a circular economic business model [5]. It can often create economic, environmental, and social benefits [4][6][7], which assists in promoting local and regional sustainable development [8]. In recent years, IS has been considered to be a core strategy [6][9][10] and a key practical approach to promote the circular economy (CE) [4][11]. Fraccascia and Yazan [11] have argued that the catalytic role of IS in achieving a circular economy should be encouraged. In China, IS has been incorporated into national policies that were specifically formulated for CE, and has been identified as a key element for promoting national CE development [12], especially at the mesolevel [13].

A variety of barriers have been identified [3][4][6][9][14][15][16][17], which will influence the viability of IS and eco-industrial development [1]. Barriers for IS have been identified as one of the key topics which current IS research addresses [18] and are in urgent need of being examined [4][6]. The operation of IS remains a complex and dynamic process [2][19], which requires continuous improvement [2][20]. Cervo et al. [4] stressed that the "creation of a symbiosis is a multi-step process that goes from the identification of an opportunity to its implementation and operation" (p. 6). When organizations implement IS, it is important to start from understanding the barriers that they could face [21]. For operating industrial symbioses, there are still barriers hindering their full potential development [15][17][22]. Barriers can arise at different phases of the symbiotic development and the importance of a barrier will vary at different stages of the process [2][15]. Thus, it is imperative to prioritize the barriers which hinder the implementation and development of IS [2][15][20][23].

2. Identification of IS Barriers

In general, the current research on identifying barriers related to IS can be mainly divided into three groups, i.e., specific barriers, generic barriers, and evaluation of barriers using mathematical methods. They are summarized in **Table 1**.

2.1 Identification of Specific Barriers

Some researchers identified some specific barriers related to IS from different perspectives, such as institutional barriers [24][25][26], organizational perspective [3], environmental regulation barriers [27], and sectoral boundary barrier [28]. They are summarized in **Table 1**.

2.2 Identification of Generic Barriers

The generic barriers related to IS were also put forward by some researchers. Some of these studies chose some IS or EIP cases to identify barriers, such as the Kwinana and Gladstone of Australia [15][17], the industrial estates of Canada [29], the Ulsan EIP project of Korea [30], and the EIPs of China [31]. These generic barriers are listed in **Table 1**.

Table 1. Identification of barriers related to IS.

Categorization of IS Barriers	Descriptions	References
Identification of specific barriers	• Institutional barriers for development of IS	[24][25][26]
	• Barriers of IS focusing on an organizational perspective	[3]
	• Barriers for impeding the development of industrial ecosystem focusing on human dimensions	[32]
	• Social barriers for waste exchange	[33]
	• Barriers to intercompany cooperation	[34]
	• Barriers for EIP focusing on the topic of management	[35]
	• Environmental regulatory barriers that hinder the IS	[27]

Categorization of IS Barriers	Descriptions	References
Identification of generic barriers	• Barriers for development of interorganizational environmental management	[36]
	• Sectoral boundary barrier for IS, which is caused by the traditional planning system of China	[28]
	• Societal and environmental problems related to EIPs	[37]
	• Barriers to reuse and recycle in IS	[38]
	• Barriers of information and knowledge for IS	[39]
	• The critical limiting factors for EIPs from the worldwide EIP experiences are categorized as symbiotic business relationships, economic value added, awareness and information sharing, policy and regulatory frameworks, organizational and institutional setups, and technical factors.	[40]
	• Barriers for the development of IS include categories of economics, information availability, corporate citizenship and business strategy, region-specific issues, regulation and technical issues.	[17]
	• Factors influencing the development and sustained operation of regional IS networks include technical, political, economic and financial, informational, organizational, and motivational.	[41]
	• Barriers associated with eco-industrial activities in CIE and PEBZ include costs, roles and responsibilities, knowledge, and regulations.	[29]
	• Potential barriers for developing EIPs include technical barriers, informational barriers, economic barriers, regulatory barriers, and motivational barriers.	[42]

9. Henriques, J.; Ferrão, P.; Castro, R.; Azevedo, J. Industrial Symbiosis: A Sectoral Analysis on Enablers and Barriers. Sustainability 2021, 13, 1723.

