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OPTIMISING THE INDUSTRIAL SYMBIOSIS (IS): THE PROPOSED REDEVELOPMENT

Harshini Mallawaarachchi[1], Y.G. Sandanayake[2], Gayani Karunasena[3] and Chunlu Liu[4]

ABSTRACT

Industrial symbiosis (IS) has been emerged aiming the integration of industrial complexes, in which by-products of materials and energy are using as feedstock instead of being wasted. Since organisations cooperatively increase their mutual sustainable benefits simultaneously through IS, a number of IS projects have been initiated across the whole world. However, most of the projects have been failed and discontinued in long term undermining the expected collaborative gains and efficiencies. Hence, recent studies articulate the necessity of having a standardised mechanism towards implementing the resource efficiency optimised IS designs. Thus, this paper aims to present the issues in the current process of IS development in order to propose a mechanism for redeveloping the process through resource flow efficiency optimisation. A systematic review of key literature was conducted in the areas of IS, its design and implementation procedures. The data collected through the secondary survey was then analysed manually to identify the different stages of the IS development process and related issues. As many scholars recognised, most of IS projects have been discontinued due to the shortcomings and the inefficiencies of the IS development process. Thus, the necessity of having a standardised and more robust model for optimising IS is recognised. Finally, the proposed redevelopment is conceptualised by introducing a new phase of re-evaluation and optimisation modelling to evaluate the symbiosis relationships prior implementation to consider them either for implementing or for re-planning.

Keywords: *Industrial Symbiosis; Issues; Optimisation Modelling; Re-development.*

1. INTRODUCTION

The global transition towards industrial regimes has been linked to the detonation of resource use by many scholars. The extract and dump nature of the industrial systems has burdened the reuse of resources, in which the materials and energy are dumped in a linear flow after been used (Gertler, 1995; Krausmann *et al*., 2009). The need of having efficient and eco-innovative industrial processes has been emerged to reduce the high resource consumption and raw material use encouraging the optimal use and recycling (United Nations Environment Programme [UNEP], 2009). Industrial Symbiosis (IS) has been introduced as a sub field of IE aiming the integration of industrial complexes, in which

[1] School of Architecture and Built Environment, Deakin University, Australia, bmallawaarachch@deakin.edu.au
[2] Department of Building Economics, University of Moratuwa, Sri Lanka, ysandanayake@uom.lk
[3] School of Architecture and Built Environment, Deakin University, Australia, gayani.karunasena@deakin.edu.au
[4] School of Architecture and Built Environment, Deakin University, Australia, chunlu.liu@deakin.edu.au

by-products of materials and energy are using as feedstock instead of wasting them (Frosch and Gallopoulos, 1989, Gertler, 1995; Boons *et al*., 2014). Thus, a number of IS projects have been initiated around the world expecting the mutual sustainable benefits (Chertow, 2000; European Commission, 2017; Sun *et al*., 2017; Tao *et al*., 2019). However, most of the projects have been reported as failed in long terms due to inefficiencies and improper design and development methodologies (Golev *et al*., 2015). Further, the shortcomings of the existing top-down approach applied in developing the IS has hindered the stability of IS to come to fruition with expected optimal outcomes, such as optimal resource flow efficiency, cost and environmental efficiencies (Desrochers, 2004; Chertow, 2007).

In line of thinking, this research formulated the main research question as, "How to optimise the resource flow efficiency of IS?". As a part of the above research, this paper aims to present the existing gaps in IS development process in order to justify the proposed redevelopment.

2. RESEARCH METHODOLOGY

This paper was written based on the publications on IS from 1989 to 2019 since its emergence. A systematic review of the key literature in IS was conducted to collect the secondary data. The ISI Web of Science (WoS) developed by Thomson Reuters Scientific is used in review as it has been recognised as mostly use tool to generate quantitative analysis for scientific research (Meho and Yang, 2007). The topic "Industrial Symbiosis" was then used to search the titles of articles published over the years. 841 of results were retrieved in WoS relating to the publications, exploring the topic of "Industrial Symbiosis". Further, the literature in conference papers and organisational reports relate to the IS development were also reviewed. In total, 32 key papers, in the field of IS referring to the concept, its design and development process, were selected.

