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Review

Analysis of the Development of Industrial Symbiosis in Emerging and Frontier Market Countries: Barriers and Drivers

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Abstract: Industrial symbiosis (IS) allows the use of the resources of a productive chain, based on collaboration between companies, finding ways to use the waste of one as inputs or raw materials for the other entity. IS seeks to generate environmental sustainability, maximize resources, and generate social, environmental, and economic benefits based on the physical exchanges of waste, residues, and materials, which generate various advantages for companies and environmental benefits for society. Over the years, research has been conducted worldwide on the implementation of IS in business settings and case studies related to IS in countries with strong economies; however, no papers mapping studies on IS that are focused on emerging and frontier market countries have been identified, and academic literature on research in these countries is also scarce. In this research, an in-depth review of the literature on IS cases in emerging and frontier market countries was conducted to provide future researchers with information on the similarities, weaknesses, strengths, and elements to consider in addressing the topic and closing research gaps in the area. In addition, a mapping was made of the evolution of studies on IS according to country, economic activity, distribution by journal, year of publication, methods used, barriers and drivers in the case studies, and the importance of this topic in the current academic context. In Asian and developing countries, the integration of companies and economic activities takes place in industrial parks, and they have legislation and government regulations that support IS. On the other hand, in the United States and Africa, integrating various sources such as energy, water, coal, and waste in industrial environments is at an early stage of development, and opportunities are being identified to promote IS between companies. This research interests a broad audience, including investors, regulators, policymakers, and researchers interested in fostering IS in emerging and frontier market countries as a mechanism for industrial and economic development.

Keywords: industrial symbiosis; circular economy; emerging market; frontier market; sustainability

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1. Introduction

The need to reduce the environmental problems associated with the large amount of waste generated by industrial activity and the depletion of natural resources has created several global challenges. One of these challenges is waste and residues, which have become one of the leading causes of environmental pollution when they are not reused in industrial processes [1]. Several authors argue that in order to mitigate natural resource use and reduce waste without compromising consumption, it is necessary to implement sustainability objectives that often consist of cross-sectoral partner efforts [2,3]. Similarly, it is necessary to propose solutions to the ecological and socio-economic challenges resulting from the growing consumption of non-renewable resources, waste generation and soil, water and air pollution, and the scarcity of resources [4,5].

Currently, as the norm, a take-make-waste perspective is adopted, wherein materials required for production are harvested, manufactured, and discarded in such a way that their intrinsic value is underutilized and, at the same time, they will go on to pollute commonly used resources (e.g., air, water bodies, and land) [1]. These issues make it necessary to implement strategies that allow companies to increase competitiveness, generate production chains, take advantage of waste or by-products, stimulate the economy, and reduce the environmental impact of waste. In a world with increasingly visible environmental, economic, and socio-political challenges, the idea of transitioning to more sustainable production and consumption practices is gaining ground [6]. As a result, there is a growing interest in circularity within and between resource and waste value chains; in this context, the concepts of the circular economy and IS become relevant, understanding IS as part of the circular economy.

The circular economy focuses on achieving sustainability goals, realizing efficient production management, and identifying new working procedures or methodologies to improve resource efficiency and environmental friendliness [7]. In circular economy practices, the available resource is kept in a closed loop, i.e., even if a product reaches the end of its useful life, its component parts are reused [8,9]. IS is presented as a tangible solution that will generate significant benefits for companies [10]. In IS, materials, including waste, are interchangeable and are used to substitute commercial products or raw materials in another system; such interactions increase the overall efficiency of the resources used, reduce emissions, and eliminate waste, compared to when the enterprise operates independently [11]. IS also challenges companies; implementing waste symbiosis introduces new supply and demand relationships and forms a collaborative supply chain network between previously unrelated companies [12,13]. In North America, Asia, and Europe, several projects that are under development implement IS, and many of their products are pretty promising [14–16]; however, IS should be understood as a concept of a global application that is relevant to countries with emerging economies and not only to developed countries. Several studies have identified and tracked the successful IS cases worldwide, focusing mainly on countries with developed economies and great experience in establishing green industries and sustainable production, where two or more institutions interrelate to obtain mutual benefits. Implementing IS in emerging and frontier countries requires the adaptation and adoption of strategies aimed at resource-sharing and the possibility of developing an eco-industrial development strategy for those areas [17].

"Emerging market countries" is a classification for grouping those areas that are no longer developing countries but that have not yet achieved developed country status [18]. "Frontier market countries" include those countries whose economies are even more volatile than those of emerging markets [19]. This paper aims to identify and analyze the IS studies carried out in emerging and frontier market countries in the literature. To this end, a classification scheme will characterize the evolution of this field of study and identify and analyze the barriers and drivers that are present in the IS cases. In this way, benchmarks will be established for future research and study topics, to develop and strengthen this area of knowledge in terms of emerging and frontier market countries.

Our focus on the emerging and frontier markets is motivated by several factors. First, in undeveloped countries, the industrial sector, integrated resource utilization, capital markets, and regulatory systems are weak [20,21]. Second, we contribute to the existing literature in several ways. Reviews of IS case analyses have been conducted worldwide, for example, in [22–25]; however, this paper is the first to examine the development of IS in emerging and frontier countries. Therefore, it establishes a baseline upon which studies, research, regulations, strategies, and policies can be defined to develop these economies, based on the industrial sector's competitiveness. This research may be of interest to a broad audience, including investors, regulators, policymakers, and researchers who are interested in developing the economies of these countries [20]. Thirdly, although there is a growing interest in IS in non-developed countries, no studies analyze characteristics, methodologies, types of studies, and success factors. Finally, another aspect to consider is that this article presents the elements that emerging countries should consider when developing IS activities to improve their economies and the integral use of resources.

Therefore, our study helps address IS research in emerging and frontier markets and provides insight into the determinants of IS implementation by firms located in countries where capital markets, regulatory systems, and enforcement mechanisms are incipient and developing. In addition, this research explores how countries and firms operating in developing institutional environments can pursue IS practices in light of the knowledge gap. It is hoped that the opportunity to develop a more nuanced understanding of IS in emerging countries will open new avenues for IS research around issues arising from those institutional peculiarities that appear to have been under-studied to date [26].

This article is organized as follows. Section 1 develops the theoretical and contextual background on IS, emerging countries, and countries with frontier markets. Section 2 presents the methodology used in selecting publications, developing a classification framework in categories for the development of the research, and the subsequent content analysis. Section 3 describes and analyzes the geographical distribution of IS studies, the type of productive activity involved in IS, the analysis of the evolution of the number of publications, their distribution by journals, and the methods used for resource integration in the case studies. Section 4 discusses the barriers and drivers of the advances and opportunities identified in each of the previous sections. Finally, Section 5 defines the conclusions of this study and gives recommendations for future research.

1.1. Industrial Symbiosis

IS is a collaborative approach between firms involving physical exchanges of materials, energy, and waste, creating economic advantages for firms and environmental benefits for society [27]. Frosch and Gallopoulos [28] introduced the concept of symbiosis as part of a hypothetical industrial ecosystem in which the "consumption of materials and energy is optimized; waste generation is minimized, and effluents from one process are used as raw material for another process" [25]. The term "industrial symbiosis" has its origins in biology, where symbiosis represents the "association of individuals of different species in a relationship where there is a mutual benefit" [29]. This concept has been extended to industries in which IS enables the utilization of resources in entities that are usually separated, propitiating a physical exchange of waste, water, by-products, and energy [30]. IS relationships promote environmental compliance, resource savings, and economic benefits by giving value for longer to waste that would otherwise end up in landfills and incinerators [22].

According to Earley [31], IS allows business relationships in which human resources, assets, ideas, and resources are exchanged, collaborations whereby companies can increase their production and have a higher profit margin, in addition to minimizing adverse effects on the environment and reducing pollution from the generation of new waste. IS can be considered as a subfield of industrial ecology, and it allows traditionally separate entities and companies to cooperate in the sharing of resources, contributing to increased sustainability and bringing environmental, economic, and social benefits [22]. IS involves industries in which physical exchanges of materials, energy, and services occur [30,32]. Mainly, this is waste resulting from production processes, which can be used by other processes, belonging either to another company or to the same company, to replace production inputs (raw materials, waste, water, energy) or to generate new products, which are then sold in markets [33]. Thus, industries that decide to implement IS can obtain economic and environmental benefits by simultaneously reducing production costs and generating environmental and social benefits for the whole collectivity [34–36]. The need to reduce the impacts of industrial operations on the environment and the growth in demand for new resources has recently drawn more attention to the need to scale up IS practices regionally to achieve more effective results [23,37].

1.2. Emerging Market Countries

Emerging economies are countries in a transitional phase, neither too rich, nor too poor, nor too closed to foreign capital, with regulatory and financial systems that have not yet fully matured [38]; that is, it refers to an economy experiencing considerable economic growth and possessing some, but not all, of the characteristics of a developed economy [18]. For a country to be considered emerging, it must possess the following defining characteristics:

Below-average per capita income: These markets have a per capita income below the average of developed countries. The World Bank defines developing countries as those with a per capita income of USD 3995 or less [39].

High economic growth rates: Governments tend to implement policies that favor rapid economic growth and industrialization in these countries. These policies lead to higher per capita disposable income, lower unemployment, better infrastructure, and higher investments. On the other hand, developed countries, such as the United States, Germany, and Japan, experience low economic growth rates due to early industrialization [19].

Market volatility: Market volatility is due to political instability, external price movements, and/or supply and demand shocks due to natural calamities. Increases in exchange rates and exchange rate volatility will likewise increase input costs, increase borrowing costs, trigger expectations of a financial crisis, and negatively affect consumption and investment expenditures [40].

Growth and investment potential: Emerging markets are often attractive to foreign investors due to the high return on investment that they can offer. In the transition from an agriculture-based economy to a developed economy, countries often require a large inflow of capital from foreign sources due to a shortage of domestic capital. As a result, these countries focus on exporting low-cost goods to wealthier nations, which drives GDP growth, stock prices, and returns for investors [19].

Morgan Stanley Capital International presented the 2021 global market accessibility review results, reflecting the current market rankings. The Emerging Market Index lists 27 countries, and these are China, Brazil, Chile, Colombia, Argentina, India, Korea, South Africa, the Czech Republic, Pakistan, Egypt, Poland, Greece, Hungary, Indonesia, Kuwait, Malaysia, Mexico, Thailand, Peru, Philippines, Qatar, Russia, Saudi Arabia, Taiwan, Turkey, and the United Arab Emirates, Benin, Burkina Faso, Ivory Coast, Guinea-Bissau, Mali, Niger, Senegal, and Togo [41].

1.3. Frontier Market Countries

Frontier market countries have become important destinations for foreign investors trying to seek profitable diversification benefits [42] because they have much more room to grow [19]. The main reason for the growing interest, despite the higher risk, is that frontier markets offer higher return potentials and are uncorrelated with other international markets [43]. It is necessary to understand the countries, their political systems, and their economic challenges because they are vulnerable to global changes in trade, currency, and central bank policy changes [19]. According to the index prepared by Morgan Stanley Capital International, frontier market countries are Croatia, Estonia, Iceland, Lithuania, Kazakhstan, Romania, Serbia, Slovenia, Kenya, Mauritius, Morocco, Nigeria, Tunisia, Bahrain, Jordan, Oman, Bangladesh, Sri Lanka, and Vietnam [41].

2. Materials and Methods

A systematic literature review was used because it allows the identification, classification, evaluation, interpretation, selection, and analysis of relevant research in the area of IS in emerging and frontier countries. In addition, it allows obtaining information in a transparent manner, minimizing any errors peculiar to the authors that could affect the results of the research. Taking into account the above, this paper proposes a comprehensive methodology consisting of the following steps:

Step 1. Data Collection Process: A systematic review of IS cases, focused on emerging and frontier market countries, was conducted based on information gathered from various databases. The process started with a search based on Scopus and Web of Science [44,45], with the phrase "industrial symbiosis". Next, we searched the publication's title in the reference section and keywords, identifying 812 publications (last updated December 2021). Duplicate articles were eliminated, and an initial sample of relevant articles was defined according to abstract relevance, selecting 323 articles. Gray literature articles were not included; these refer only to the IS as an example or are mentioned only in the introduction as a way to contextualize or distinguish a concept (see review process in Figure 1).

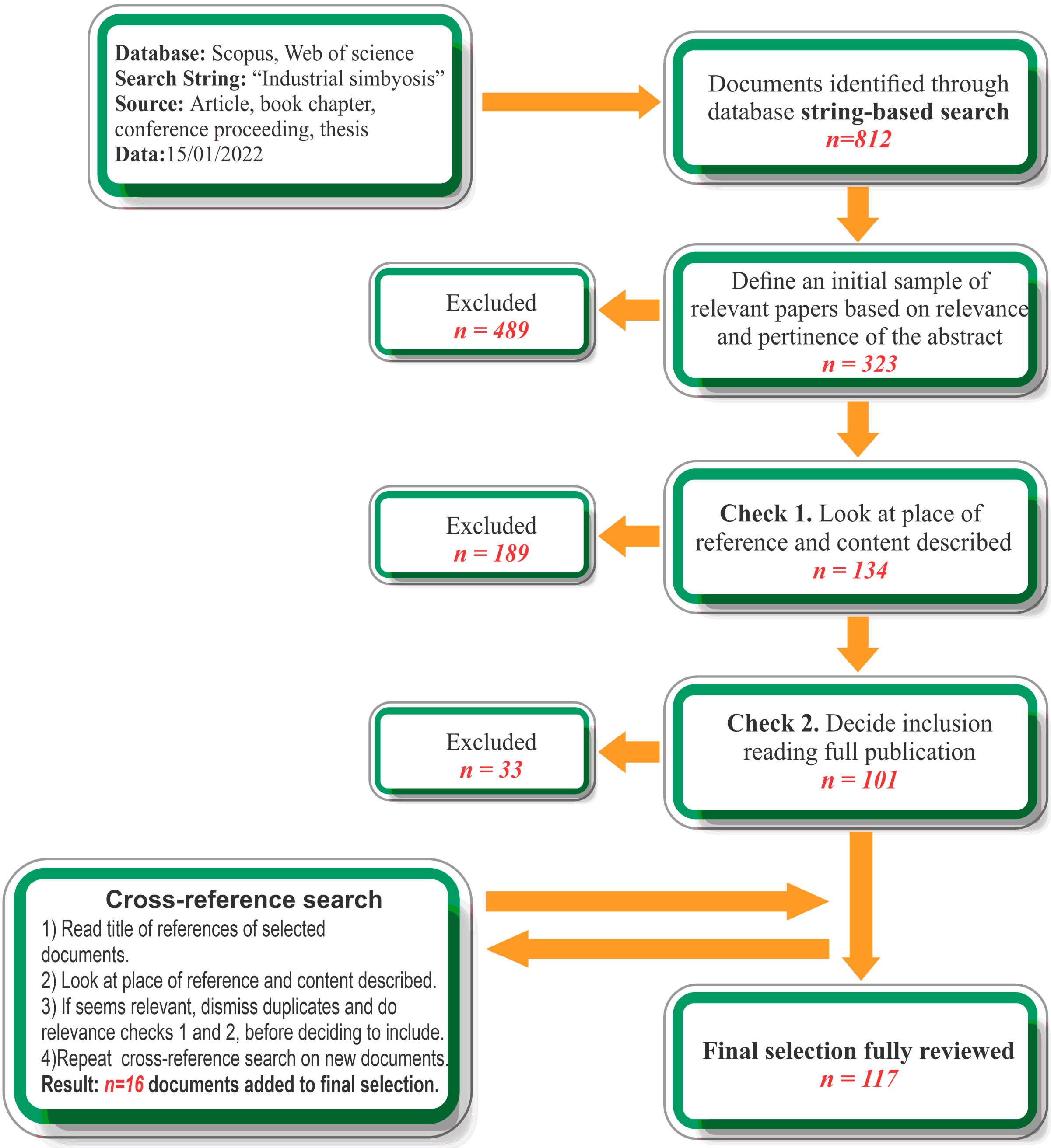

Figure 1. The systematic literature review process.

With a systematic review of the abstract and the full article, it was verified that the studies found addressed research that was developed in the field of IS. If there were doubts about the inclusion of the articles for subsequent content analysis after reading, the text was examined, analyzing the context in which the term "industrial symbiosis" was inserted and whether they referred to studies developed in emerging and frontier market countries. Initially, 101 studies were selected, and a systematic database search cross-reference snowballing process was performed, following the procedure of Geissdoerfer et al. [45] and of Santa-Maria et al. [44]; i.e., references cited in the analyzed articles were used to search for other publications related to the topic of interest. This process was repeated until no more relevant cross-references could be identified, which, after the two relevance checks, provided 16 additional publications, giving a total of 117 publications that were reviewed in their entirety.