Categorization of IS Barriers	Descriptions	References
	• Challenges in the Ulsan EIP project include the reluctance of companies and industrial representatives to take an active role in the initiative, environment regulations and standards, and no integrated management of the two industrial complexes.	[30]
	• Barriers for establishing IS relationships include technical, economic, informational, organizational, and regulatory (legal).	[43]
	• From industrial park senior manager perspectives, barriers for EIP development in 51 Chinese industrial parks include capital, policy, informational, tangible resources, and intangible resources.	[31]
	• Barriers to IS based on a case study of Gladstone include commitment to sustainable development, information, cooperation, technical, regulatory, community, and economic.	[15]
	• Barriers which can hinder the implementation of IE at the industrial estate level include technical barriers, information barriers, economic barriers, regulatory barriers, and motivational barriers.	[44]
	• Challenges that organizations may face when developing byproduct synergy include regulatory, economic, technical, and organizational barriers.	[45]
	• Barriers in forming an IS network in an industrial park in the Philippines include lack of trust among locators, lack of information sharing among locators, lack of top management support, lack of training for implementing IS, lack of policy to incentivize initiative of IS, lack of funding to promote IS, lack of technology and infrastructure readiness, lack of institutional support for integration, coordination, and	[14] [15] [31] [14]

Industrial Parks. Chem. Eng. Trans. 2016, 52, 811–816.

assists in detecting which barriers can be categorized as cause or effect factors. Based on the work of Bacudio et al. [14], Promentilla et al. [23] proposed a methodological framework to analyze the barriers for an EIP in the Philippines. The related contents are also listed in **Table 1**.

Categorization of IS Barriers	Descriptions	References
	communication, lack of willingness to collaborate, and lack of awareness of IS concepts.	
Evaluation of barriers using mathematical methods	• The IS maturity grid includes seven IS barriers that are tested against five stages of IS maturity and was applied to a real IS example of Gladstone industrial region of Queensland, Australia.	[15]
	• Adopt a factor analysis to identify and group a number of barriers for EIP development, and adopt cluster analysis to categorize and evaluate the levels of barriers perceived by senior officials who manage the EIPs.	[31]
	• Adopt the Decision Making Trial and Evaluation Laboratory (DEMATEL) method to identify barriers for implementing IS in an industrial park.	[14]
	• Propose a methodological framework which combines DEMATEL, Interpretive Structural Modeling (ISM), and Fuzzy Analytic Network Process (ANP) to analyze the barriers of designing and implementing an EIP.	[17]

by-products' under current environmental regulations [27], which prevents the reuse of wastes [15]. Based on EU policy and legal framework, Watkins et al. [26] concluded that the current end-of-waste criteria of the Waste Framework Directive (WFD) do not support the development of IS. Singh et al. [51] reported that "there is a lack of clarity on various areas of European Union legislation such as reuse and recovery" (p. 101752). Regulations may also impede transportation and reuse of wastes [45][52]. Van Beers et al. [17] mentioned strict transportation procedures and requirements that need to be applied for a byproduct that is classified as a controlled waste. Desrochers [38] mentioned that it is prohibited to export wastes categorized as "hazardous waste" to the United States under the Resource Conservation and Recovery Act (RCRA). Papathanasoglou et al. [25] reported that industrial units belonging to certain categories are not permitted to be located in the same industrial area in terms of the existing institutional framework in Greece, which restricts the shift towards the establishment of IS. Furthermore, Papathanasoglou et al. [25] argued that besides barriers of IS resulting from implementation of the current regulations, lack of comprehensive and specialized legislation hinders the development of IS as well.

In addition, closely related to the context of China, the planned economic system that was previously chosen by the Chinese government resulted in sectoral boundary barriers, which impeded the development of IS [28].