Majority of the papers were selected from journal published literature, such as Journal of Industrial Ecology, Journal of Cleaner Production, Resources Conservation and Recycling and Sustainability, which is 78% from the total number of publications. Only 22% of literature is related to the conference papers and other institutional reports on IS initiatives across the globe. The majority of the papers were selected to review the conceptual consideration of the IS development, issues and the related case studies including China, Denmark, Netherlands, United States, Europe, New York and Australia to name a few. The selected articles were manually reviewed to identify the current status and the gaps in the process of IS development.

3. KEY LITERATURE FINDINGS

3.1 THE CONCEPT OF INDUSTRIAL SYMBIOSIS

IS is an approach to the apply IE principles (Milani *et al*., 2018). As scholars revealed, IS imitates the behaviour of natural eco systems in which waste of one firm become a resource for another (Grant *et al*., 2010). "IS engages the separate entities in a collective approach to competitive advantage involving physical exchange of materials, energy, water and by-products" (Chertow, 2007, p.12) for mutually agreed economic and environmental paybacks (Christensen, 2006). ISs are industrial networks that cooperatively increase their use of resources among different industries for economic, environmental, and social benefits simultaneously, such as waste elimination, CO_2

savings, water savings, cost savings, creating and safeguarding jobs, name in few (Lieder and Rashid, 2016; Domenech, *et al*., 2019; Maqbool *et al*., 2019). IS grasps a high prospective to make a substantial impact to improve resource efficiency and innovation (Ghali and Frayret, 2019).

3.2 THE APPROACHES FOR DEVELOPING IS IN GLOBAL CONTEXT

A number of IS initiatives have been launched across the whole world since its benefits have been understood (European Commission, 2017; Sun *et al*., 2017; Tao *et al*., 2019). For example, the model of IS was first fully realized in the eco-industrial park at Kalundborg, Denmark (Chertow, 2000). Simultaneously, at least sixty state-level industrial parks have been established in China during last decade, which account for a large proportion of the world's industrial parks (Liu *et al*., 2018). Indeed, the IS networks in European countries have been impacted considerably on their environmental and economic development through water savings, reduction of raw material extraction and carbon emissions reductions. For instance, Scotland has experienced a 38,836.60t of GHG savings while Hungary has obtained 1876t GHG savings, 619t of material savings and 13,018m^3 of water savings during the period of 2007 to 2012 (Domenech *et al*., 2019).

According to IS theory and practice, IS networks can be emerged in different ways and are shown to follow significantly different developmental pathways (Tao *et al*., 2019).To differentiate IS from other types of exchanges, Chertow (2000) firstly introduced a "3-2 heuristic" as the minimum basis to develop the symbiotic relationships. According to this, at least three different firms have to be engaged in the process to exchange at least two types of resources. The initiation of the IS relationships was confronted by Boons *et al*. (2015) by introducing two new perspective of IS, such as, technical and organisational. As Boons *et al*. (2015) further stated, IS can be approached in three different ways from the technical perspective, such as process oriented, residue oriented and place-oriented IS. The process oriented IS considers the corporative network around the industry while the residual flow is the main concern in residue-oriented IS. In place oriented IS, the network is destined to a specific location. There are four different ways to implement IS under organisational perspective, namely anchor manufacturing, eco-cluster development, government planning and the business incubator (Boons *et al*., 2011).