Step 2. Development of research questions: The classification process is based on the following questions:

RQ1. What is the geographical distribution of emerging and frontier market countries conducting IS research?
RQ2. In which economic sectors have IS studies been conducted?
RQ3. What has been the contribution of journals to the evolution of published articles?
RQ4. What has been the evolution of articles published on IS and the research methods used in the cases analyzed?
RQ5. What type of resource integration is present in the case studies?

Each question has several answers, which are used to divide the reviewed articles into categories. The resulting categories are listed below:

(A) Geographic distribution: this classification determines the continent, country, and region in which the research was conducted, and identifies whether it concerns emerging market or frontier market countries. Regarding the geographical distribution of the countries researching IS, the classification was made according to the location of the case study. In addition, theoretical studies were classified in cases with multiple institutions in an investigation, taking into account the nationality of the largest number of authors.
(B) Type of industries involved in industrial symbiosis: a categorization is made according to the economic sector in which the studies were carried out.
(C) Evolution of the number of published articles: this shows how articles on IS have varied from year to year in emerging and frontier market countries. The methods used in each case study being analyzed are identified.
(D) Contribution of journals: selected articles are classified according to the journal in which they were published.
(E) Resource integration: the main resource integrations present in the case studies analyzed are identified.

Step 3. Review analysis: a comparison was made from different perspectives, analyzing research trends in the area, the evolution of the number of published articles, the contribution of the journals in the evolution of the articles, their geographical distribution, the selection of IS cases, and an identification of the methods used.

Step 4. Based on the analysis of the literature, a discussion was developed around the barriers and drivers that point to the development of IS in emerging and frontier countries and the importance of this topic in the current academic context [46].

3. Results

3.1. Geographic Distribution

This subsection develops the analysis around research question 1 (RQ1). Over the years, research has been conducted globally on the implementation of IS in enterprise environments and case studies related to IS in countries with strong economies, such as case studies of Kalundborg in Denmark, Kwinana and Gladstone in Australia, and Rotterdam Europoort in the Netherlands [47]; however, studies conducted on IS in emerging and frontier market countries are not abundant in the literature. The IS cases reported in the literature and considered in this paper cover several countries—America, Asia, Europe, and Africa; however, only studies conducted in emerging and frontier market countries are considered for this analysis. The statistical records of published cases on IS that are identified in this work are as follows: Asia with 79 studies, corresponding to 67.52% of the total cases, followed by America with 23 studies, corresponding to 19.65%, Europe, with 11 cases, which is equivalent to 9.40%, and Africa has the remaining 3.41%, with 4 cases.

Figure 2 shows the geographical distribution of the IS case studies in emerging market countries and frontier market countries. Seventy-three cases were identified in emerging countries and nine cases in frontier countries. China has the most cases reported in the IS literature, followed by other countries such as Brazil, India, Singapore, Taiwan, South Korea, and the Philippines. Thirty studies carried out in China were analyzed, with China standing out as the country with the most developments in IS.

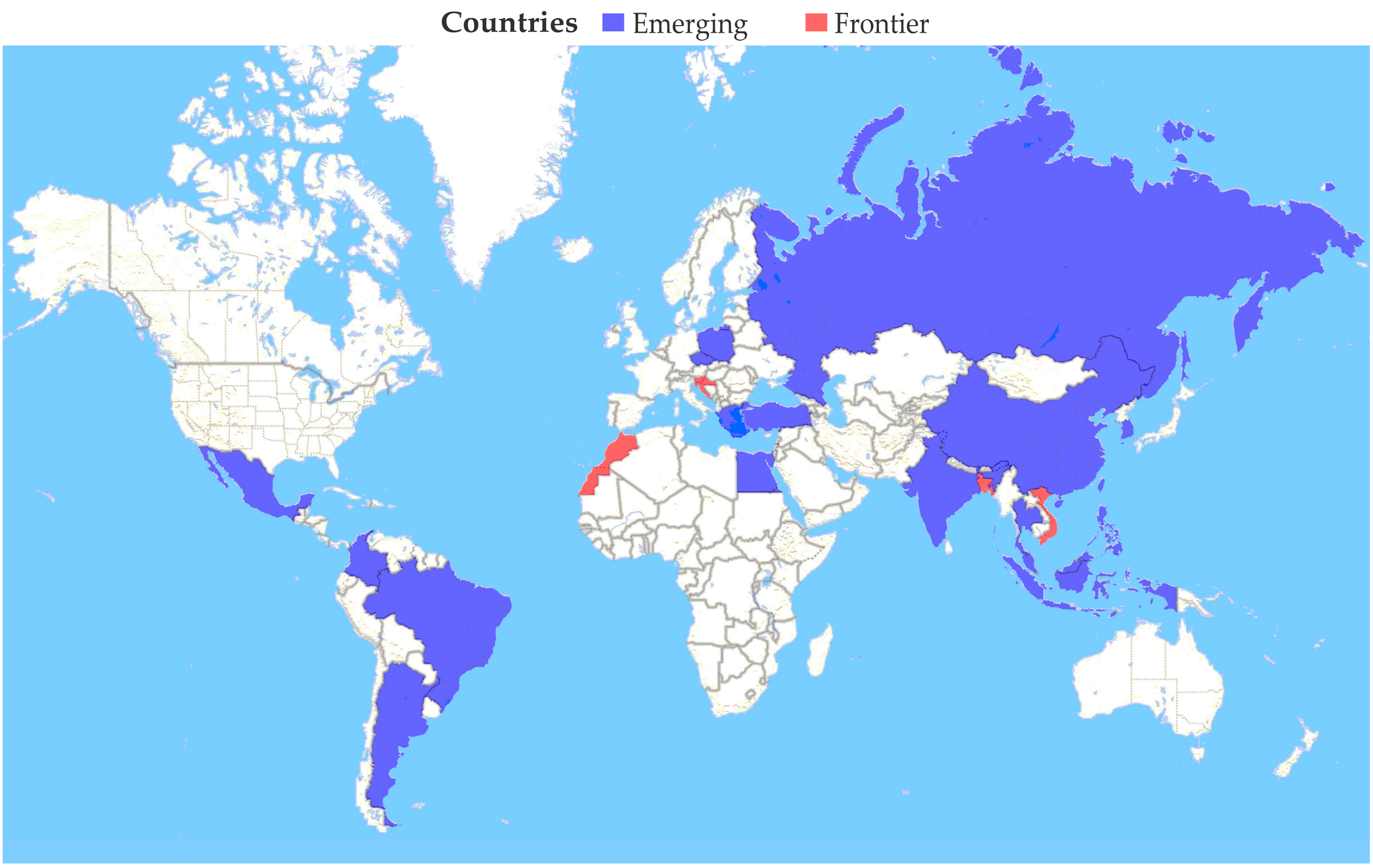

Figure 2. Emerging and frontier countries that have registered cases of IS.

Nineteen studies on IS conducted in Brazil were identified; in this country, laws related to shared responsibility in waste management among supply chain actors and closed material cycles have been established [48]. However, many municipalities in that country have difficulties sustaining their waste and implementing IS processes in their industrial activities [49].

Singapore ranks third in the number of publications on IS emerging economies with 10 cases, followed by India with 9 cases. Although these countries do not register a great tradition of inter-firm synergy practices and the number of published case studies is still small, the important role of IS as a means of enhancing the development of these regions is recognized [50]. Although its gross domestic product in recent years has increased significantly, India still has high poverty rates, with a population experiencing difficulty in accessing primary conditions and many social problems, as well as high population growth and rapid urbanization [22,51,52]. In addition, lack of environmental legislation, lack of economic incentives and fiscal benefits, lack of financial resources and infrastructure are some of the barriers that point to the development of circular practices and IS in this country [53]. Singapore is a city-state that, over the past fifty years, has experienced high economic growth, moving from a third-world country facing economic and social challenges to a major global economic hub with continued growth potential [54]. The government has made significant investments in R&D research, comprising 2.22% of the GDP compared to the World Bank average of 1.18% [55,56]; it is ranked among the top ten most innovative countries by the Global Innovation Index over the past three years [56,57]. However, Singapore can build a world-class industry in a short time if it strategically embraces its comparative advantages and continues with continuous improvement processes in its programs and policies, to foster IS and improve its endowment structure [54].

Taiwan ranks fourth among emerging and frontier market countries, with the most studies conducted on IS. The country has implemented a series of policies and regulatory adaptations throughout its industrialization process, which have enabled it to close the loop between its production and consumption activities, making it a global leader among recycling industries and in green supply chains for textiles, information technology, and electrical and electronic components [58]. As a result, Taiwan, once nicknamed "Trash Island," now boasts the second-highest effective recycling rate in the world after Germany [58,59] and is highly successful in developing circular materials and new products [60].

3.2. Type of Productive Activity Involved in Industrial Symbiosis

This subsection develops the analysis around research question 2 (RQ2). The economic activities presented in the analyzed cases of IS in emerging market countries and frontier market countries were grouped according to the international standard industrial classification of all economic activities (ISIC, Revision 4), which is a system developed by the United Nations for the classification of economic data and consists of a coherent and consistent international classification structure for productive activities [61]. Of the 21 activities defined in ISIC, the IS cases studied in this document can be classified into nine distinct sections:

A: Agriculture, forestry, and fishing.
B: Mining and quarrying.
C: Manufacturing.
D: Electricity, gas, steam, and air conditioning supply.
E: Water supply: sewerage, waste management, and remediation activities.
F: Construction.
G: Wholesale and retail trade: repair of motor vehicles and motorcycles.
H: Transportation and storage.
I: Professional, scientific, and technical activities.

According to the fields of study addressed by the authors in the IS cases analyzed, a classification was made according to the productive activity and country in which the activity was developed. The works analyzed were classified according to the area of study and field of action that reported the most data: manufacturing; agriculture; forestry and fishing; mining and quarrying; electricity, gas, steam, and air conditioning supply; water supply: sewerage, waste management, and remediation activities; professional; scientific and technical activities; construction; transportation and storage; and wholesale and retail trade: repair of motor vehicles and motorcycles. Figure 3 shows the percentage distribution of the papers reviewed concerning the activities addressed in the study.

China is a country that possesses a great industrial capacity. It was the nation demonstrating the largest scale of manufacturing industry in 2020 according to statistics issued by the International Monetary Fund (IMF); the country's GDP ranked second in the world, while the country ranked 120th among 180 countries and regions, according to the Environmental Performance Index (EPI) of Yale University. It is, therefore, important to resolve the contradiction between economic growth and environmental protection [62]. In terms of IS activities in China, studies in the mining and quarrying sector stand out, being related to metallurgical, steel, iron, and other mineral industries, with 56.6% of the total number of identified cases, followed by water supply, where sewerage, waste management, and remediation activities represent 23.3%, while manufacturing represents 13.3%.

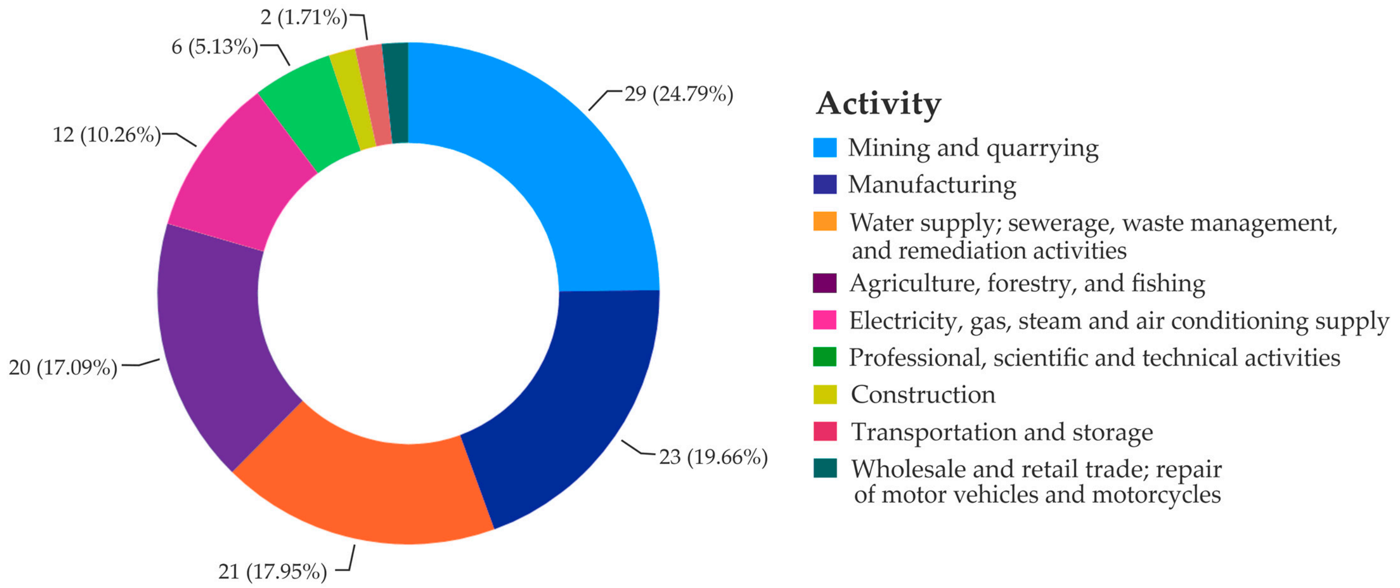

Figure 3. Distribution of the number of publications, sorted by activity (2008–2021).

Of note are several studies on the evaluation of symbiotic networks in various scenarios via topological models of carbon and iron metabolism [63], the modeling of an original independent supply chain network as an integrated IS network, via recycling and the exchange of waste materials [64], an evaluation of environmental benefits (raw material savings and waste reuse), CO_2 emission reduction and ecological benefits [65], an IS evaluation via life cycle assessment [66], the chromium and carbon metabolic behavior of an IS network [67], and how to achieve collaborative effects that influence emission reduction for multi-company networks [68].

In Brazil, studies that address its manufacturing activities stand out, with 31.57% of the cases, followed by agriculture, forestry, and fishing with 26.31%, and electricity, gas, steam, and air conditioning supply with 21.05% of the total number of cases in this country. This configuration may be because Brazilian participation in global value chains has increased since 2000 [69]. Although South America has only a small share in value-added trade, Brazil operates as a regional hub since it is a reference in this region and conducts international trade with several countries, regions, and trade blocs. In addition, Brazil is a supplier of intermediate inputs [69,70]. Manufacturing activities highlight those cases that seek to investigate how IS can be incorporated in the context of product development [71], to identify strategies related to the circular economy that could be stimulated in the upgrading process in industrial cluster companies [72], and the transition to new circular business strategies [73].

Brazil has favorable conditions for the development of agriculture, including abundant land, good rainfall distribution throughout the year, adequate air temperature, and the abundance of cheap labor, making it a major player in international agribusiness [74,75]. Within the IS cases concerning agriculture, forestry, and fishing activities, those that propose to quantify the level of IS in the system [76], the potential implementation of rooftop greenhouses in business parks from a theoretical perspective [77], and the creation of models that could accurately identify gaps or levels of enterprise development stand out [78]. The IS cases in Brazil that are related to electricity, gas, steam, and air conditioning are focused on validating environmental impact indicators and IS indicators [79], identifying the dynamic behavior of eco-industrial parks [80], and determining the social barriers to overcome in promoting opportunities for waste exchange [81].

In Singapore, agriculture, forestry, and fishing are the economic activities that report the most cases in terms of IS, with 33.33% of the total cases studied in that country, highlighting the evaluation of the economic viability of IS through a system using a collaborative platform [82] and the analysis of the environmental performance of an entire IS network from a life-cycle assessment model based on the multilevel matrices of networks [83].

In India, the cases with the highest share are those addressing agriculture, forestry, and fishing activities, with 33.33% of the cases, while manufacturing, mining, and quarrying occupy 22.22% of the total cases in this country. This is because India experienced significant unilateral trade liberalization in the early 1990s [84], followed by favorable conditions such as low labor costs and the supply of raw materials with huge employment potential [85]. In terms of manufacturing activities, cases seeking to propose mathematical models for designing circular production systems [86] and the thermochemical conversion of sugarcane bagasse to produce cleaner energy [87] stand out. Referring to agriculture, forestry, and fishing will highlight works that aim to identify and understand existing and potential IS connections [88] and reuse and recycling through complex networks of distributors and reprocessors [89]. IS cases in India that are related to mining and quarrying focused on examining the social interactions among personnel in eco-industrial networks [90] and on quantifying material flows, to identify symbiotic connections [91].