3.2 Economic Barriers

Economic considerations are a critical factor for the success of IS [2][41][53][54]. The existing pricing mechanism for waste products can be a barrier to IS [15]. Ayres [55] argued that "many industrial wastes cannot be economically

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3.3 Technological Barriers

Concerns about the technical feasibility of waste exchange can be a barrier for IS [43][45]. Van Beers et al. [17] noted that IS concerns the capture, recovery, and reuse of byproducts. They reported that many potential IS opportunities have been prevented from being realized because of technological challenges, such as availability of (reliable) recovery technologies [17]. Lu et al. [58] mentioned some technical barriers associated with waste water regeneration and solid waste reutilization. Gibbs [42] perceived the possibility that local companies have no potential to 'fit together' as an example of technical barriers. In addition, lack of evaluation technique related to IS has received attention by some researchers. Costa et al. [59] emphasized lack of evaluation of the potential recycling function of manufacturing technologies already in place as a challenging technological barrier. Sakr et al. [40] considered that "the lack of local technical know-how capable of identifying and evaluating IS opportunities" (p. 1166) is an important technical issue.

3.4 Organizational Barriers

Heeres et al. [43] mentioned that the anticipated waste exchange might not conform to the current corporate organizational structure, which can be considered as an organizational barrier for IS. Walls and Paquin [3] argued that organizational structure can result in insufficient autonomy of subsidiaries for engaging in waste exchanges, thus limiting IS. For example, some researchers found that companies which are subsidiaries of national or international corporations may be "unable to alter materials linkages" [50] (p. 1693), or may lack interest in IS exchange [3][40]. This is considered to be a result of having limited decision-making powers [29][40][50]. Furthermore, Heeres et al. [43] found that in the case of the Fairfield EIP project, "absence of an entrepreneurs association that represents all Fairfield industrial companies" (p. 993) is one of the factors causing problems for this project.

The culture of an organization plays an important role in implementing IS practices. A shared vision and beliefs can form a common culture among actors of an IS [3][60][61]. Some researchers argued that organizational cultures with low levels of interfirm cooperation could cause a certain reluctance against taking part in symbiotic relationships [41], or could prevent companies from working across organizational borders [50].

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In addition, Tudor et al. [54] postulated that "one of the main impacts of leaving recycling elsewhere, and its materials/products" (p. 204) will influence the functioning of the entire chain in a small industrial network. Heeres et al. [43] found that in the Rietvelden/Vutter (RiVu) EIP project, having "few large, financially strong companies" (p. 993) is one of the barriers for this project.

3.5 Informational Barriers

Informational support assists in discovering IS opportunities through identification of possible compatible flows [2][20] and making decisions on the establishment of IS [62]. Heeres et al. [43] further suggested that informational barriers can be perceived as "the right people do not have the needed information at the right time" (p. 987). Gibbs [42] argued that it may be difficult to find new uses for waste products due to barriers such as poor information on the potential market and potential supply. Chertow [63] found that business managers "often lack access to information about their neighbors in different industries" (p. 24).

Heeres et al. [43] found that a communication platform is critical for EIP projects. Raabe et al. [39] considered that one major barrier faced by companies participating in IS is lack of information relating to possible and available byproducts. They suggested that a collaboration platform providing information could be helpful for companies engaging in a symbiosis [39].

In addition, there is difficulty in exchanging information between companies. LeBlanc et al. [29] found that some businesses, especially the large ones, "seemed hesitant to participate openly in eco-industrial activities because of the risks associated with sharing information with potential competitors" (p. 12). Based on the context of Egyptian industry, Sakr et al. [40] found that companies resist exchanging information "for fear that it may be used against them by the regulatory authorities" (p. 1163).

3.6 Cognitive Barriers

Cognition or perception is identified as one of the barriers for the development of IS by some researchers [45][64]. Mangan and Olivetti [45] pointed out that waste is often perceived as something with negative connotations by companies. This makes companies unwilling to focus on waste and participate in IS relationships [45]. Ehrenfeld and Gertler [64] argued that it is difficult for companies to integrate wastes into their strategic processes because wastes have a long history of being ignored. Notarnicola et al. [22] found that a main constraint for IS implementation is that the strategic approach of companies is highly oriented to the primary product with a focus on core business. In this circumstance, the waste is regarded as something to be disposed of quickly [22]. Some authors found that one of the barriers in enabling IS is that companies lack understanding of concepts, principles, potential benefits, and cooperation related to IS activities [29][34][37][39][40].