In 2012, Chertow and Ehrenfeld (2012) introduced five new development options for IS, such as built and recruit model, planned eco-industrial park model (PEIP), self-organising symbiosis model (SOS), retrofit industrial park model (RIP) and the circular economy eco-industrial park model (CE-EIP). As Chertow and Ehrenfeld (2012) further stated, built and recruit model encourages the eco-industrial development. A main feature considered in PEIP model is locating the organisational entities based on their geographic proximity. The decisions made by the independent agents are considered in SOS model. RIP model has been introduced for industrial parks which were already existed in the industry (Wen *et al*., 2018). Indeed, CE-EIP model is a new concern towards developing more sophisticated symbiotic relationships. According to the study by Yuan *et al*. (2006), CE has been emerged in China in early 2009 and has been interacted with IS as a new occurrence in industry (Tao *et al*., 2019). Further, Tao *et al*. (2019) introduced four new IS models, such as newly planned model, retrofit model, speed-dating/ exogenous model and intrinsic/endogenous model. Further to authors, all four models foster the involvement of the government in IS planning and development. Furthermore, Domenech *et al*. (2019) identified three types of IS activities, namely self-organised activity, facilitated networks and planned networks in practice. As they further verified, an intermediary or a third party may coordinate the symbiotic activities in facilitated networks. The planned networks may take place as a result of a corporative plan in which the firms engaged in the network are sharing infrastructure, services and the coordination and promotion related liabilities of IS exchanges.

3.2.1 The Development Process of IS

The designing and planning of IS can be identified with respective to several stages. As outlined by Grant *et al*. (2010), five stages of any IS project lifecycle can be identified as synergy identification, symbiosis assessment, barrier removal, implementation and follow up (review and documentation). Further, National Industrial Symbiosis Programme in UK came up with six processes in IS implementation (National Industrial Symbiosis Programme [NISP], 2013 cited in Tao *et al*., 2019) as; building the IS network by recruiting new members and assessing the characteristics of the organisation (sector and business size, etc), availability of resources and locations, facilitating a platform (workshop) for the participants in selected firms to share information regarding the possible resource exchanges, identifying and mapping the possible synergetic opportunities among the firms, using a suitable data management tool (SYNERGie etc) to identify the benefits of the proposed exchanges and the ways to reduce cost through effective management of resources, introducing a central or an intermediate position to coordinate the network and verifying the output reports of facilitated synergies. Considering the existing stages in IS development, Tao *et al*. (2019) re-identified the five stages of IS development in their study as, awareness development, planning, negotiation, implementation and evaluation. Accordingly, the key stages of IS development can be determined as stated in Figure 1.

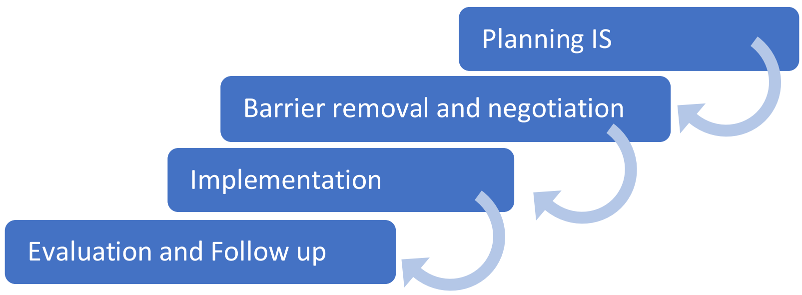

Figure 1: Key stages of IS development process

The stages of IS development process can be described as follows:

Phase 1: Planning IS

This phase includes the initial planning of IS. Conducting expert facilitated workshops, identifying the firms and their synergies, assessing and mapping the opportunities are included under this phase. Synergy identification and pre-assessment occur through three primary means, such as new process discovery, resource matching and relationship mimicking (Grant *et al*., 2010). Further, the economic gains and cost possibilities and the possibilities towards creating job opportunities of the activities will also be considered (Chertow and Lombardi, 2005).

Phase 2: Barrier removal and negotiation

After identifying the suitable partners for the relationship in IS network, negotiation is taken place to comply with the volume, quality, price and the supplying frequency of the resources (waste, energy etc). Further, introducing strategies to overcome the barriers in implementing IS activities is also considered at this stage. As Golev *et al*. (2015) identified, the barriers may include the unavailability of information, lack of commitment of partners, trust and coordination issues among the partners, regulatory, social and economic concerns.