In Taiwan, mining and quarrying activities are of great importance, with 50% of the total number of cases in this field being studied in that country, highlighting the analysis of the economic and environmental benefits of green supply chains [92]. The above is mainly due to the development of industrial parks that are fully government-led, using public land, publicly funded infrastructure facilities, a comprehensive service with efficient back-up, automated customs services, on-the-job training, a national and international network, incentives, and investment benefits [93].

In South Korea, 80% of the related economic activities in IS studies refer to manufacturing activities, highlighting the practical approach of quantifying total and allocated greenhouse gas emissions from IS exchanges by integrating a greenhouse gas protocol and life-cycle assessment [94], with an economic and environmental performance assessment of IS networks [95]. In addition, research to demonstrate the feasibility of symbiosis networks, designed using policy instruments and based on research and development processes [96]. Figure 4 shows the cases by country and by productive activity.

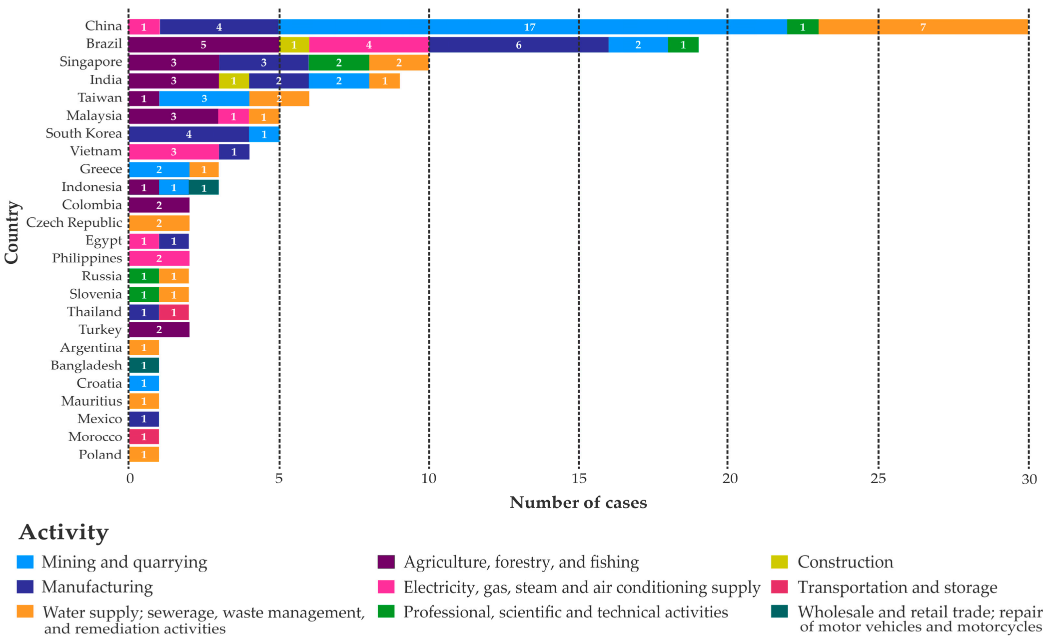

Figure 4. Distribution of the number of case study publications, shown by country and by activity.

3.3. Contribution of Journals in the Evolution of Published Articles

This subsection develops the analysis around research question 3 (RQ3). The selected articles were collected from different journals and conference articles. Therefore, the distribution by journals is not uniform, as shown in Figure 5, which identifies the distribution of articles by journals, with the highest number of publications in the IS area and the continent in which the study was carried out. The journals with the most publications in IS regarding emerging and frontier market countries are the *Journal of Cleaner Production* with 43 cases and a presence in the four continents with studies on IS.

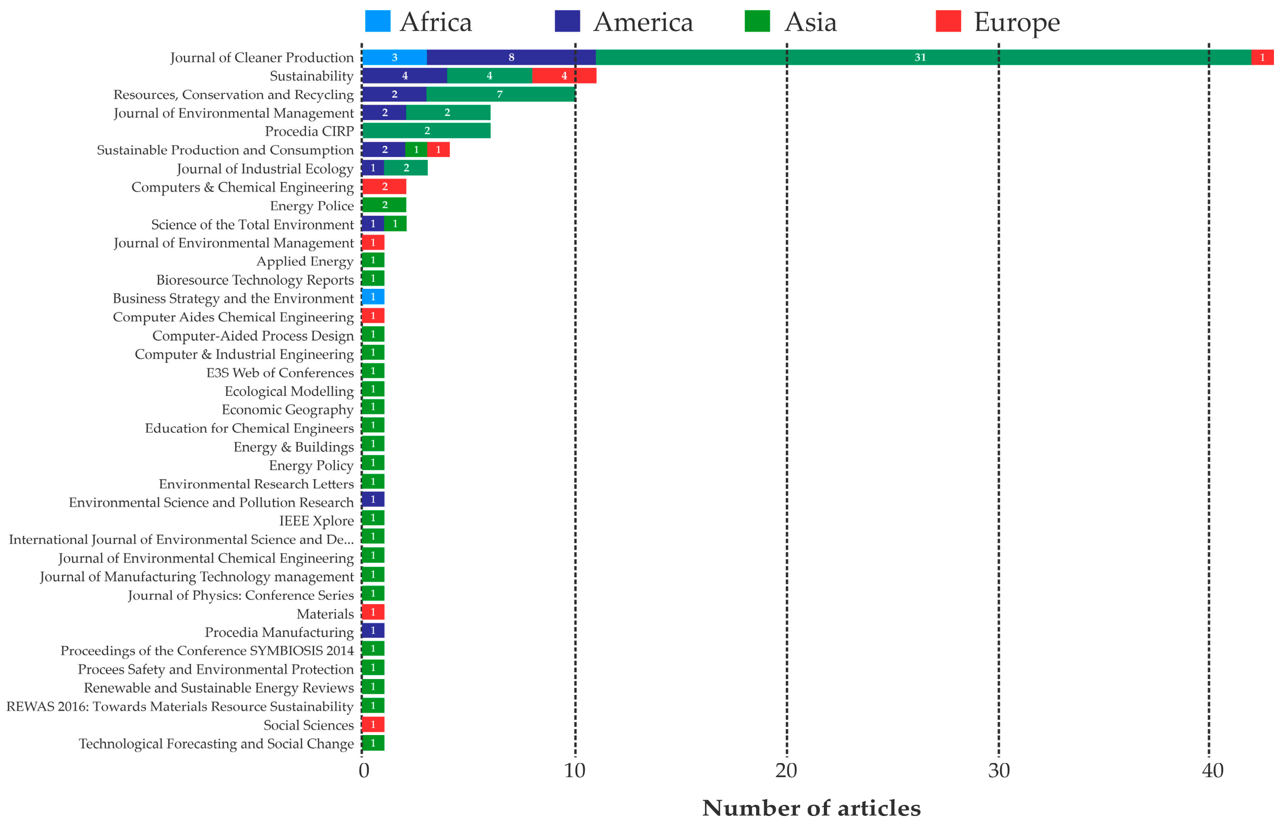

Figure 5. List of journals with the highest number of articles published.

The second journal with the second-highest number of cases is *Sustainability*, with 11, *Resources, Conservation and Recycling* with 10, the *Journal of Environmental Management* with 6, *Procedia CIRP* with 5 cases, and *Sustainable Production and Consumption* with 4 cases. In the universe of the 117 sources, these six journals contribute 68.37% of all publications. The studies carried out in Asia have a large distribution in the leading journals that publish research on IS, with a high share of the total number of articles published.

3.4. Evolution of the Number of Published Articles

This subsection develops the analysis around research question 4 (RQ4). The main data from the 117 selected studies were extracted to conclude the trend of IS research in countries with emerging economies. The temporal distribution of IS articles is shown in Figure 6, which presents the evolution of the number of articles published since 2008. It is clear from the figure analysis that the number of articles has grown, reflecting the increasing interest of the scientific community in these countries regarding this topic. From 2014 onwards, a prolonged growth is identified, referring to previous years, reaching the highest number of publications in 2018 with 18 cases.

Please note that the number of publications in 2021 represents the articles from the first six months of the year. This amount will likely exceed the value of 2018 due to the publications already verified and included in this analysis. This increase in the number of studies conducted in emerging and frontier market countries may be related to the development of programs and policies that have encouraged the practice of IS [97]. The international interest in this topic of study may also be an important factor in the growth of the number of publications.

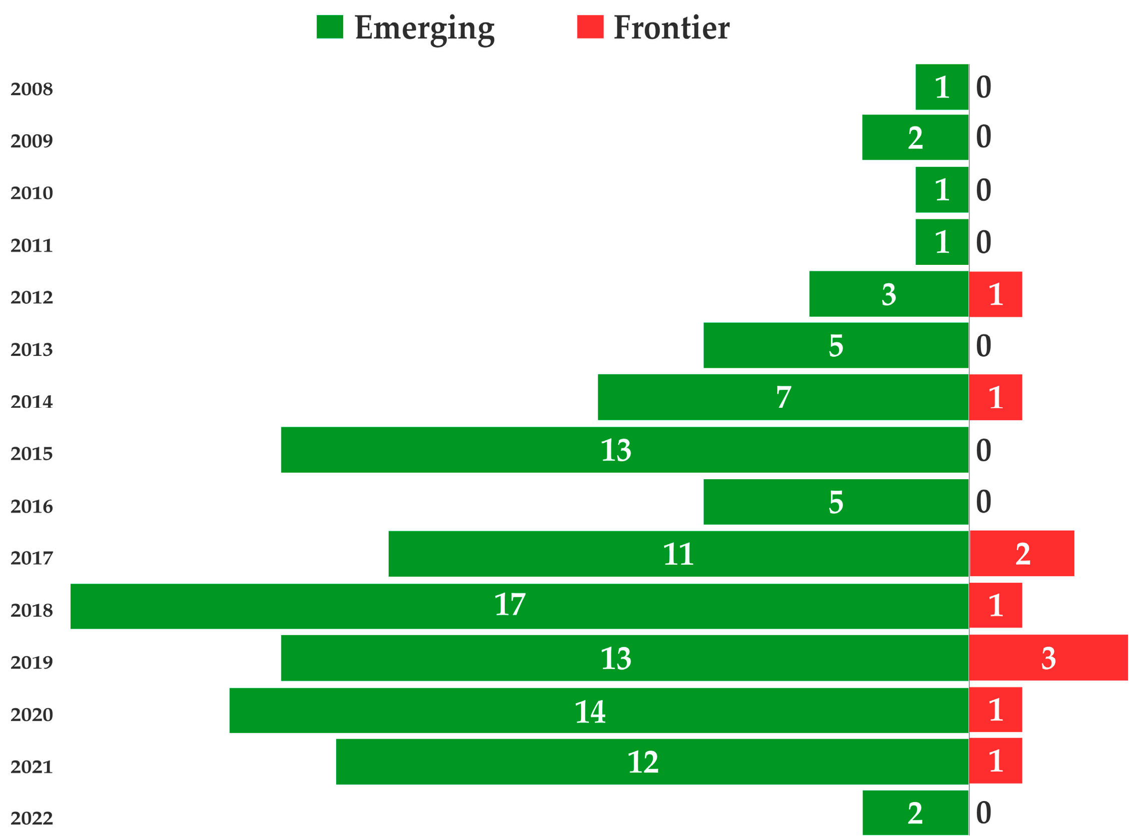

Figure 6. Temporal distribution of IS cases in emerging and frontier countries.

According to the previous section, we can categorize the IS cases by year and economic activity. The predominance of the manufacturing category can be justified because, within economic activities, a significant volume of waste is generated; the capacity to absorb this waste and incorporate it as a raw material in their production processes is important. Waste recycling and water resource management also feature prominently in the IS cases to establish the link between industries and how they play an active part in the chain of waste transformation into new products [25]. Within this category, the activities most frequently presented in IS are biorefinery companies, waste utilization in industrial parks, forestry industries, and furniture manufacturing.

The second sector is agriculture, forestry, and fishing, the activities of which are directly related to the primary sector, mainly agricultural and livestock activities, which are also identified in these cases—not only those directly related to crops but also those related to the use of animal waste. Figure 7 shows the cases by productive activity and year. Regarding this analysis, in 2021, the publications in the category of water supply, comprising sewerage, waste management, and remediation activities, and agriculture, forestry, and fishing stand out with a varied distribution from year to year, which does not allow identifying a clear pattern regarding the annual distribution of productive activities.

In order to identify the industrial activities used in the studies carried out in emerging and frontier market countries, Table 1 summarizes the IS cases existing in these countries. First, an updated analysis of the published studies is carried out, highlighting the location, industry type, and the number of companies involved. Next, the cases are arranged alphabetically, according to the continent in which the research was carried out. Then, they are organized by year of publication, sorted in order from the most recent to the oldest. Finally, the regions were also arranged in descending order, according to the year of publication of the articles.

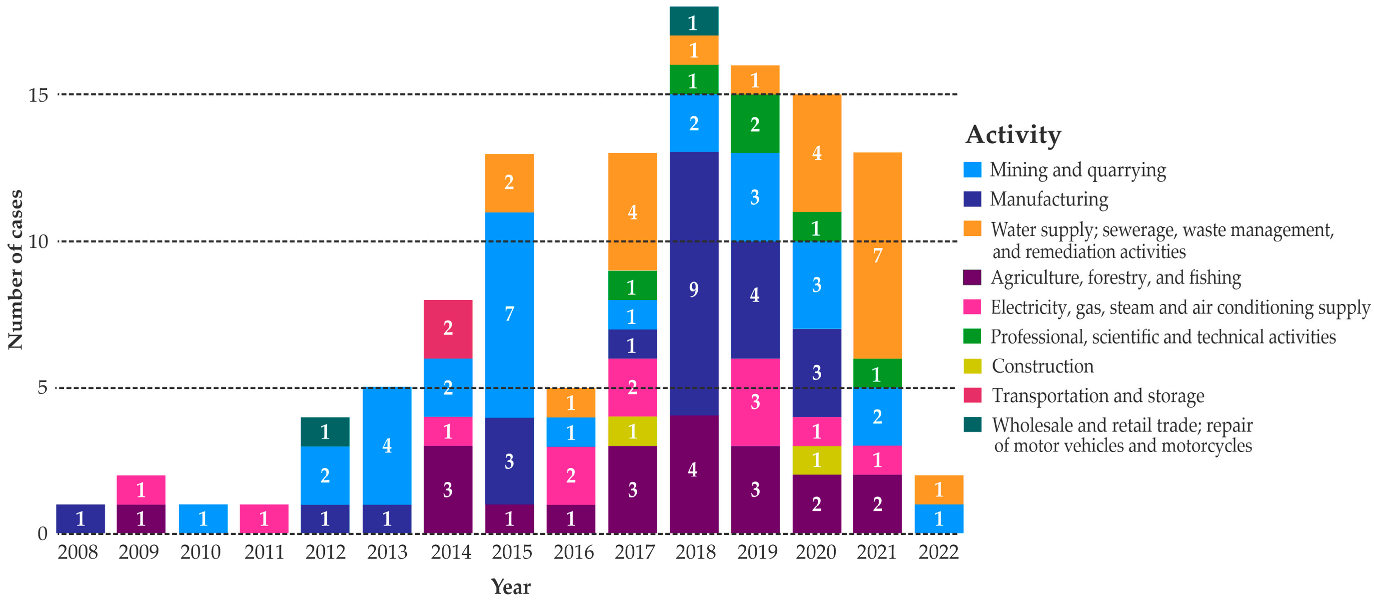

Figure 7. Distribution of the number of publications by activity and year.

Table 1. Industrial symbiosis application, methods used, and economic activity in emerging and frontier countries (emerging = E, frontier = F).