3.7 Motivational Barriers

Some researchers argued that there may be motivational barriers wherein stakeholders must be willing to cooperate [34][42][44]. In this respect, the barriers may be a lack of trust [42][43][44]. Gibbs [42] also noted that a lack of

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trust would inhibit the establishment of a symbiotic relationship. Compared with Dutch industry, Heeres et al. [43] found that when participating in EIP projects, US companies have more distrust towards the local government that acts as the EIP project promoter. Lehtoranta et al. [49] suggested that creation of trust is more challenging for larger regions when attempting to implement IS.

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3.8 Safety Barriers

Chertow [63] argued that concern about the use of industrial byproducts, especially in symbioses involving agriculture, needs to be carefully examined because it is an important environmental and health issue. This means that an IS relationship focusing on utilizing wastes may be hindered if it can cause safety problems for environment and human health. Chertow [63] further pointed out that there is still no widely reported evidence of environmental health problems resulting from byproduct exchanges that has been found. In a case study of IS around the Gulf of Bothnia, Salmi et al. [27] found that while there were no significant technological barriers on utilization of wastes around that region, from an ecological point of view, they argued that the marine transport of hazardous materials across the open sea during winter is certainly risky and recommended that a risk assessment on marine transport should be conducted [27].

Table 2. Classification of IS barriers.

Categories of Barriers	Type of Barrier	References
Governmental barriers	• Policy barriers	[3][47][49][64][65]
	• Regulatory barriers	-
	• Barriers resulting from implementation of current regulations	[15][17][26][27][29][38][41][43][45][50][51][52][65][66]
	• Barriers resulting from lack of specialized regulations	[25]
	• Government institutional or government management system barriers	[25][28][41]
Economic barriers	• Cost barrier	[3][17][27][41][65]
	• Investment barrier	[3][49][57]

Categories of Barriers	Type of Barrier	References
	• Benefit barriers	[42][45][56]
Technological barriers	• Lack of recovery and recycling technology	[17][58]
	• Lack of evaluation technique	[40][42][59]
Organizational barriers	• Organizational structure	[3][29][40][41][43][50]
	• Organizational cultures	[41][50]
	• Main companies	[43][54]
Informational barriers	• Lack of access to information	[39][41][42][43][56][63]
	• Difficulty in exchanging information	[29][40]
Cognitive barriers	• Lack of understanding related to IS activities	[22][29][34][37][39][40][45][64]
Motivational barriers	• Lack of trust and cooperation	[42][43][44][49]
Safety barriers	• Potential risks for human health	[63]
	• Potential risks for environment or ecology	[27][63]

4. Prioritizing the IS barriers in a Comprehensive Manner with More Case Studies

From an extensive literature review, it can be seen that the current research related to IS barriers is mainly qualitative. Evaluation of the IS barriers is still very limited. It is imperative to prioritize the barriers in a comprehensive manner with more case studies. There has one study which proposed a Group AHP-TOPSIS Model to semi-quantitatively evaluate the barriers which impede the implementation of IS [67]. The model is designed as a two-level hierarchical structure, which assists in identifying the degrees of importance of generic barriers and the specific barriers corresponding to their generic barriers. An operating IS of China is taken as a case to test the proposed model. It shows that at the generic barriers level, the top four degrees of importance of generic barriers are technological barriers, economic barriers, safety barriers, and informational barriers. Technological barriers are the most important generic barrier for the IS and should be given the most attention to be managed or eliminated. The top five specific barriers are information platform barriers, human safety and health barriers, technology of extending industrial chain barriers, product added value barriers, and cost barriers. Information platform barriers are the most important specific barrier and should be emphasized. This demonstrates that the model assists in prioritizing the different barriers in a comprehensive manner. In the future, more research on prioritizing the IS barriers with case studies from different countries needs to be developed. This will help to provide empirical evidence IS barriers studies and should be helpful for managers, decision-makers, and policy planners to understand the IS barriers, focus on several critical barriers, and set comprehensive efforts for improving the operation of an IS, which could facilitate the transition to a circular economy.