Phase 3: Implementation

The decisions will be taken place to implement the identified synergies at this stage (Maqbool *et al*., 2019). The suitable approach to manage the symbiosis is also considered prior implementing the exchanges (Chertow and Ehrenfeld, 2012). Further, identifying and distributing the tasks and responsibilities among the firms also come under this phase. This stage is completely governed by the firms those who have engaged in the IS network (Grant *et al*., 2010).

Phase 4: Evaluation and follow up

This phase mainly includes two tasks, such as continuous monitoring of impact and disseminating the outcomes. This phase ensures the stability of the IS activities through continuous improvement. Further, communicating the results and outcomes of the implemented IS relationship is a major concern (Maqbool *et al*., 2019).

3.3 ISSUES IN EXISTING PROCESS

It is a well-known fact that many of the IS projects have resulted in failures without achieving the expected results. As Chertow (2007) identified, IS projects have been failed and discontinued in long term due to inefficiencies. While its numerous benefits motivate the formation and development of symbiotic relationships among the industries, the obstacles toward implementing synergies can also be observed in systems, which could undermine the expected collaborative gains (Golev *et al*., 2015).

As found by scholars, IS relationships can be failed even after reaching its planning stage (Chertow, 2007; Gibbs and Deutz, 2007). The shortcomings of the top-down approach in IS development has been attributed towards the failure of the majority of the cases (Desrochers, 2004). Furthermore, the unstable resource flow could also be resulted in long term inefficiencies (Chertow, 2007). The risk of interdependency on the industry partners and the authority of control over decisions can be influenced the stability of the resource flow. IS networks fundamentally exchange the resources, however, they could subside the stability of the resource flow due to the lack of quality, continuity, and quantity of flows and or could not achieve the expected efficiencies (Fichtner *et al*., 2005).

An investigation of eco-industrial parks in United States (30 parks) and in Europe (33 parks) made by Gibbs *et al*. (2005) have found that not all projects have been succeeded. Gibbs *et al*. (2005) recognised the difficulty in organising the stable IS relationships and the fewer number of initiatives for exchanging resources as the key issues. As they further stated, Brownsville Eco-Industrial Park, Texas, Brownsville Eco-Industrial Park, Texas and Plattsburgh Eco-Industrial Park, New York are the example projects which have been failed due to the deficiency in the process. Further, out of 15 IS projects in Londonderry, New Hampshire, and Cape Charles have been failed in long term even though they have been identified as the successful projects in early stages (Bakke, 2005 cited in Chertow, 2007).

Although there is a general recognition of the importance of initiating IS in achieving ecological and economic benefits until recently, there is neither a standardised mechanism for modelling the IS networks and their respective effect towards resource efficiency improvements (Zhang *et al*., 2015). Most of the case studies have been presented for quantifying the reduction of environmental impacts and the possible economic gains. However, such an approach of analysis does not provide any indication whether the project has been achieved the expected efficiency to which extent or not achieved. Hence, a measure of efficiency for IS networks is also lacking (Fraccascia *et al*., 2017), which manipulates for increasing the risk of the difficulty in achieving expected efficiencies. However, not having a standardised mechanism for optimising IS and for assuring it's expected returns in long term can be found in existing practice and related literature, which despites having a more robust model of IS (Chertow, 2007).

4. THE PROPOSED REDEVELOPMENT

The facts reviewed above foster the need of developing a systematic mechanism for optimising the IS. Despite much research in IS, the research gaps in IS development supporting the proposed redevelopment can be highlighted as follows;

- In most of the studies, the main focus has been given to prove the development of IS in respective countries through subjective evaluations. However, fewer studies were fund on assessing the issues of IS networks where many of IS projects have been failed and discontinued in long term.
- Since there is no prior evaluation for optimising the resource flow network and expected collaborative gains prior implementing the IS relationships, the fear of dependency on partners, risk of resource flow stability and the lack of quality, continuity, and quantity of flows have resulted escalating the failure rate of IS projects.
- Even though a broader and subjective consideration of IS networks has been adopted in previous research works, a standardised way to model the stable IS network and its resource flow to quantify their optimum returns and efficiencies remains experimental.