Country	Market	Activity	No. of Enterprises	Method
Africa				
Egypt	E	Manufacturing	39	Literature review, interviews [98]
		Electricity, gas, steam, and air conditioning supply		Statistical data collected from private and public sources, field visits, inspection reports of the factories [99]
Mauricio	F	Agriculture, agroindustry, forestry, plastic	3	Interviews, industrial waste audit reports, hazardous waste inventory and national issues [100]
Morocco	F	Transportation and storage		On-site visits, and individual or collective interviews performed on site [101]
America				
Argentina	E	Water supply: sewerage, waste management, and remediation activities		Environmental impact assessment, conducted according to the surface multifunctionality and eco-efficiency assessment methods [102]
Brazil	E	Mining and quarrying	6	Literature review, exchange resources analysis [103]
		Mining and quarrying	8	Literature review, guided tours by the plants, consultation of internal documents of the companies, open interviews, feedback from the respondents [104]
		Agriculture, forestry, and fishing	172	Literature review, archetypal models—recycling, cascading, and repurposing, organic feedstock models [105]
		Professional, scientific, and technical activities		Literature review [106]
		Manufacturing	8	Quiz format, survey of opportunities [107]
		Agriculture, forestry, and fishing	24	Questionnaire, visits to forestry companies [76]
		Manufacturing	1	Semi-structured and non-structured interviews, onsite observations, and longitudinal data related to the business model's implementation [73]
		Manufacturing		Chemical synthesis, adsorption and desorption assays, statistical analysis [108]

Table 1. *Cont.*

Country	Market	Activity	No. of Enterprises	Method
Brazil	E	Manufacturing	1	Survey of the material streams and synergy matrix, environmental impact assessment, inventory of the productive units, interviews with coordinators [109]
		Manufacturing	24	Simulation of IS indicators through extreme conditions scenarios [72]
		Manufacturing		Simulation of IS indicators through extreme conditions scenarios [71]
		Agriculture, forestry, and fishing		Proposal of the design for IS [110]
		Agriculture, forestry, and fishing		Literature review, questionnaire [78]
		Construction	2	Direct observations; indicators of quantitative data analysis and SWOT analysis [111]
		Electricity, gas, steam, and air conditioning supply		Agent-based modeling [79]
		Electricity, gas, steam, and air conditioning supply	13	Survey of companies and institutions [81]
		Agriculture, forestry, and fishing	1	Short-term potential implementation of rooftop greenhouses in industrial and logistic parks [77]
		Electricity, gas, steam, and air conditioning supply		Systematic literature review [80]
		Electricity, gas, steam, and air conditioning supply	2	Analysis of case studies [112]
Mexico	E	Manufacturing, textile industry	15	Open and face-to-face interviews, and on-site visits [113]
Colombia	E	Agriculture, forestry, and fishing	36	Workshops, surveys, semi-structured interviews [50]
		Agriculture, forestry, and fishing	1	Short-term potential implementation of Rooftop Greenhouses in industrial and logistic parks [77]
Asia				
China	E	Mining and quarrying	1	Material flow analysis, ecological energy analysis [63]
		Mining and quarrying	2	Multi-objective model [64]
		Manufacturing		Literature review, modeling, simulation [114]
		Electricity, gas, steam, and air conditioning supply		Comprehensive bottom-up technology structure simulation and energy conservation and emission reduction effects evaluation system [115]
		Water supply: sewerage, waste management and remediation activities		An integrated framework to uncover symbiotic performance quantitatively [65]
		Manufacturing		Literature review, modelation [116]
		Water supply: sewerage, waste management and remediation activities		Cost-benefit analysis, feasibility analysis [117]
		Water supply: sewerage, waste management and remediation activities		Data analysis [118]
		Mining and quarrying	9	Life cycle assessment [66]
		Mining and quarrying		Analysis of industrial processes [67]
		Mining and quarrying		Centrality and centralization measures, average clustering coefficient, average path length, and power law distribution of degree [119]
		Mining and quarrying		Input-output matrix, fuzzy goals programming, optimization model, simulation [68]
		Mining and quarrying		Mathematical analysis, simulation, and theorem validation [120]

Table 1. *Cont.*

Country	Market	Activity	No. of Enterprises	Method
China	E	Water supply: sewerage, waste management and remediation activities		A hybrid model with the integration of process-based life cycle assessment (or material flow analysis), and input-output analysis [121]
		Mining and quarrying	14	Participant observation, interviews, questionnaire-based survey, and simulation analysis [122]
		Water supply: sewerage, waste management and remediation activities		Material flow analysis [123]
		Professional, scientific, and technical activities		Analysis of documents, networks, projects, national programs, and national statistical sources [124]
		Mining and quarrying	19	Material flow analysis [125]
		Water supply: sewerage, waste management and remediation activities		Literature review, evaluation of direct and indirect environmental impacts [126]
		Water supply: sewerage, waste management and remediation activities		Material flow analysis [127]
		Mining and quarrying		Data analysis, reports of the enterprise, expert interviews, and literature reviews [128]
		Mining and quarrying	13	Surveys, material flow analysis [128]
		Mining and quarrying		Literature review, analysis of documents, data analysis [129]
		Mining and quarrying	5	Questionnaires and field surveys, flow analysis and resource productivity indicator [130]
		Manufacturing	20	Literature review, data analysis [131]
		Manufacturing	31	Data analysis, literature review, interview, questionary, material flow analysis [132]
		Mining and quarrying		Analysis of the IS network [133]
		Mining and quarrying	1	Material flow analysis [134]
		Mining and quarrying		Carbon flow analysis [135]
		Mining and quarrying	7	Material flow analysis, cost analysis [136]
Taiwan	E	Water supply: sewerage, waste management, and remediation activities		Analysis industrial waste database [137]
		Mining and quarrying		Historical background and development analysis [138]
		Water supply: sewerage, waste management, and remediation activities		Big data and internet of things [139]
		Mining and quarrying	27	Material flow and energy flow analyses [92]
		Agriculture, forestry, and fishing		Material flow and energy flow analyses [92]
		Mining and quarrying thermoelectric	482	Material flow and energy flow analyses [92]
India	E	Agriculture, forestry, and fishing		Biochemical analysis, statistical analysis [140]
		Construction	1	Analysis material flow, data analysis [141]
		Manufacturing	1	Multi-objective mixed-integer linear programming model and sensitivity analysis [86]
		Water supply: sewerage, waste management, and remediation activities	1	Public and private data sources, list of industrial and manufacturing establishments [142]
		Manufacturing		Literature review [87]
		Agriculture, forestry, and fishing		Direct observations, literature review, data analysis [88]

Table 1. *Cont.*

Country	Market	Activity	No. of Enterprises	Method
India	E	Mining and quarrying	12	Field surveys, structured interviews, material flow analysis, social network analysis, statistical network correlation analyses, and quantitative and qualitative measures [90]
		Mining and quarrying	>14	Structured interviews with managers and material flow analysis [91]
		Agriculture, forestry, and fishing	13	Field data collection, interviews, material flow analysis, and network analysis [89]
Malaysia	E	Electricity, gas, steam, and air conditioning supply		Pinch-based targeting methodologies [143]
		Water supply: sewerage, waste management, and remediation activities		Mathematical model [144]
		Agriculture, forestry, and fishing	5	On-site survey, stakeholder analysis [145]
		Agriculture, forestry, and fishing	4	Mathematical model [146]
		Agriculture, forestry, and fishing		Multi-objective design [147]
Singapore	E	Agriculture, forestry, and fishing		Data analysis, literature review [83]
		Professional, scientific, and technical activities		Teaching method based on usage of online resources [148]
		Agriculture, forestry, and fishing		Matrix-based model [149]
		Professional, scientific, and technical activities		Text analytics [150]
		Manufacturing		Literature review [151]
		Water supply: sewerage, waste management, and remediation activities		Data analysis [152]
		Agriculture, forestry, and fishing		Simulation subsystem [82]
		Manufacturing		Literature review [153]
		Water supply: sewerage, waste management, and remediation activities		Data analysis [154]
Turkey	E	Agriculture, forestry, and fishing	10	Life cycle assessment method. Multi-objective multi-period mathematical mode [155]
		Agriculture, forestry, and fishing	10	Literature review, establishment of a pilot scale network, creation of database, site visits and discussions with local stakeholders [156]
Vietnam	F	Electricity, gas, steam, and air conditioning supply	57	Survey, company interventions, policy development [97]
		Electricity, gas, steam, and air conditioning supply	58	Survey, company interventions, policy development [97]
		Electricity, gas, steam, and air conditioning supply	22	Survey, company interventions, policy development [97]
		Manufacturing		Fuzzy set theory, fuzzy Delphi method, factor analysis and fuzzy importance-performance analysis [157]
Indonesia	E	Agriculture, forestry, and fishing		Literature review, data analysis, designing models [158]
		Wholesale and retail trade: repair of motor vehicles and motorcycles		Theoretical analysis [159]
		Mining and quarrying	1	Data analysis [160]

Table 1. *Cont.*

Country	Market	Activity	No. of Enterprises	Method
South Korea	E	Manufacturing	11	Theoretical analysis. Three by-product impact allocation methods [161]
		Manufacturing	2	Cost-benefit analysis [94]
		Mining and quarrying	21	Theoretical analysis [95]
		Manufacturing	41	Theoretical analysis [96]
		Manufacturing	7	Describe national policies and the developmental activities [162]
Philippines	E	Electricity, gas, steam, and air conditioning supply	1	On-site survey and questionnaires [163]
		Electricity, gas, steam, and air conditioning supply		Mathematical model [164]
Thailand	E	Transportation and storage		On-site visits, and individual or collective interviews performed on site [101]
		Manufacturing	61	Surveys of the surrounding communities, participative observations [165]
Bangladesh	F	Wholesale and retail trade: repair of motor vehicles and motorcycles		Interviews [166]
Europe				
Czech Republic	E	Water supply: sewerage, waste management and remediation activities		A pinch analysis-based method for solid waste integration [167]
		Water supply: sewerage, waste management and remediation activities		IS model considering the cost and environmental objectives [168]
Slovenia	F	Water supply: sewerage, waste management and remediation activities		Analysis of documents, networks, projects, national programs and national statistical sources [169]
		Professional, scientific, and technical activities	7	Literature review [47]
Greece	E	Water supply: sewerage, waste management and remediation activities		Knowledge graphs, data analysis [170]
		Mining and quarrying	1	Ontology engineering, tacit knowledge from experts with explicit knowledge from participants [171]
		Mining and quarrying	15	A new ontological framework that supports processing technologies participation in IS [172]
Croatia	F	Mining and quarrying	19	Characterization of raw materials, evaluation of the potential of waste materials [173]
Russia	E	Professional, scientific, and technical activities		Literature review, semi-structured interviews [174]
		Professional, scientific, and technical activities		Literature review [174]
Poland	E	Water supply: sewerage, waste management, and remediation activities		Data analysis [175]

From an analysis of Table 1, it is possible to conclude that the economic activities present in IS are very diverse, illustrating the importance and applicability of this type of practice in business environments. However, it is important to note that not all the studies analyzed reflect the total number of companies involved in symbiosis. Therefore, this analysis aims to illustrate the types of productive activity and the frequency with which they appear in the different IS cases, without delving into the number of companies that make up the network of companies.

3.5. Resource Integration

This subsection develops the analysis around research question 5 (RQ5). One of the main aspects to be taken into account in IS is the management and utilization of the residual resources of the companies; therefore, it is necessary to plan the exchange of "unused" residual resources to benefit the participating companies and ensure the exploitation of IS opportunities [25,176]. The restructuring of consumption and production patterns using innovative designs and business models that allow the integral use of resources is fundamental to the success of IS and is related to the 4R (reduce, reuse, recycle and recover) principles of the circular economy [177]. Integrating resources into business activities enables sustainable and cleaner production in an environmentally friendly way by minimizing greenhouse gas emissions, waste generation, and material waste [25]. The growing need to conserve resources has led to the development of various concepts, tools, and frameworks to support optimal resource management [178]. IS considers the efficient use of energy, materials, water, assets, logistics, and expertise and the reuse of unused or residual resources from another company for other activities. When analyzing the cases studied in this research from the perspective of resource integration, there is a lack of studies involving the integration of multiple resources, and most of them are theoretical or potential applications, evidencing the need to deepen studies that cover real cases. In the emerging countries of Africa, Europe America, research is at an early stage of development concerning projects conducted. In Asian countries, the research carried out in industrial parks, in which different companies, economic activities and resources are integrated, stands out. To design a successful IS, identifying the resources that can be exploited is essential to define and develop a complete description allowing integrated optimization processes. Therefore, the classification used by Lawal et al. [25] is used to present an analysis of the optimized resources in the cases studied, which identifies the integration of resources in waste, water, energy, and carbon.

3.5.1. Waste Integration

An essential aspect of IS is companies' involvement in the collection, management, utilization, and exchange of waste and the maximization of its advantages, allowing related industries to benefit [25,179]. Waste, mainly biomass, can be used and integrated into power networks to produce energy. A study conducted in Brazil by Oliveira Pavan et al. [105] converted biomass residues into bioelectricity, based on the anchoring dynamics between sugar and alcohol plants. The research was conducted in the state of São Paulo and explored the use of different urban solid-waste feedstocks, such as vinasse, animal waste, and sludge through circular business models. Chen and Liu [137] developed an interactive IS query information system, which explores by-product synergies from industrial waste data in Taiwan and offers users three types of interactive data visualizations. In China, a waste material recycling and exchange decision model was developed using a constraint approach to solve a multi-objective model, identifying that material price is the most important factor affecting decision-making through parameter robustness analysis [64]. In Singapore, Kerdlap et al. [83], in a food waste valorization network, assessed the life-cycle environmental impacts of seeking to convert food waste into valuable resources through the M3-IS-LCA methodology, which was designed to perform a process-based life-cycle assessment of any IS scenario. Momirski et al. [169] conducted research with the objective of finding out if there are strategies in the selected companies for waste exchange that support the emergence, existence, and development of IS in Slovenia, identifying the fact that in this country, IS processes are in the early stages, with a slower development than expected.

3.5.2. Water Integration

To ensure sustainability, market competitiveness, and the reduction of impacts generated by industrial activities on climate change, water consumption in all processes must be reduced [180]. Misrol et al. [144] developed an optimal water reclamation recovery and reuse network that integrates domestic and industrial sources. Such a model considered techno-economic elements, including water quality freshwater reduction and revenue generation from reclaimed resources as an IS strategy. Chertow et al. [142] developed an algorithm based on life-cycle assessment. This sought to identify the public benefits to cities by converting the maximum quantity of resources recoverable by local businesses into an estimate of the capacity of the retained municipal infrastructure, in terms of landfill space and water demand. Vimal et al. [86] modeled a network and quantified the economic benefits using multi-objective mixed-integer linear programming. Data were obtained from the organization and simulated using the optimization package, GAMS. The model was able to calculate the economic benefit achieved through circular operations in the case study's organization. The water flow of elements through the network was also obtained, and the flow of different elements. Therefore, studies were developed that sought the integration of water in industrial processes, including implementing a circular business model to provide safe drinking water in Brazil. The water filtration business model was structured to maximize the use of the product. Consequently, the resulting product satisfies a social need while generating fewer adverse environmental effects than water in plastic bottles [73].

3.5.3. Energy Integration

In the industrial sector, energy is vital for developing business activities. A gradual increase in energy demand was identified due to electrical advances in increasing comfort, industrial demands, access to technology, and the population increase [181]. Yong et al. [143] analyzed an urban–industrial symbiosis system through an energy-targeting framework. The proposed system incorporates energy integration and storage, heat integration and storage, renewable energy sources, and waste heat cogeneration. Sun et al. [117] evaluated and quantified the energy-saving and CO_2 emission reduction effects of different municipal solid-waste treatment options to promote sustainable development in the Chinese city of Shenyang. They identified the fact that with an urban–industrial symbiosis strategy, 8.05×10^6 GJ of energy could be recovered from the system, and carbon emission could be reduced by 1.3%. S. Wang et al. [66] evaluated, through life-cycle assessment in an energy-intensive industrial park, a way to reduce environmental impacts and obtain economic benefits by identifying effective impact reductions; this can be achieved through symbiosis linkages, including 9456 TJ of primary energy, in which the greatest contribution is from steam exchange between the power plants, methanol/ethylene glycol chemical plant, and other enterprises. Ng, Hassim, et al. [147] introduced a bioenergy-based disjunctive fuzzy optimization approach to determine the optimal pathways, based on the stated interests of the processing plants. Mantese and Amaral [110] simulated IS indicators through extreme-condition scenarios. The indicators were simulated through an agent-based model in two different scenarios, one in a stable environment and one with significant changes.

3.5.4. Carbon Integration

Global warming generates enormous adverse effects on the environment due to greenhouse gases, especially CO_2 or carbon dioxide. Therefore, the manufacturing and industrial sectors are making many efforts to mitigate or eliminate its effects [25]. Air pollution can generate political costs for companies that pollute, resulting in reducing their revenues. These costs can be interpreted in two ways. Firstly, it can result in punishments from the central government, which is detrimental to the firm's good name. Secondly, public opinion against air pollution can also lead to regulations being imposed on firms [182]. It is essential to consider that well-designed environmental regulation can incentivize firms to enter a virtuous circle of continuous learning and improve their efficiency in production processes [183]. In this context, it is necessary for commitment and effectiveness from business management, in terms of reducing environmental emissions in production and operational processes, to reduce the company's environmental impact on the community and, thus, reduce operating costs [20].

In China, the implementation of low-carbon IS systems with financial constraints and environmental regulations was conducted using an evolutionary game model; it was identified that external financing, an appropriate financial mix, and environmental regulations promote the low-carbon industrial symbiosis system [114]. Cao et al. [115] evaluated the environmental and economic performance of national IS in China quantitatively for the first time; the technological structure of IS was simulated by bottom-up modeling, identifying that the proposed IS system can save 35.7 million tons of coal equivalent and reduce 189 kt of SO_2 emissions, 139 kt of NO_x emissions, and 64 kt of PM emissions. Dong et al. [121] analyzed urban IS as an innovation system using a hybrid life-cycle assessment approach; planned symbiosis would enable the reduction of CO_2 emissions by 29.66, 557.42, and 520.13 kt-CO_2/year in power purchase, material consumption, and waste disposal stage. The results highlight that urban IS can "green" industries and use industry to contribute to urban development. Yeşilkaya et al. [155] analyzed the potential environmental and economic benefits, using a multi-objective multi-period mathematical model for an IS network. The model achieves reduced costs and emissions compared to the scenario where material exchange is not available. Santos and Magrini [109] proposed a bio-succinic acid biorefinery symbiotic network in Brazil. They analyzed the CO_2 produced per ethanol produced, considering the main production processes, the current destinations of their waste streams, and the existing waste exchange practices.

4. Discussion

Emerging and frontier market countries face a significant challenge related to the socio-economic improvement of the business sectors and the reduction of waste and emissions of polluting particles, in order to move toward economic reconversion, which will allow the modernization of the productive apparatus, the strengthening of emerging economic sectors and the promotion of business development.

Identifying the barriers and drivers that promote or inhibit companies' participation in IS is of great importance for the development and feasibility of this approach in emerging and frontier countries. Some IS practices work well, while some IS attempts have problems or fail, even though, at first glance, IS appears to present a mutually beneficial relationship for the parties involved. The answer is closely related to the barriers and drivers that influence the development of such activities [118] and, hence, the importance of identifying those factors that influence the participation of firms from emerging and frontier countries in IS activities.

4.1. Barriers to IS in Emerging and Frontier Countries

4.1.1. Financial Barriers to Promoting IS

Limited access to financial resources is one of the most important barriers to promoting IS [163]. The cost of processing hinders the return on investment and current macroeconomic constraints drive companies to cut costs, so there is a lack of financing to encourage the adoption of new eco-industrial concepts [81]. In addition, the high logistical cost is also a factor that hinders the development of IS activities [104].

4.1.2. Lack of Knowledge of the Concept of Waste Trading

Since landfilling has been the ordinary waste disposal option for decades, many industries in emerging and frontier countries have never opted for recycling opportunities; stakeholders believe that it is cheaper to divert waste materials to landfills than to participate in symbiosis networks. There is a lack of awareness and sensitization regarding the benefits of undertaking IS; some stakeholders are only concerned with making profits from product sales and are unaware of the revenues associated with trading waste materials [100]. Industrial plants should be susceptible to forming synergies and adapt to structural and market changes [163].

4.1.3. Lack of Awareness of IS Projects

Few case studies develop IS in emerging and frontier countries, except in China, Brazil, Singapore, and India. The business sector understands the need to combine recycling options with factors such as technology and the integration of resources focused on the sustainable use of inputs. The lack of knowledge of IS in top-level management is a significant inhibitor to the development of integrated resource-use activities; therefore, the development of IS must be fully integrated into the management and planning system.

While commercial, economic benefits are or can be a major factor to encourage companies to participate in material exchanges, senior management generally does not have the time, commitment, or capabilities to identify and take advantage of these opportunities, or they have insufficient understanding of IS terminologies, due to the lack of mechanisms to educate potential stakeholders [118,163].

4.1.4. Deficiency of Regulatory Frameworks

Regulatory frameworks are critical to fostering IS activities. Government policy should be designed and implemented to play an "enabling role" by providing policy, coordination, and educational and infrastructure support. The lack of favorable policies indicates that IS participants' economic incentives, especially regarding support for the utilizers of waste or products, are too weak [118]. This barrier is supported by the fact that less stringent environmental legislation or enforcement governing industrial waste results, for example, regarding industrial (often hazardous) waste being mixed with other waste materials before disposal [100]. To be successful, environmental strategies must encompass a combination of innovative policy tools that build on creating a demand for compliance and enforcement [99]. In addition, government policies (e.g., tax relief) should be implemented to stimulate and regulate IS [92,163].

4.1.5. Absence of Landfill Fees

In most emerging and frontier countries, it seems easier to divert waste to a nearby transfer station or landfill than to establish a mechanism for waste exchange at the factory level. The situation is made worse by the absence of a landfill fee for non-hazardous waste. For one industry, in particular, the fact that there are fewer personnel involved in diverting waste to landfills than in conducting waste exchanges makes the practice of IS even more difficult [184]. In addition, current regulations on pollution abatement and resource conservation are generally relaxed, coupled with lax enforcement in some areas, allowing companies to dump waste illegally [118].

4.1.6. Business Confidentiality

Confidentiality issues are one of the main reasons preventing the creation of an industrial network, as the lack of trust and communication between companies prevents the sharing of waste characteristics, which consequently inhibits any possibility of recycling. Trust between collaborating members in an IS network is a prerequisite for collaboration, as most industries have minimal or no prior cooperation mechanism, which can lead to concerns about intellectual property or trade-secret leakage [24,163]. Concerns about intellectual property or trade-secret leakage constitute a significant obstacle for waste and by-product producers, while difficulties in reaching agreements often affect waste and by-product users. These problems indicate that IS development needs much coordination [118].

4.1.7. Lack of Innovation in the Business Sector

The lack of research requires technical actions that foster innovation. The participation of new regional actors, existing SMEs or innovative startups, and local institutions can support these technical actions [113]. It is necessary to identify and integrate the best available technologies for innovation that will strengthen efforts to develop IS activities, i.e., energy conservation technologies, the cleaner production of energy, water, and materials in industrial manufacturing processes, and the adoption of efficient technology [92,96].

4.1.8. Lack of Green Technology

Many local industries and companies lack access to green technology and still rely on conventional technology, especially in emerging and frontier countries. In addition, institutional, regulatory, and financial barriers further exacerbate technology barriers by impeding the creation of new technology. If these barriers are not addressed and green technology is not created, it will be even more challenging to address climate change, biodiversity loss, and other environmental problems in the future [92].

4.1.9. Lack of Infrastructure

Sustainable by-product exchange requires a well-built infrastructure [92,163]. Obsolete infrastructure is widespread in both developed countries and emerging and frontier countries. Without replacing this obsolete infrastructure, it is not easy to take on the necessary tasks to build green supply chains. Without the most basic infrastructure, such as roads and communication networks, emerging and frontier countries cannot transfer and implement successful IS activities [92]. In a specific geographic area, there may be an abundance of primary input with low purchase cost, which could significantly decrease the likelihood of IS implementation. On the other hand, the scarcity of inputs in a given geographic area could reduce barriers against IS implementation in terms of replacing this primary input with waste [185].

4.1.10. Social Barriers

Social barriers are prerequisites for the participation of companies in the establishment of technological and logistic solutions. More socially oriented barriers, including information, cooperation, community, and commitment to sustainable development, are identified as impacting the success of IS applications, which is why it would be necessary to overcome these social barriers for companies to share common strategies on the implementation of waste conversion and utilization that enable a migration toward the circular economy system [81]. The role of Brazilian managers in addressing sustainability issues has been analyzed, establishing that, although they express a commitment to respecting people and protecting the natural environment, there is in fact a cultural barrier that implies a "selfish attitude" [186].

4.1.11. Imbalance between Availability and Demand

The availability of materials and the imbalance generated when the supply of materials is greater than the demand, or when the demand for materials is greater than the supply, also hinder the relationships between IS companies. The continuity of material exchange relationships depends on additional research in each particular case, to find new applications for the materials and wastes generated that need to be used in an integrated manner [104]. The imbalance between availability and demand is an asymmetry, a constraint that requires technical actions, such as developing tools to share information and optimize material exchange networks [187].

4.2. Drivers of IS in Emerging and Frontier Countries

It should be noted that the use of residues, by-products, and waste from industrial activities is well below their potential in these countries and that fossil energy sources, such as coal and gas, are in the process of depletion due to years of exploitation of these resources, along with the environmental problems generated. From an analysis of the IS cases reported in the literature in emerging and frontier countries, it has been identified that the factors that promote the creation of IS relationships can be classified as follows:

4.2.1. Finance—Controlling Costs and Reinforcing Efficiency

The most cited driver is cost reduction [64], mainly related to market changes that sharpen competition, such as raw material replacement, virgin material, by-products, payment for the reduction of new material purchases, and energy recovery [104]. Companies achieve competitive advantage through cost reduction due to reuse; from an operational perspective, for the development of strategies in IS relationships using business dynamics. The literature widely recognizes that companies are driven to explore IS opportunities via the potential economic benefit of avoiding waste discharge, to reduce direct input purchase costs and additional cooperative costs [185]. For industrial purposes, many imported raw materials can be substituted by locally available industrial wastes or by-products, which can generate economic benefits for participating companies [100].

4.2.2. Governance—Creating Trust and Promoting Positive Financial Outcomes

The government and different sectors of the economy play an important role in driving companies to transform their operations toward sustainable development [188]. Therefore, governments should maintain good relations with local enterprises and create a more flexible and favorable business environment that motivates enterprises to participate actively and to develop IS activities. Environmental and social reasons are most frequently the drivers of government action to promote IS [22].

A great institutional effort and national policies are required to transform the opportunities from applying IS into tangible benefits that promote a reduction in the consumption of natural resources, energy, and raw materials that directly negatively impact environmental sustainability. For example, banks could cooperate with other financial institutions to build an information-sharing platform for industrial systems, which will improve the efficiency of loan regulation and reduce costs; meanwhile, manufacturers could allocate commercial loans and credits appropriately, to make full use of financial sources [114].

4.2.3. Legislation—Compliance with Environmental Protection Requirements

Compliance with regulations aimed at environmental protection is also mentioned as a stimulating factor for the take-up of IS. The practice of IS helps in correctly managing solid waste, preserving the environment, and eliminating pollution derived from the processing of raw materials from natural resources. One way to achieve this synergy is via promoting compliance with environmental regulations [189]. Therefore, environmental regulations foster the IS system. Furthermore, as an environmental regulator, the government should set reasonable carbon taxes and emission limits for manufacturers to improve their enthusiasm for realizing emission reduction and waste generation [114]. Mandatory provisions effectively promote IS implementation among enterprises [105]. For example, China declared eco-industrial parks to be one of the main components of its circular economy strategy. Similarly, Thailand, South Korea, and the Philippines are developing national strategies for eco-industrial parks, to help alleviate the widespread environmental degradation caused by failures in end-of-pipe pollution control approaches. It should be noted that strict environmental laws and standards are important driving forces for companies to adopt pollution prevention approaches, especially those projects that can provide economic gains and improved environmental performance, such as IS—provided that they are effectively monitored by the relevant government agencies [99].

4.2.4. Understanding the Broader Market and Recognizing Megatrends

It is necessary for emerging and frontier countries to reduce greenhouse gas emissions, the burning of waste, and the use of agro-industrial, forestry, and agricultural residues and energy crops to produce electricity and/or heat. These issues have gradually become increasingly important in the business environments of these nations, due to the successful cases reported in the literature around the world, mainly in developed countries such as the United States, Switzerland, the United Kingdom, Australia, and Japan, among others.

On the one hand, by considering IS and the circular economy, it is possible to propose, create and deliver value through new opportunities for innovative business models that are fundamental to maintaining a competitive advantage regarding sustainability by providing opportunities to propose, create and deliver value through cost efficiency and strategic management [107]. On the other hand, these situations become opportunities for government and business managers to continue their efforts to develop and create IS; this collaboration between different actors in society, such as private institutions, public agencies, governments, academia, and communities is essential if environmental sustainability, the adoption of innovative practices and the promotion of local economic development are to be achieved.

4.2.5. Digital—Embracing Technology and Improving Productivity

The modeling, optimization, and simulation of IS activities can be helpful for future development and potential applications in emerging and frontier countries, from which industries can implement cooperation resource-sharing and analyze the flows between enterprises in a symbiotic network [118]. The application of technological topics can generate optimal strategies for IS system participants under different conditions and constraints [114]. The simulation of IS processes should contain the technological structure of the symbiosis system, define the system boundaries, and achieve a performance evaluation of the IS system [115].

4.2.6. Innovations—Circular Business Models as a Competitive Advantage

Operations based on ecosystem thinking will pose new challenges and require more technical and business adaptations than the centralized and linear production methods traditionally followed by industries [105]. An innovative and hybrid industrial–urban symbiosis that considered process synergy, municipal waste recycling, and waste energy utilization in a particular Chinese city is highlighted as a successful case. The results highlight the fact that industrial–urban symbiosis "greens" industries and uses industry to contribute to urban development, formulate next-generation urban planning policies, and shed light on sustainable urban development [121].

4.2.7. People—Retaining Employees and Developing High-Quality Teams

People, especially decision-makers in enterprises, play a crucial role in developing IS activities. From the standpoint of high environmental awareness of the company and the employees, it is possible to meet the requirements of an environmental management system, the environmental requirements, social responsibility, and the morale of the company [118].

5. Conclusions

An analysis of the literature review of IS experiences in emerging and frontier countries, such as China, Brazil, Singapore, India, Taiwan, and Malaysia, among others, shows that IS is a possible environmental planning strategy that can promote the circular economy, sustainable development, the improvement of business conditions and the use of waste materials and by-products that were previously considered waste. Furthermore, the literature review identified that using the IS approach can leverage economic dynamism through material synergies with the surrounding productive and research activities.

China, Brazil, Singapore, and India were the countries that reported the most cases in the literature on IS. Although the cases reported in African countries are extremely scarce, it was possible to find cases of symbiosis. The manufacturing sector was the most prevalent in IS relationships, due to the waste generated and the ability to integrate waste and by-products in the production cycle [22]. Within this category, the activities that occur most frequently in IS are biorefinery companies, waste utilization in industrial parks, forestry industries, waste treatment companies, wastewater treatment, and furniture manufacturing.

Emerging and frontier market countries have a long way to go if they wish to implement real, sustainable development actions by reducing the environmental impacts generated by business activity and economic diversification. In these countries, it is necessary to adopt innovative practices regarding sustainability and implement environmentally friendly business activities, with national policies that facilitate IS activities. Furthermore, collaborative behavior among the actors involved is fundamental for the successful development of IS, which is why private institutions, public agencies, governments, academia, and communities need to cooperate in an articulated manner, seeking sustainability through the adoption of innovative practices; these considerations are necessary if we want to advance in the construction of synergies and the promotion of local economic development.

Although the implementation of symbiotic business networks and IS are general and applicable to any country, it is necessary to analyze the particularities of each region in terms of norms, social and cultural considerations, and environmental regulations. Due to the limited number of publications in emerging and frontier market countries, it is recommended to assess the potential for new synergies, i.e., to examine in detail the industrial capacity of these countries at the local level and identify constraints and benefits, as well as to realize potential IS applications that promote the dissemination and positioning of these practices, focused on sustainable resource utilization.

Business models and regulatory frameworks that are tested and practiced in developed countries are not necessarily applicable to emerging market countries or frontier market countries, due to the difference not only in development stages but also in social, political, and cultural frameworks [190,191]. In this context, it is essential to identify differences in the fields of application of IS strategies that are applicable to industries in emerging market countries, the frontier market countries, and to those applicable in developed countries.

As a development opportunity, it is a requirement to stimulate the conservation of resources such as water and energy through numerical optimization and mathematical modeling, which presents little progress. The research conducted in China and Brazil addresses a broader spectrum than the rest of the countries, generating gaps between these nations' industrial sectors. As a challenge, it is necessary to ensure IS processes that guarantee the integration of resources and that all parties involved will benefit economically. This presents an excellent opportunity to generate green energy harvesting techniques, due to the world's high dependence on non-renewable energy sources and the waste of renewable resources incorporated into IS processes in these countries.

The proper implementation of IS strategies in emerging market countries requires economic, political, and planning capacity, as well as the development of large-scale physical and technical infrastructure from the national to the local level in these countries, which is not always possible for most developing nations [192,193]. Therefore, it is necessary to carry out more studies in the different business sectors of emerging and frontier countries. These should identify joint practices that can or should be adopted to establish standard agreements for the development of policies and strategies, from the perspective of IS, that generate social, environmental, and economic benefits from physical exchanges of waste, residues, and materials [194].