The proposed redevelopment for optimising resource flow efficiency of IS is presented in Figure 2.

As Figure 2 illustrates, the process begins with planning of IS which may occur through existing or planned business relationships of the firms. As identified in key literature, identifying possible synergies and resource matching may take place. The gathered inputs and output data and related resource links can be evaluated in the next step. Compared to the traditional top down approach, the second step will be formalised to evaluate the identified symbioses to make a decision of which IS model could give an optimum resource flow efficiency.

The development of this robust model may take three key steps. The first step will be to identify the standardised ways to determine functional characteristics of the IS network, and its effect on resource efficiency. Second step will be to investigate the various optimisation methods and their extent of application in industrial symbiosis context. Developing a model for optimising the resource flow efficiency of IS will be the third and the most important step of this research. Finally, the validity and the applicability of the developed model will be tested in both secondary data and a real industry scenario.

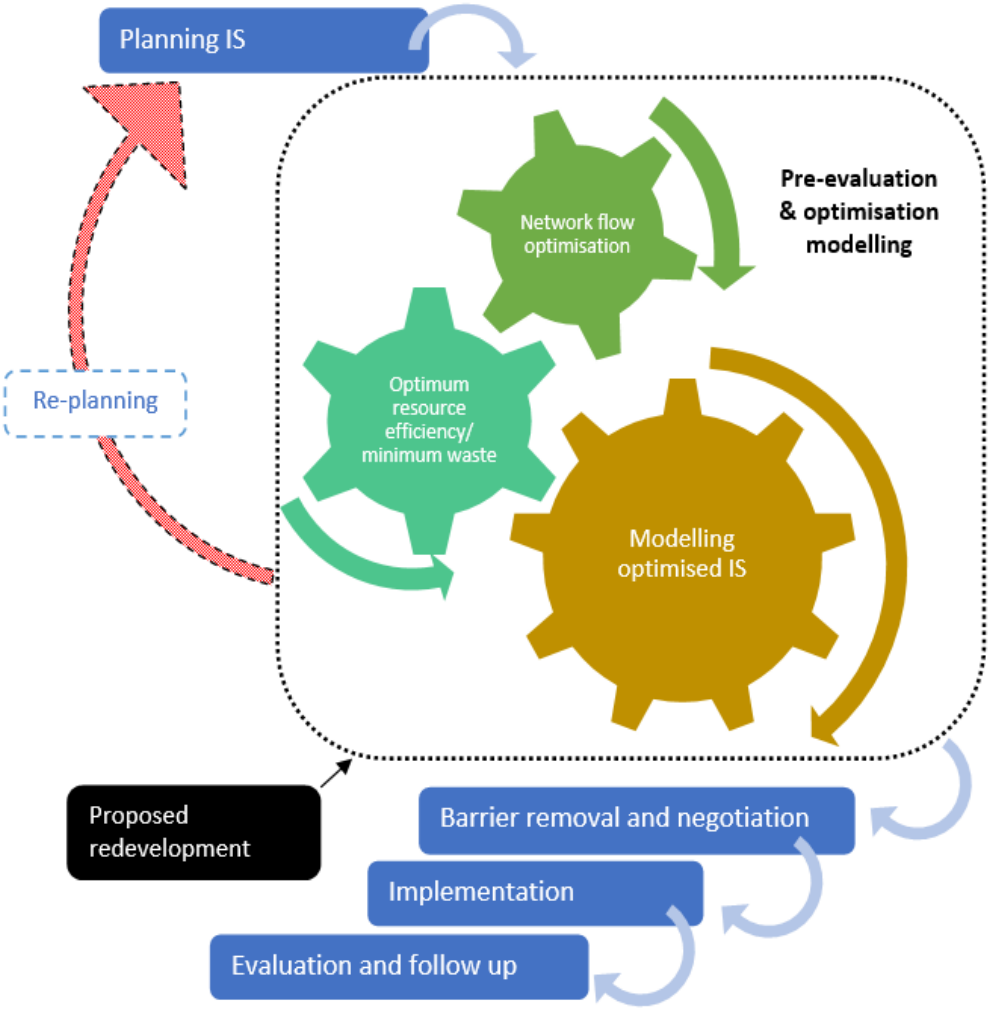

Figure 2: The proposed redevelopment

5. CONCLUSIONS AND THE WAY FORWARD

This paper provides an underpinned overview about the concept of IS, its development and the issues that have been arisen in the IS design and implementation process. Many of IS projects have been failed and discontinued in long term due to the issues in the existing process specially, less stability, lack of quality and continuity of the resource flow. However, there is no a standardised mechanism to evaluate the IS networks and expected collaborative gains. Thus, a prior evaluation for optimising the IS network and the resource flow before its implantation was identified as a timely need. Accordingly, the new phase of pre-evaluation for optimisation modelling was proposed adding into the development process of IS. The proposed redevelopment can be applied in any context to evaluate the identified synergies of IS prior its implementation thus, the re-planning is possible. The application of the proposed model may assist the industries to obtain a holistic idea about their engagement in IS which may reduce the interdependency risk of the IS partners. Further, the proposed model may result in high stability of the resource flow in which firms may maintain the required optimum resource flow efficiency by continuing the resource input and output flows in long term. This may also reduce the resource cost especially for raw material extraction, storage and disposal.