This study is one of the first attempts to investigate the development of IS in emerging and frontier market countries and, as such, contributes to defining a baseline against which strategies can be designed to move these countries toward the development of cleaner production technologies and environmentally sustainable processes.

The main limitations of this study are due to the methodology implemented in the search for articles. By focusing only on publications written in English, some important documents on this topic were probably omitted. Since only research and conference articles were used, there should be more IS cases describing emerging and frontier countries that are not reported in this way, such as reports, book chapters, or public documents. The identification of barriers and drivers of this study can provide relevant information to the government sector and business decision-makers on the importance of applying IS systems in different business environments worldwide.

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References

1. Ajwani-Ramchandani, R.; Figueira, S.; Torres de Oliveira, R.; Jha, S. Enhancing the circular and modified linear economy: The importance of blockchain for developing economies. *Resour. Conserv. Recycl.* **2021**, *168*, 105468. [CrossRef]
2. Frig, M.; Sorsa, V.P. Nation branding as sustainability governance: A case comparative case analysis. *Bus. Soc.* **2020**, *59*, 1153–1180. [CrossRef]
3. Oskam, I.; Bossink, B.; de Man, A.P. Valuing Value in Innovation Ecosystems: How Cross-Sector Actors Overcome Tensions in Collaborative Sustainable Business Model Development. *Bus. Soc.* **2020**, *60*, 1059–1091. [CrossRef]
4. Goyal, S.; Chauhan, S.; Mishra, P. Circular economy research: A bibliometric analysis (2000–2019) and future research insights. *J. Clean. Prod.* **2021**, *287*, 125011. [CrossRef]
5. Lieder, M.; Rashid, A. Towards circular economy implementation: A comprehensive review in context of manufacturing industry. *J. Clean. Prod.* **2016**, *115*, 36–51. [CrossRef]
6. Södergren, K.; Palm, J. The role of local governments in overcoming barriers to industrial symbiosis. *Clean. Environ. Syst.* **2021**, *2*, 100014. [CrossRef]
7. Lim, M.K.; Lai, M.; Wang, C.; Lee, S.Y. Circular economy to ensure production operational sustainability: A green-lean approach. *Sustain. Prod. Consum.* **2022**, *30*, 130–144. [CrossRef]
8. Karuppiah, K.; Sankaranarayanan, B.; Ali, S.M.; Jabbour, C.J.C.; Bhalaji, R.K.A. Inhibitors to circular economy practices in the leather industry using an integrated approach: Implications for sustainable development goals in emerging economies. *Sustain. Prod. Consum.* **2021**, *27*, 1554–1568. [CrossRef]
9. Lonca, G.; Lesage, P.; Majeau-Bettez, G.; Bernard, S.; Margni, M. Assessing scaling effects of circular economy strategies: A case study on plastic bottle closed-loop recycling in the USA PET market. *Resour. Conserv. Recycl.* **2020**, *162*, 105013. [CrossRef]
10. Tang, X.; He, Y.; Salling, M. Optimal pricing and production strategies for two manufacturers with industrial symbiosis. *Int. J. Prod. Econ.* **2021**, *235*, 108084. [CrossRef]
11. Foong, S.Z.Y.; Ng, D.K.S. Simultaneous design and integration of multiple processes for eco-industrial park development. *J. Clean. Prod.* **2021**, *298*, 126797. [CrossRef]
12. Herczeg, G.; Akkerman, R.; Hauschild, M.Z. Supply chain collaboration in industrial symbiosis networks. *J. Clean. Prod.* **2018**, *171*, 1058–1067. [CrossRef]
13. Miemczyk, J.; Johnsen, T.E.; Macquet, M. Sustainable purchasing and supply management: A structured literature review of definitions and measures at the dyad, chain and network levels. *Supply Chain Manag. Int. J.* **2012**, *17*, 478–496. [CrossRef]
14. De Pascale, A.; Arbolino, R.; Szopik-Depczyńska, K.; Limosani, M.; Ioppolo, G. A systematic review for measuring circular economy: The 61 indicators. *J. Clean. Prod.* **2021**, *281*, 124942. [CrossRef]
15. Domenech, T.; Bleischwitz, R.; Doranova, A.; Panayotopoulos, D.; Roman, L. Mapping Industrial Symbiosis Development in Europe_ typologies of networks, characteristics, performance and contribution to the Circular Economy. *Resour. Conserv. Recycl.* **2019**, *141*, 76–98. [CrossRef]
16. Kobayashi, H.; Murata, H.; Fukushige, S. Connected lifecycle systems: A new perspective on industrial symbiosis. *Procedia CIRP* **2020**, *90*, 388–392. [CrossRef]
17. Chiu, A.S.F.; Yong, G. On the industrial ecology potential in Asian developing countries. *J. Clean. Prod.* **2004**, *12*, 1037–1045. [CrossRef]
18. The Balance. MSCI Index and What It Measures. Available online: https://www.thebalance.com/msci-index-what-is-it-and-what-does-it-measure-3305948 (accessed on 15 December 2021).
19. CFI. Emerging Markets. Corporate Finance Institute. Available online: https://corporatefinanceinstitute.com/resources/knowledge/economics/emerging-markets/ (accessed on 15 November 2021).
20. Chourou, L.; Grira, J.; Saadi, S. Does empathy matter in corporate social responsibility? Evidence from emerging markets. *Emerg. Mark. Rev.* **2021**, *46*, 100776. [CrossRef]
21. Khanna, T.; Palepu, K.G. Why focused strategies may be wrong for emerging markets. *Harv. Bus. Rev.* **1997**, *75*, 41–51.
22. Neves, A.; Godina, R.; Azevedo, S.G.; Matias, J.C.O. A comprehensive review of industrial symbiosis. *J. Clean. Prod.* **2020**, *247*, 119113. [CrossRef]
23. Vahidzadeh, R.; Bertanza, G.; Sbaffoni, S.; Vaccari, M. Regional industrial symbiosis: A review based on social network analysis. *J. Clean. Prod.* **2021**, *280*, 124054. [CrossRef]
24. Walls, J.L.; Paquin, R.L. Organizational Perspectives of Industrial Symbiosis: A Review and Synthesis. *Organ. Environ.* **2015**, *28*, 32–53. [CrossRef]
25. Lawal, M.; Wan Alwi, S.R.; Manan, Z.A.; Ho, W.S. Industrial symbiosis tools—A review. *J. Clean. Prod.* **2021**, *280*, 124327. [CrossRef]
26. Khan, M.; Lockhart, J.; Bathurst, R. The institutional analysis of CSR: Learnings from an emerging country. *Emerg. Mark. Rev.* **2021**, *46*, 100752. [CrossRef]

27. Fraccascia, L.; Giannoccaro, I.; Albino, V. Ecosystem indicators for measuring industrial symbiosis. *Ecol. Econ.* **2021**, *183*, 106944. [CrossRef]
28. Frosch, R.A.; Gallopoulos, N.E. Strategies for Manufacturing. *Sci. Am.* **1989**, *261*, 144–152. [CrossRef]
29. Schwarz, E.J.; Steininger, K.W. Implementing nature's lesson: The industrial recycling network enhancing regional development. *J. Clean. Prod.* **1997**, *5*, 47–56. [CrossRef]
30. Chertow, M.R. Industrial symbiosis: Literature and Taxonomy. *Annu. Rev. Energy Environ.* **2000**, *25*, 313–337. [CrossRef]
31. Earley, K. Industrial symbiosis: Harnessing waste energy and materials for mutual benefit. *Renew. Energy Focus* **2015**, *16*, 75–77. [CrossRef]
32. Lombardi, D.R.; Laybourn, P. Redefining Industrial Symbiosis: Crossing Academic-Practitioner Boundaries. *J. Ind. Ecol.* **2012**, *16*, 28–37. [CrossRef]
33. Albino, V.; Fraccascia, L. The industrial symbiosis approach: A classification of business models. *Procedia Environ. Sci. Eng. Manag.* **2015**, *2*, 217–223.
34. Simboli, A.; Taddeo, R.; Morgante, A. The potential of Industrial Ecology in agri-food clusters (AFCs): A case study based on valorisation of auxiliary materials. *Ecol. Econ.* **2015**, *111*, 65–75. [CrossRef]
35. Taddeo, R.; Simboli, A.; Morgante, A.; Erkman, S. The Development of Industrial Symbiosis in Existing Contexts. Experiences from Three Italian Clusters. *Ecol. Econ.* **2017**, *139*, 55–67. [CrossRef]
36. Yuan, Z.; Shi, L. Improving enterprise competitive advantage with industrial symbiosis: Case study of a smeltery in China. *J. Clean. Prod.* **2009**, *17*, 1295–1302. [CrossRef]
37. Kokoulina, L.; Ermolaeva, L.; Patala, S.; Ritala, P. Championing processes and the emergence of industrial symbiosis. *Reg. Stud.* **2019**, *53*, 528–539. [CrossRef]
38. Ashraf, B.N.; Qian, N.; Shen, Y. The impact of trade and financial openness on bank loan pricing: Evidence from emerging economies. *Emerg. Mark. Rev.* **2021**, *47*, 100793. [CrossRef]
39. The World Bank. World Bank Country and Lending Groups. Available online: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519 (accessed on 17 November 2021).
40. Erdoğan, S.; Gedikli, A.; Çevik, E.İ. Volatility spillover effects between Islamic stock markets and exchange rates: Evidence from three emerging countries. *Borsa Istanb. Rev.* **2020**, *20*, 322–333. [CrossRef]
41. MSCI. *MSCI Global Market Accessibility Review*; MSCI: New York, NY, USA, 2021.
42. Cagliesi, G.; Guidi, F. A three-tiered nested analytical approach to financial integration: The case of emerging and frontier equity markets. *Int. Rev. Financ. Anal.* **2021**, *74*, 101698. [CrossRef]
43. Guney, Y.; Karpuz, A.; Komba, G. The effects of board structure on corporate performance: Evidence from East African frontier markets. *Res. Int. Bus. Financ.* **2020**, *53*, 101222. [CrossRef]
44. Santa-Maria, T.; Vermeulen, W.J.V.; Baumgartner, R.J. Framing and assessing the emergent field of business model innovation for the circular economy: A combined literature review and multiple case study approach. *Sustain. Prod. Consum.* **2021**, *26*, 872–891. [CrossRef]
45. Geissdoerfer, M.; Vladimirova, D.; Evans, S. Sustainable business model innovation: A review. *J. Clean. Prod.* **2018**, *198*, 401–416. [CrossRef]
46. Cuentas, S.; Peñabaena-Niebles, R.; Garcia, E. Support vector machine in statistical process monitoring: A methodological and analytical review. *Int. J. Adv. Manuf. Technol.* **2017**, *91*, 485–500. [CrossRef]
47. Mileva-Boshkoska, B.; Rončević, B.; Uršič, E.D. Modeling and evaluation of the possibilities of forming a regional industrial symbiosis networks. *Soc. Sci.* **2018**, *7*, 13. [CrossRef]
48. Guarnieri, P.; Cerqueira-Streit, J.A.; Batista, L.C. Reverse logistics and the sectoral agreement of packaging industry in Brazil towards a transition to circular economy. *Resour. Conserv. Recycl.* **2020**, *153*, 104541. [CrossRef]
49. Pereira, T.; Fernandino, G. Evaluation of solid waste management sustainability of a coastal municipality from northeastern Brazil. *Ocean Coast. Manag.* **2019**, *179*, 104839. [CrossRef]
50. Park, J.; Duque-Hernández, J.; Díaz-Posada, N. Facilitating business collaborations for industrial symbiosis: The pilot experience of the sustainable industrial network program in Colombia. *Sustainability* **2018**, *10*, 3637. [CrossRef]
51. Gupta, D.; Ghersi, F.; Vishwanathan, S.S.; Garg, A. Achieving sustainable development in India along low carbon pathways: Macroeconomic assessment. *World Dev.* **2019**, *123*, 104623. [CrossRef]
52. Falebita, O.; Koul, S. From developing to sustainable economy: A comparative assessment of India and Nigeria. *Environ. Dev.* **2018**, *25*, 130–137. [CrossRef]
53. Singh, M.P.; Chakraborty, A.; Roy, M. Developing an extended theory of planned behavior model to explore circular economy readiness in manufacturing MSMEs, India. *Resour. Conserv. Recycl.* **2018**, *135*, 313–322. [CrossRef]
54. Vu, K.M. Embracing globalization to promote industrialization: Insights from the development of Singapore's petrochemicals industry. *China Econ. Rev.* **2018**, *48*, 170–185. [CrossRef]
55. World Bank. Government Expenditure on R&D. Available online: https://data.worldbank.org/indicator/GC.XPN.TOTL.GD.ZS (accessed on 2 December 2021).
56. Cheah, S.L.Y.; Ho, Y.P.; Li, S. How the effect of opportunity discovery on innovation outcome differs between DIY laboratories and public research institutes: The role of industry turbulence and knowledge generation in the case of Singapore. *Technol. Forecast. Soc. Chang.* **2020**, *160*, 120250. [CrossRef]

57. GII. Global Innovation Index. Available online: https://www.globalinnovationindex.org/Home (accessed on 11 November 2021).
58. Wu, C.Y.; Hu, M.C.; Ni, F.C. Supporting a circular economy: Insights from Taiwan's plastic waste sector and lessons for developing countries. *Sustain. Prod. Consum.* **2021**, *26*, 228–238. [CrossRef] [PubMed]
59. Eunomia. *Recycling-Who Really Leads the World?* European Environmental Bureau: Brussels, Belgium, 2018.
60. Huang, Y.F.; Azevedo, S.G.; Lin, T.J.; Cheng, C.S.; Lin, C.T. Exploring the decisive barriers to achieve circular economy: Strategies for the textile innovation in Taiwan. *Sustain. Prod. Consum.* **2021**, *27*, 1406–1423. [CrossRef]
61. United Nations. *International Standard Industrial Classification of All Economic Activities (ISIC), Rev. 4*; Department of Economic and Social Affairs: New York, NY, USA, 2008.
62. Wu, W.; Sheng, L.; Tang, F.; Zhang, A.; Liu, J. A system dynamics model of green innovation and policy simulation with an application in Chinese manufacturing industry. *Sustain. Prod. Consum.* **2021**, *28*, 987–1005. [CrossRef]
63. Wu, J.; Lu, J.; Jin, R. Quantitative indicators for evolution of a typical iron and steel industrial symbiosis network. *J. Clean. Prod.* **2021**, *287*, 125491. [CrossRef]
64. Huang, L.; Zhen, L.; Yin, L. Waste material recycling and exchanging decisions for industrial symbiosis network optimization. *J. Clean. Prod.* **2020**, *276*, 124073. [CrossRef]
65. Lu, C.; Wang, S.; Wang, K.; Gao, Y.; Zhang, R. Uncovering the benefits of integrating industrial symbiosis and urban symbiosis targeting a resource-dependent city: A case study of Yongcheng, China. *J. Clean. Prod.* **2020**, *255*, 120210. [CrossRef]
66. Wang, S.; Lu, C.; Gao, Y.; Wang, K.; Zhang, R. Life cycle assessment of reduction of environmental impacts via industrial symbiosis in an energy-intensive industrial park in China. *J. Clean. Prod.* **2019**, *241*, 118358. [CrossRef]
67. Wu, J.; Lv, J.; Shang, J.; Guo, Y.; Pu, G. Evaluating chromium coupled with carbon metabolism and environmental performance in the chromate industrial symbiosis network in China. *Resour. Conserv. Recycl.* **2019**, *149*, 188–196. [CrossRef]
68. Zhang, B.; Du, Z.; Wang, Z. Carbon reduction from sustainable consumption of waste resources: An optimal model for collaboration in an industrial symbiotic network. *J. Clean. Prod.* **2018**, *196*, 821–828. [CrossRef]
69. de Araújo, I.F.; Perobelli, F.S.; Faria, W.R. Regional and global patterns of participation in value chains: Evidence from Brazil. *Int. Econ.* **2021**, *165*, 154–171. [CrossRef]
70. Baldwin, R.; Lopez-Gonzalez, J. Supply-chain Trade: A Portrait of Global Patterns and Several Testable Hypotheses. *World Econ.* **2015**, *38*, 1682–1721. [CrossRef]
71. Mantese, G.C.; Bianchi, M.J.; Amaral, D.C. The industrial symbiosis in the product development: An approach through the DFIS. *Procedia Manuf.* **2018**, *21*, 862–869. [CrossRef]
72. de Oliveira, F.R.; França, S.L.B.; Rangel, L.A.D. Challenges and opportunities in a circular economy for a local productive arrangement of furniture in Brazil. *Resour. Conserv. Recycl.* **2018**, *135*, 202–209. [CrossRef]
73. Sousa-Zomer, T.T.; Magalhães, L.; Zancul, E.; Cauchick-Miguel, P.A. Exploring the challenges for circular business implementation in manufacturing companies: An empirical investigation of a pay-per-use service provider. *Resour. Conserv. Recycl.* **2018**, *135*, 3–13. [CrossRef]
74. Martinelli, L.A.; Naylor, R.; Vitousek, P.M.; Moutinho, P. Agriculture in Brazil: Impacts, costs, and opportunities for a sustainable future. *Curr. Opin. Environ. Sustain.* **2010**, *2*, 431–438. [CrossRef]
75. Vannozzi Brito, V.; Borelli, S. Urban food forestry and its role to increase food security: A Brazilian overview and its potentialities. *Urban For. Urban Green.* **2020**, *56*, 126835. [CrossRef]
76. Wahrlich, J.; Simioni, F.J. Industrial symbiosis in the forestry sector: A case study in southern Brazil. *J. Ind. Ecol.* **2019**, *23*, 1470–1482. [CrossRef]
77. Sanyé-Mengual, E.; Martinez-Blanco, J.; Finkbeiner, M.; Cerdà, M.; Camargo, M.; Ometto, A.R.; Velásquez, L.S.; Villada, G.; Niza, S.; Pina, A.; et al. Urban horticulture in retail parks: Environmental assessment of the potential implementation of rooftop greenhouses in European and South American cities. *J. Clean. Prod.* **2016**, *172*, 3081–3091. [CrossRef]
78. Saraceni, A.V.; Resende, L.M.; de Andrade Júnior, P.P.; Pontes, J. Pilot testing model to uncover industrial symbiosis in Brazilian industrial clusters. *Environ. Sci. Pollut. Res.* **2017**, *24*, 11618–11629. [CrossRef]
79. Mantese, G.C.; Amaral, D.C. Comparison of industrial symbiosis indicators through agent-based modeling. *J. Clean. Prod.* **2017**, *140*, 1652–1671. [CrossRef]
80. Felicio, M.; Amaral, D.; Esposto, K.; Gabarrell Durany, X. Industrial symbiosis indicators to manage eco-industrial parks as dynamic systems. *J. Clean. Prod.* **2016**, *118*, 54–64. [CrossRef]
81. Ceglia, D.; de Abreu, M.C.S.; Da Silva Filho, J.C.L. Critical elements for eco-retrofitting a conventional industrial park: Social barriers to be overcome. *J. Environ. Manag.* **2017**, *187*, 375–383. [CrossRef]
82. Raabe, B.; Low, J.S.C.; Juraschek, M.; Herrmann, C.; Tjandra, T.B.; Ng, Y.T.; Kurle, D.; Cerdas, F.; Lueckenga, J.; Yeo, Z.; et al. Collaboration Platform for Enabling Industrial Symbiosis: Application of the By-product Exchange Network Model. *Procedia CIRP* **2017**, *61*, 263–268. [CrossRef]
83. Kerdlap, P.; Low, J.S.C.; Tan, D.Z.L.; Yeo, Z.; Ramakrishna, S. M3-IS-LCA: A Methodology for Multi-level Life Cycle Environmental Performance Evaluation of Industrial Symbiosis Networks. *Resour. Conserv. Recycl.* **2020**, *161*, 104963. [CrossRef]
84. Singh, R.; Chanda, R. Technical regulations, intermediate inputs, and performance of firms: Evidence from India. *J. Int. Econ.* **2021**, *128*, 103412. [CrossRef]
85. Khurana, S.; Haleem, A.; Luthra, S.; Mannan, B. Evaluating critical factors to implement sustainable oriented innovation practices: An analysis of micro, small, and medium manufacturing enterprises. *J. Clean. Prod.* **2021**, *285*, 125377. [CrossRef]