Since this is a part of a research for optimising the IS, this paper only conceptualise the proposed redevelopment. The next stage of the research will be intended to develop the proposed model for optimising the resource flow efficiency of IS.

6. REFERENCES

Boons, F., Spekkink, W., and Jiao, W., 2014. A process perspective on industrial symbiosis: Theory, methodology, and application. *Journal of Industrial Ecology*, *18*(3), pp.341-355.

Boons, F., Spekkink, W., and Mouzakitis, Y., 2011. The dynamics of industrial symbiosis: a proposal for a conceptual framework based upon a comprehensive literature review. *Journal of Cleaner Production*, *19*(9-10), pp.905-911.

Boons, F., Spekkink, W., Isenmann, R., Baas, L., Eklund, M. and Brullot, S., 2015. Comparing industrial symbiosis in Europe: Towards a conceptual framework and research methodology. In *International perspectives on industrial ecology*. Edward Elgar Publishing.

Chertow, M. and Ehrenfeld, J., 2012. Organizing self-organizing systems: Toward a theory of industrial symbiosis. *Journal of Industrial Ecology*, *16*(1), pp.13-27.

Chertow, M.R. and Lombardi, D.R., 2005. Quantifying economic and environmental benefits of co-located firms. *Environmental Science and Technology*, 39(17), pp.6535-6541.

Chertow, M.R., 2000. Industrial symbiosis: literature and taxonomy. *Annual Review of Energy and the Environment*, *25*(1), pp.313-337.

Chertow, M.R., 2007. Uncovering" industrial symbiosis. *Journal of Industrial Ecology*, *11*(1), 11-30.

Christensen, J., 2006. The History of the Industrial Symbiosis at Kalundborg, Danemark. In *Scientific Workshop 'Frontiers of Research in Industrial Ecology'*.

Desrochers, P., 2004. Industrial symbiosis: the case for market coordination. *Journal of Cleaner Production*, *12*(8-10), pp.1099-1110.

Domenech, T., Bleischwitz, R., Doranova, A., Panayotopoulos, D. and Roman, L., 2019. Mapping Industrial Symbiosis Development in Europe_ typologies of networks, characteristics, performance and contribution to the Circular Economy. *Resources, Conservation and Recycling*, *141*, pp.76-98.

European Commission, 2017. The role of waste-to-energy in the circular economy. In: *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions*, 11.

Fichtner, W., Tietze-Stöckinger, I., Frank, M. and Rentz, O., 2005. Barriers of interorganisational environmental management: two case studies on industrial symbiosis. *Progress in Industrial Ecology, an International Journal*, *2*(1), pp.73-88.

Fraccascia, L., Albino, V. and Garavelli, C.A., 2017. Technical efficiency measures of industrial symbiosis networks using enterprise input-output analysis. *International Journal of Production Economics*, *183*, pp.273-286.

Frosch, R.A. and Gallopoulos, N.E., 1989. Strategies for manufacturing. *Scientific American*, *261*(3), pp.144-152.

Gertler, N., 1995. *Industry ecosystems: developing sustainable industrial structures* (Doctoral dissertation, Massachusetts Institute of Technology).

Ghali, M.R. and Frayret, J.M., 2019. Social semantic web framework for industrial synergies initiation. *Journal of Industrial Ecology*, *23*(3), pp.726-738.

Gibbs, D. and Deutz, P., 2007. Reflections on implementing industrial ecology through eco-industrial park development. *Journal of Cleaner Production*, *15*(17), pp.1683-1695.

Gibbs, D., Deutz, P. and Proctor, A., 2005. Industrial ecology and eco-industrial development: A potential paradigm for local and regional development?. *Regional Studies*, *39*(2), pp.171-183.

Golev, A., Corder, G.D. and Giurco, D.P., 2015. Barriers to industrial symbiosis: Insights from the use of a maturity grid. *Journal of Industrial Ecology*, *19*(1), pp.141-153.

Grant, G.B., Seager, T.P., Massard, G. and Nies, L., 2010. Information and communication technology for industrial symbiosis. *Journal of Industrial Ecology*, *14*(5), pp.740-753.

Krausmann, F., Gingrich, S., Eisenmenger, N., Erb, K.H., Haberl, H. and Fischer-Kowalski, M., 2009. Growth in global materials use, GDP and population during the 20th century. *Ecological Economics*, *68*(10), pp.2696-2705.

Lieder, M., and Rashid, A., 2016. Towards circular economy implementation: a comprehensive review in context of manufacturing industry. *Journal of Cleaner Production, 115*, pp.36-51.

Liu, Z., Adams, M., Cote, R.P., Geng, Y. and Li, Y., 2018. Comparative study on the pathways of industrial parks towards sustainable development between China and Canada. *Resources, Conservation and Recycling*, *128*, pp.417-425.

Maqbool, A., Mendez Alva, F. and Van Eetvelde, G., 2019. An assessment of European information technology tools to support industrial symbiosis. *Sustainability*, *11*(1), p.131.

Meho, L.I. and Yang, K., 2007. Impact of data sources on citation counts and rankings of LIS faculty: Web of Science versus Scopus and Google Scholar. *Journal of the American Society for Information Science and Technology*, 58(13), pp.2105-2125.

Milani, A., Schluter, L. and Gjerding, A. N., 2018. *An Ecosystem Analysis of Industrial Symbiosis Development in Aalborg*, Denmark, Department of Business and Management, Innovation, Knowledge and Entrepreneurial Dynamics, Aalborg University: Denmark.

Sun, L., Spekkink, W., Cuppen, E. and Korevaar, G., 2017. Coordination of industrial symbiosis through anchoring. *Sustainability*, *9*(4), p.549.

Tao, Y., Evans, S., Wen, Z. and Ma, M., 2019. The influence of policy on industrial symbiosis from the Firm's perspective: A framework. *Journal of Cleaner Production*, *213*, pp.1172-1187.

United Nations Environment Programme, 2009. *Global green new deal.* United Nations Environment Programme, New York, NY.

Wen, Z., Hu, Y., Lee, J.C.K., Luo, E., Li, H. and Ke, S., 2018. Approaches and policies for promoting industrial park recycling transformation (IPRT) in China: Practices and lessons. *Journal of Cleaner Production*, *172*, pp.1370-1380.

Yuan, Z., Bi, J. and Moriguichi, Y., 2006. The circular economy: A new development strategy in China. *Journal of Industrial Ecology*, *10*(1-2), pp.4-8.

Zhang, Y., Zheng, H., Chen, B., Su, M. and Liu, G., 2015. A review of industrial symbiosis research: theory and methodology. *Frontiers of Earth Science*, *9*(1), pp.91-104.