86. Vimal, K.E.K.; Rajak, S.; Kandasamy, J. Analysis of network design for a circular production system using multi-objective mixed integer linear programming model. *J. Manuf. Technol. Manag.* **2019**, *30*, 628–646. [CrossRef]
87. Gopinath, A.; Bahurudeen, A.; Appari, S.; Nanthagopalan, P. A circular framework for the valorisation of sugar industry wastes: Review on the industrial symbiosis between sugar, construction and energy industries. *J. Clean. Prod.* **2018**, *203*, 89–108. [CrossRef]
88. Chattopadhyay, S.; Kumar, N.; Fine, C.; Olivetti, E. Industrial symbiosis among small and medium scale enterprises: Case of Muzaffarnagar, India. In *REWAS 2016, towards Materials Resource Sustainability*; Springer: Berlin/Heidelberg, Germany, 2016; pp. 173–177. [CrossRef]
89. Bain, A.; Ashton, W.; Shenoy, M. Resource reuse and recycling in an Indian industrial network: Efficiency and flexibility considerations. In Proceedings of the 2009 Second International Conference on Infrastructure Systems and Services: Developing 21st Century Infrastructure Networks (INFRA), Nagar, India, 9–11 December 2009; pp. 1–7. [CrossRef]
90. Ashton, W.S.; Bain, A.C. Assessing the "Short Mental Distance" in Eco-Industrial Networks. *J. Ind. Ecol.* **2012**, *16*, 70–82. [CrossRef]
91. Bain, A.; Shenoy, M.; Ashton, W.; Chertow, M. Industrial symbiosis and waste recovery in an Indian industrial area. *Resour. Conserv. Recycl.* **2010**, *54*, 1278–1287. [CrossRef]
92. Li, J.; Pan, S.Y.; Kim, H.; Linn, J.H.; Chiang, P.C. Building green supply chains in eco-industrial parks towards a green economy: Barriers and strategies. *J. Environ. Manag.* **2015**, *162*, 158–170. [CrossRef]
93. Lai, H.C.; Shyu, J.Z. A comparison of innovation capacity at science parks across the Taiwan Strait: The case of Zhangjiang High-Tech Park and Hsinchu Science-based Industrial Park. *Technovation* **2005**, *25*, 805–813. [CrossRef]
94. Kim, H.W.; Ohnishi, S.; Fujii, M.; Fujita, T.; Park, H.S. Evaluation and Allocation of Greenhouse Gas Reductions in Industrial Symbiosis. *J. Ind. Ecol.* **2018**, *22*, 275–287. [CrossRef]
95. Park, H.S.; Behera, S.K. Methodological aspects of applying eco-efficiency indicators to industrial symbiosis networks. *J. Clean. Prod.* **2014**, *64*, 478–485. [CrossRef]
96. Behera, S.K.; Kim, J.H.; Lee, S.Y.; Suh, S.; Park, H.S. Evolution of "designed" industrial symbiosis networks in the Ulsan Eco-industrial Park: "Research and development into business" as the enabling framework. *J. Clean. Prod.* **2012**, *29–30*, 103–112. [CrossRef]
97. Stucki, J.; Flammini, A.; van Beers, D.; Phuong, T.T.; Anh, N.T.; Dong, T.D.; Huy, V.Q.; Hieu, V.T.M. Eco-industrial park (EIP) development in Viet Nam: Results and key insights from UNIDO's EIP project (2014–2019). *Sustainability* **2019**, *11*, 4667. [CrossRef]
98. ElMassah, S. Industrial symbiosis within eco-industrial parks: Sustainable development for Borg El-Arab in Egypt. *Bus. Strategy Environ.* **2018**, *27*, 884–892. [CrossRef]
99. Sakr, D.; Baas, L.; El-Haggar, S.; Huisingh, D. Critical success and limiting factors for eco-industrial parks: Global trends and Egyptian context. *J. Clean. Prod.* **2011**, *19*, 1158–1169. [CrossRef]
100. Mauthoor, S. Uncovering industrial symbiosis potentials in a small island developing state: The case study of Mauritius. *J. Clean. Prod.* **2017**, *147*, 506–513. [CrossRef]
101. Cerceau, J.; Mat, N.; Junqua, G.; Lin, L.; Laforest, V.; Gonzalez, C. Implementing industrial ecology in port cities: International overview of case studies and cross-case analysis. *J. Clean. Prod.* **2014**, *74*, 1–16. [CrossRef]
102. Bonilla-Gámez, N.; Toboso-Chavero, S.; Parada, F.; Civit, B.; Arena, A.P.; Rieradevall, J.; Gabarrell Durany, X. Environmental impact assessment of agro-services symbiosis in semiarid urban frontier territories. Case study of Mendoza (Argentina). *Sci. Total Environ.* **2021**, *774*, 145682. [CrossRef]
103. Liar, F.; Stolte, B.; Bertolucci, L.A.; Gobbo, J.A. Proposal of an assessment tool to diagnose industrial symbiosis readiness. *Sustain. Prod. Consum.* **2022**, *30*, 916–929. [CrossRef]
104. Sellitto, M.A.; Murakami, F.K.; Butturi, M.A.; Marinelli, S.; Kadel, N.; Rimini, B. Barriers, drivers, and relationships in industrial symbiosis of a network of Brazilian manufacturing companies. *Sustain. Prod. Consum.* **2021**, *26*, 443–454. [CrossRef]
105. Oliveira Pavan, M.; Soares Ramos, D.; Yones Soares, M.; Carvalho, M.M. Circular business models for bioelectricity: A value perspective for sugar-energy sector in Brazil. *J. Clean. Prod.* **2021**, *311*, 127615. [CrossRef]
106. Faria, E.; Caldeira-Pires, A. Social, Economic, and Institutional Configurations of the Industrial Symbiosis Process: A Comparative Analysis of the Literature and a Proposed Theoretical and Analytical Framework. *Sustainability* **2021**, *13*, 7123. [CrossRef]
107. de Souza, F.F.; Ferreira, M.B.; Saraceni, A.V.; Betim, L.M.; Pereira, T.L.; Petter, R.R.H.; Pagani, R.N.; de Resende, L.M.M.; Pontes, J.; Piekarski, C.M. Temporal comparative analysis of industrial symbiosis in a business network: Opportunities of circular economy. *Sustainability* **2020**, *12*, 1832. [CrossRef]
108. Cunha, G.; dos Santos, B.T.; Alves, J.R.; Alves Silva, I.A.; de Souza Cruz, D.R.; Romão, L.P.C. Applications of magnetic hybrid adsorbent derived from waste biomass for the removal of metal ions and reduction of 4-nitrophenol. *J. Environ. Manag.* **2018**, *213*, 236–246. [CrossRef]
109. Santos, V.E.N.; Magrini, A. Biorefining and industrial symbiosis: A proposal for regional development in Brazil. *J. Clean. Prod.* **2018**, *177*, 19–33. [CrossRef]
110. Mantese, G.C.; Amaral, D.C. Agent-based simulation to evaluate and categorize industrial symbiosis indicators. *J. Clean. Prod.* **2018**, *186*, 450–464. [CrossRef]
111. Freitas, L.; Magrini, A. Waste management in industrial construction: Investigating contributions from industrial ecology. *Sustainability* **2017**, *9*, 1251. [CrossRef]
112. Elabras Veiga, L.B.; Magrini, A. Eco-industrial park development in Rio de Janeiro, Brazil: A tool for sustainable development. *J. Clean. Prod.* **2009**, *17*, 653–661. [CrossRef]

113. Morales, E.M.; Diemer, A.; Cervantes, G.; Carrillo-González, G. "By-product synergy" changes in the industrial symbiosis dynamics at the Altamira-Tampico industrial corridor: 20 Years of industrial ecology in Mexico. *Resour. Conserv. Recycl.* **2019**, *140*, 235–245. [CrossRef]
114. Zhao, X.; Xue, Y.; Ding, L. Implementation of low carbon industrial symbiosis systems under financial constraint and environmental regulations: An evolutionary game approach. *J. Clean. Prod.* **2020**, *277*, 124289. [CrossRef]
115. Cao, X.; Wen, Z.; Zhao, X.; Wang, Y.; Zhang, H. Quantitative assessment of energy conservation and emission reduction effects of nationwide industrial symbiosis in China. *Sci. Total Environ.* **2020**, *717*, 137114. [CrossRef]
116. He, M.; Jin, Y.; Zeng, H.; Cao, J. Pricing decisions about waste recycling from the perspective of industrial symbiosis in an industrial park: A game model and its application. *J. Clean. Prod.* **2020**, *251*, 119417. [CrossRef]
117. Sun, L.; Fujii, M.; Li, Z.; Dong, H.; Geng, Y.; Liu, Z.; Fujita, T.; Yu, X.; Zhang, Y. Energy-saving and carbon emission reduction effect of urban-industrial symbiosis implementation with feasibility analysis in the city. *Technol. Forecast. Soc. Chang.* **2020**, *151*, 119853. [CrossRef]
118. Ji, Y.; Liu, Z.; Wu, J.; He, Y.; Xu, H. Which factors promote or inhibit enterprises' participation in industrial symbiosis? An analytical approach and a case study in China. *J. Clean. Prod.* **2020**, *244*, 118600. [CrossRef]
119. Zhang, X.; Chai, L. Structural features and evolutionary mechanisms of industrial symbiosis networks: Comparable analyses of two different cases. *J. Clean. Prod.* **2019**, *213*, 528–539. [CrossRef]
120. Wang, D.; Wang, Y.; Song, X. Evolution model with time lag effects for the coal industrial symbiosis system: A case study of Ordos, China. *J. Clean. Prod.* **2018**, *187*, 863–876. [CrossRef]
121. Dong, L.; Liang, H.; Zhang, L.; Liu, Z.; Gao, Z.; Hu, M. Highlighting regional eco-industrial development: Life cycle benefits of an urban industrial symbiosis and implications in China. *Ecol. Model.* **2017**, *361*, 164–176. [CrossRef]
122. Li, B.; Xiang, P.; Hu, M.; Zhang, C.; Dong, L. The vulnerability of industrial symbiosis: A case study of Qijiang Industrial Park, China. *J. Clean. Prod.* **2017**, *157*, 267–277. [CrossRef]
123. Sun, L.; Li, H.; Dong, L.; Fang, K.; Ren, J.; Geng, Y.; Fujii, M.; Zhang, W.; Zhang, N.; Liu, Z. Eco-benefits assessment on urban industrial symbiosis based on material flows analysis and emergy evaluation approach: A case of Liuzhou city, China. *Resour. Conserv. Recycl.* **2017**, *119*, 78–88. [CrossRef]
124. Liu, Z.; Adams, M.; Cote, R.P.; Geng, Y.; Chen, Q.; Liu, W.; Sun, L.; Yu, X. Comprehensive development of industrial symbiosis for the response of greenhouse gases emission mitigation: Challenges and opportunities in China. *Energy Policy.* **2017**, *102*, 88–95. [CrossRef]
125. Guo, B.; Geng, Y.; Sterr, T.; Dong, L.; Liu, Y. Evaluation of promoting industrial symbiosis in a chemical industrial park: A case of Midong. *J. Clean. Prod.* **2016**, *135*, 995–1008. [CrossRef]
126. Dong, L.; Fujita, T.; Dai, M.; Geng, Y.; Ren, J.; Fujii, M.; Wang, Y.; Ohnishi, S. Towards preventative eco-industrial development: An industrial and urban symbiosis case in one typical industrial city in China. *J. Clean. Prod.* **2016**, *114*, 387–400. [CrossRef]
127. Li, H.; Dong, L.; Ren, J. Industrial symbiosis as a countermeasure for resource dependent city: A case study of Guiyang, China. *J. Clean. Prod.* **2015**, *107*, 252–266. [CrossRef]
128. Yu, B.; Li, X.; Shi, L.; Qian, Y. Quantifying CO_2 emission reduction from industrial symbiosis in integrated steel mills in China. *J. Clean. Prod.* **2015**, *103*, 801–810. [CrossRef]
129. Wu, J.; Li, C.; Yang, F. The disposition of chromite ore processing residue (COPR) incorporating industrial symbiosis. *J. Clean. Prod.* **2015**, *95*, 156–162. [CrossRef]
130. Wen, Z.; Meng, X. Quantitative assessment of industrial symbiosis for the promotion of circular economy: A case study of the printed circuit boards industry in China's Suzhou New District. *J. Clean. Prod.* **2015**, *90*, 211–219. [CrossRef]
131. Liu, C.; Côté, R.P.; Zhang, K. Implementing a three-level approach in industrial symbiosis. *J. Clean. Prod.* **2015**, *87*, 318–327. [CrossRef]
132. Yu, F.; Han, F.; Cui, Z. Evolution of industrial symbiosis in an eco-industrial park in China. *J. Clean. Prod.* **2015**, *87*, 339–347. [CrossRef]
133. Dong, L.; Gu, F.; Fujita, T.; Hayashi, Y.; Gao, J. Uncovering opportunity of low-carbon city promotion with industrial system innovation: Case study on industrial symbiosis projects in China. *Energy Policy* **2014**, *65*, 388–397. [CrossRef]
134. Dong, L.; Zhang, H.; Fujita, T.; Ohnishi, S.; Li, H.; Fujii, M.; Dong, H. Environmental and economic gains of industrial symbiosis for Chinese iron/steel industry: Kawasaki's experience and practice in Liuzhou and Jinan. *J. Clean. Prod.* **2013**, *59*, 226–238. [CrossRef]
135. Zhang, H.; Dong, L.; Li, H.; Fujita, T.; Ohnishi, S.; Tang, Q. Analysis of low-carbon industrial symbiosis technology for carbon mitigation in a Chinese iron/steel industrial park: A case study with carbon flow analysis. *Energy Policy* **2013**, *61*, 1400–1411. [CrossRef]
136. Dong, L.; Fujita, T.; Zhang, H.; Dai, M.; Fujii, M.; Ohnishi, S.; Geng, Y.; Liu, Z. Promoting low-carbon city through industrial symbiosis: A case in China by applying HPIMO model. *Energy Policy* **2013**, *61*, 864–873. [CrossRef]
137. Chen, P.C.; Liu, K.H. Development of an interactive industrial symbiosis query system with structured industrial waste database in Taiwan. *J. Clean. Prod.* **2021**, *297*, 126673. [CrossRef]
138. Maynard, N.J.; Vaishnav Raj, K.S.; Hua, C.Y.; Lo, S.F. Industrial symbiosis in Taiwan: Case study on Linhai industrial park. *Sustainability* **2020**, *12*, 4564. [CrossRef]

139. Tseng, M.L.; Tan, R.R.; Chiu, A.S.F.; Chien, C.F.; Kuo, T.C. Circular economy meets industry 4.0, Can big data drive industrial symbiosis? *Resour. Conserv. Recycl.* **2018**, *131*, 146–147. [CrossRef]
140. Kundu, D.; Banerjee, S.; Karmakar, S.; Banerjee, R. Valorization of citrus lemon wastes through biorefinery approach: An industrial symbiosis. *Bioresour. Technol. Rep.* **2021**, *15*, 100717. [CrossRef]
141. Cherian, P.; Palaniappan, S.; Menon, D.; Anumolu, M.P. Comparative study of embodied energy of affordable houses made using GFRG and conventional building technologies in India. *Energy Build.* **2020**, *223*, 110138. [CrossRef]
142. Chertow, M.R.; Gordon, M.; Hirsch, P.; Ramaswami, A. Industrial symbiosis potential and urban infrastructure capacity in Mysuru, India. *Environ. Res. Lett.* **2019**, *14*, 75003. [CrossRef]
143. Yong, W.N.; Liew, P.Y.; Woon, K.S.; Wan Alwi, S.R.; Klemeš, J.J. A pinch-based multi-energy targeting framework for combined chilling heating power microgrid of urban-industrial symbiosis. *Renew. Sustain. Energy Rev.* **2021**, *150*, 111482. [CrossRef]
144. Misrol, M.A.; Wan Alwi, S.R.; Lim, J.S.; Manan, Z.A. An optimal resource recovery of biogas, water regeneration, and reuse network integrating domestic and industrial sources. *J. Clean. Prod.* **2021**, *286*, 125372. [CrossRef]
145. Sharib, S.; Halog, A. Enhancing value chains by applying industrial symbiosis concept to the Rubber City in Kedah, Malaysia. *J. Clean. Prod.* **2017**, *141*, 1095–1108. [CrossRef]
146. Ng, R.T.L.; Ng, D.K.S.; Tan, R.R.; El-Halwagi, M.M. Disjunctive fuzzy optimisation for planning and synthesis of bioenergy-based industrial symbiosis system. *J. Environ. Chem. Eng.* **2014**, *2*, 652–664. [CrossRef]
147. Ng, R.T.L.; Hassim, M.H.; Ng, D.K.S.; Tan, R.R.; El-Halwagi, M.M. Multi-Objective Design of Industrial Symbiosis in Palm Oil Industry. *Comput. Aided Chem. Eng.* **2014**, *34*, 579–584. [CrossRef]
148. Yin, C.Y.; Lee, L.Y. Teaching chemical engineering students industrial symbiosis using online resources: A Singapore case study. *Educ. Chem. Eng.* **2019**, *27*, 28–34. [CrossRef]
149. Kerdlap, P.; Low, J.S.C.; Steidle, R.; Tan, D.Z.L.; Herrmann, C.; Ramakrishna, S. Collaboration platform for enabling industrial symbiosis: Application of the industrial-symbiosis life cycle analysis engine. *Procedia CIRP* **2019**, *80*, 655–660. [CrossRef]
150. Yeo, Z.; Low, J.S.C.; Tan, D.Z.L.; Chung, S.Y.; Tjandra, T.B.; Ignatius, J. A collaboration platform for enabling industrial symbiosis: Towards creating a self-learning waste-to-resource database for recommending industrial symbiosis transactions using text analytics. *Procedia CIRP* **2019**, *80*, 643–648. [CrossRef]
151. Kerdlap, P.; Low, J.S.C.; Ramakrishna, S. Zero waste manufacturing: A framework and review of technology, research, and implementation barriers for enabling a circular economy transition in Singapore. *Resour. Conserv. Recycl.* **2019**, *151*, 104438. [CrossRef]
152. Song, B.; Yeo, Z.; Kohls, P.; Herrmann, C. Industrial Symbiosis: Exploring Big-data Approach for Waste Stream Discovery. *Procedia CIRP* **2017**, *61*, 353–358. [CrossRef]
153. Kastner, C.A.; Lau, R.; Kraft, M. Quantitative tools for cultivating symbiosis in industrial parks; a literature review. *Appl. Energy* **2015**, *155*, 599–612. [CrossRef]
154. Bin, S.; Zhiquan, Y.; Jonathan, L.S.C.; Jiewei, D.K.; Kurle, D.; Cerdas, F.; Herrmann, C. A big data analytics approach to develop industrial symbioses in large cities. *Procedia CIRP* **2015**, *29*, 450–455. [CrossRef]
155. Yeşilkaya, M.; Daş, G.S.; Türker, A.K. A multi-objective multi-period mathematical model for an industrial symbiosis network based on the forest products industry. *Comput. Ind. Eng.* **2020**, *150*, 106883. [CrossRef]
156. Alkaya, E.; Böğürcü, M.; Ferda, U. Industrial symbiosis in Iskenderun Bay: A journey from pilot applications to a national Program in Turkey. In Proceedings of the Conference SYMBIOSIS, Athens, Greece, 21 June 2014; pp. 1–8. Available online: http://uest.ntua.gr/conference2014/pdf/alkaya_et_al.pdf (accessed on 3 November 2021).
157. Tseng, M.L.; Bui, T.D. Identifying eco-innovation in industrial symbiosis under linguistic preferences: A novel hierarchical approach. *J. Clean. Prod.* **2017**, *140*, 1376–1389. [CrossRef]
158. Aviasti, A.; Nugraha, N.; Amaranti, R.; Nurrahman, A.A. Industrial symbiosis of fragrant lemongrass distillation in West Java. *J. Phys. Conf. Ser.* **2019**, *1375*, 12054. [CrossRef]
159. Ismail, Y. Promoting Industrial Symbiosis at Supply Chain. *E3S Web. Conf.* **2018**, *68*, 1003. [CrossRef]
160. Ulhasanah, N.; Goto, N. Preliminary Design of Eco-City by Using Industrial Symbiosis and Waste Co-Processing Based on MFA, LCA, and MFCA of Cement Industry in Indonesia. *Int. J. Environ. Sci. Dev.* **2012**, *6*, 553–561. [CrossRef]
161. Kim, H.W.; Dong, L.; Choi, A.E.S.; Fujii, M.; Fujita, T.; Park, H.S. Co-benefit potential of industrial and urban symbiosis using waste heat from industrial park in Ulsan, Korea. *Resour. Conserv. Recycl.* **2018**, *135*, 225–234. [CrossRef]
162. Park, H.S.; Rene, E.R.; Choi, S.M.; Chiu, A.S.F. Strategies for sustainable development of industrial park in Ulsan, South Korea-From spontaneous evolution to systematic expansion of industrial symbiosis. *J. Environ. Manag.* **2008**, *87*, 1–13. [CrossRef] [PubMed]
163. Bacudio, L.R.; Benjamin, M.F.D.; Eusebio, R.C.P.; Holaysan, S.A.K.; Promentilla, M.A.B.; Yu, K.D.S.; Aviso, K.B. Analyzing barriers to implementing industrial symbiosis networks using DEMATEL. *Sustain. Prod. Consum.* **2016**, *7*, 57–65. [CrossRef]
164. Aviso, K.B. Design of robust water exchange networks for eco-industrial symbiosis. *Process Saf. Environ. Prot.* **2014**, *9*, 160–170. [CrossRef]
165. Panyathanakun, V.; Tantayanon, S.; Tingsabhat, C.; Charmondusit, K. Development of eco-industrial estates in Thailand: Initiatives in the northern region community-based eco-industrial estate. *J. Clean. Prod.* **2013**, *51*, 71–79. [CrossRef]
166. Gregson, N.; Crang, M.; Ahamed, F.U.; Akter, N.; Ferdous, R.; Foisal, S. Territorial Agglomeration and Industrial Symbiosis: Sitakunda-Bhatiary, Bangladesh, as a Secondary Processing Complex. *Econ. Geogr.* **2012**, *88*, 37–58. [CrossRef]

167. Fan, Y.V.; Varbanov, P.S.; Klemeš, J.J.; Romanenko, S.V. Urban and industrial symbiosis for circular economy: Total EcoSite Integration. *J. Environ. Manag.* **2021**, *279*, 111829. [CrossRef] [PubMed]
168. Chin, H.H.; Varbanov, P.S.; Klemeš, J.J.; Bandyopadhyay, S. Subsidised water symbiosis of eco-industrial parks: A multi-stage game theory approach. *Comput. Chem. Eng.* **2021**, *155*, 107539. [CrossRef]
169. Momirski, L.A.; Mušič, B.; Cotič, B. Urban strategies enabling industrial and urban symbiosis: The case of slovenia. *Sustainability* **2021**, *13*, 4616. [CrossRef]
170. Chatzidimitriou, T.; Gentimis, T.; Michalopoulos, C.; Kokossis, A.C.; Dalamagas, T. Intelligent Management Platform for Material Exchange Optimization and Industrial Symbiosis. In *31 European Symposium on Computer Aided Process Engineering*; Türkay, M., Gani, R., Eds.; Elsevier: Amsterdam, The Netherlands, 2021; Volume 50, pp. 761–766. [CrossRef]
171. Cecelja, F.; Raafat, T.; Trokanas, N.; Innes, S. E-Symbiosis: Technology-enabled support for Industrial Symbiosis targeting Small and Medium Enterprises and innovation. *J. Clean. Prod.* **2015**, *98*, 336–352. [CrossRef]
172. Raafat, T.; Trokanas, N.; Cecelja, F.; Bimi, X. An ontological approach towards enabling processing technologies participation in industrial symbiosis. *Comput. Chem. Eng.* **2013**, *59*, 33–46. [CrossRef]
173. Flegar, M.; Serdar, M.; Londono-Zuluaga, D.; Scrivener, K. Regional waste streams as potential raw materials for immediate implementation in cement production. *Materials* **2020**, *13*, 5456. [CrossRef]
174. Tolstykh, T.; Shmeleva, N.; Gamidullaeva, L. Evaluation of circular and integration potentials of innovation ecosystems for industrial sustainability. *Sustainability* **2020**, *12*, 4574. [CrossRef]
175. Czaplicka-Kotas, A.; Kulczycka, J.; Iwaszczuk, N. Energy clusters as a new urban symbiosis concept for increasing renewable energy production-a case study of Zakopane city. *Sustainability* **2020**, *12*, 5634. [CrossRef]
176. King, S.; Lusher, D.; Hopkins, J.; Simpson, G.W. Industrial symbiosis in Australia: The social relations of making contact in a matchmaking marketplace for SMEs. *J. Clean. Prod.* **2020**, *270*, 122146. [CrossRef]
177. Al-Saidi, M.; Das, P.; Saadaoui, I. Circular Economy in Basic Supply: Framing the Approach for the Water and Food Sectors of the Gulf Cooperation Council Countries. *Sustain. Prod. Consum.* **2021**, *27*, 1273–1285. [CrossRef]
178. Al-Thani, N.A.; Al-Ansari, T. Comparing the convergence and divergence within industrial ecology, circular economy, and the energy-water-food nexus based on resource management objectives. *Sustain. Prod. Consum.* **2021**, *27*, 1743–1761. [CrossRef]
179. Jato-Espino, D.; Ruiz-Puente, C. Bringing Facilitated Industrial Symbiosis and Game Theory Together to Strengthen Waste Exchange in Industrial Parks. *Sci. Total Environ.* **2021**, *771*, 145400. [CrossRef]
180. Kamat, S.; Bandyopadhyay, S. A hybrid approach for heat integration in water conservation networks through non-isothermal mixing. *Energy* **2021**, *233*, 121143. [CrossRef]
181. Mahmood, D.; Javaid, N.; Ahmed, G.; Khan, S.; Monteiro, V. A review on optimization strategies integrating renewable energy sources focusing uncertainty factor—Paving path to eco-friendly smart cities. *Sustain. Comput. Inform. Syst.* **2021**, *30*, 100559. [CrossRef]
182. Yang, M.; Tang, W. Air pollution, political costs, and earnings management. *Emerg. Mark. Rev.* **2021**, 100867. [CrossRef]
183. Darmandieu, A.; Garcés-Ayerbe, C.; Renucci, A.; Rivera-Torres, P. How does it pay to be circular in production processes? Eco-innovativeness and green jobs as moderators of a cost-efficiency advantage in European small and medium enterprises. *Bus. Strategy Environ.* **2021**, *31*, 1184–1203. [CrossRef]
184. Mauthoor, S.; Mohee, R.; Kowlesser, P.; Musruck, R. An analysis of the wastes emanating from edible oil refineries in Mauritius: A SIDS perspective. *Waste Manag.* **2015**, *40*, I–II. [CrossRef]
185. Yazan, D.M.; Fraccascia, L. Sustainable operations of industrial symbiosis: An enterprise input-output model integrated by agent-based simulation. *Int. J. Prod. Res.* **2020**, *58*, 392–414. [CrossRef]
186. de Paiva Duarte, F. Barriers to Sustainability: An Exploratory Study on Perspectives from Brazilian Organizations. *Sustain. Dev.* **2015**, *23*, 425–434. [CrossRef]
187. Yeo, Z.; Masi, D.; Low, J.S.C.; Ng, Y.T.; Tan, P.S.; Barnes, S. Tools for promoting industrial symbiosis: A systematic review. *J. Ind. Ecol.* **2019**, *23*, 1087–1108. [CrossRef]
188. Wu, B.; Fang, H.; Jacoby, G.; Li, G.; Wu, Z. Environmental regulations and innovation for sustainability? Moderating effect of political connections. *Emerg. Mark. Rev.* **2021**, *50*, 100835. [CrossRef]
189. Geissdoerfer, M.; Savaget, P.; Bocken, N.M.P.; Hultink, E.J. The Circular Economy—A new sustainability paradigm? *J. Clean. Prod.* **2017**, *143*, 757–768. [CrossRef]
190. Relva, S.G.; da Silva, V.O.; Gimenes, A.L.V.; Udaeta, M.E.M.; Ashworth, P.; Peyerl, D. Enhancing developing countries' transition to a low-carbon electricity sector. *Energy* **2021**, *220*, 119659. [CrossRef]
191. Stadelmann, M.; Castro, P. Climate policy innovation in the South—Domestic and international determinants of renewable energy policies in developing and emerging countries. *Glob. Environ. Chang.* **2014**, *29*, 413–423. [CrossRef]
192. Browning, S.; Beymer-Farris, B.; Seay, J.R. Addressing the challenges associated with plastic waste disposal and management in developing countries. *Curr. Opin. Chem. Eng.* **2021**, *32*, 100682. [CrossRef]
193. Wilson, D.C.; Velis, C.A.; Rodic, L. Integrated sustainable waste management in developing countries. *Proc. Inst. Civ. Eng. Waste Resour. Manag.* **2013**, *166*, 52–68. [CrossRef]
194. Negri, M.; Cagno, E.; Colicchia, C.; Sarkis, J. Integrating sustainability and resilience in the supply chain: A systematic literature review and a research agenda. *Bus. Strategy Environ.* **2021**, *30*, 2858–2886. [CrossRef]